

(NASA-CR-153009) AN EVALUATION OF SEASAT-A  
CANDIDATE OCEAN INDUSTRY ECONOMIC  
VERIFICATION EXPERIMENTS Final Report  
(ECON, Inc., Princeton, N.J.) 249 p  
HC A11/MF A01

N77-24561

Unclas  
15011

CSCL 05C G3/43

*NASW-3047*

AN EVALUATION OF SEASAT-A  
CANDIDATE OCEAN INDUSTRY ECONOMIC  
VERIFICATION EXPERIMENTS



76-242-1

NINE HUNDRED STATE ROAD  
PRINCETON, NEW JERSEY 08540  
609 924-8778



AN EVALUATION OF SEASAT-A  
CANDIDATE OCEAN INDUSTRY ECONOMIC  
VERIFICATION EXPERIMENTS

Prepared for  
Special Programs Division  
Office of Applications  
National Aeronautics and Space Administration

Contract No. NASW-3047

April 1, 1977

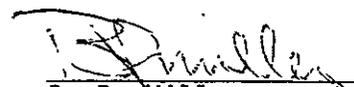


## NOTE OF TRANSMITTAL

This study of potential SEASAT-A ocean industry economic verification experiments was performed for the Special Programs Division, Office of Applications, National Aeronautics and Space Administration, under contracts NASW-2558, Modification 7, and NASW-3047. This study was performed as a part of a 90-day task beginning on September 1, 1976 and was completed on November 30, 1976. The specific objectives of this 90-day task were to expand the level of detail for the economic verification experiments, and to provide an evaluation of the candidate experiments. As a result, this study draws heavily upon work previously reported to NASA during September 1976.\* The work was reviewed with the Industrial Application Panel of the Ocean Dynamics Advisory Subcommittee in December 1976 and January 1977. Following this review, sections were updated and a new section, describing an experiment to monitor the nesting habitats of the North American goose, was added during February and March 1977.

This study was performed by a team consisting of Battelle Memorial Institute and ECON, Inc. Dr. Alfred C. Robinson of Battelle was responsible for the proposed experiments involving the U.S. offshore oil and gas industries, and assisted in the study of innovation and the technology transfer process. Ms. Celia Drumheller, Dr. George Hazelrigg, Mr. Kenneth Hicks, Mr. Keith Lietzke, Mr. B. P. Miller and Dr. William Steele, all made important contributions to the definition and evaluation of the economic verification experiments. Dr. Hazelrigg also contributed to the section on innovation and the technology transfer process.

Many individuals from academic institutions, government, and industry assisted the study team in their effort to gain an understanding of the industrial applications of SEASAT and the potential for economic verification experiments. While the list is too numerous to mention each individual contribution, I do wish to express particular thanks to Dr. Vincent Cardone of CUNY, Mr. S.W. McCandless and Mr. Donald Montgomery of NASA Headquarters for their assistance and guidance in this study of the SEASAT-A economic verification experiments.

  
B. P. Miller

---

\* SEASAT-A Candidate Ocean Industry Economic Verification Experiments.  
(Draft) ECON, Inc., September 1976.

## TABLE OF CONTENTS

	<u>Page</u>
Note of Transmittal	ii
List of Figures	v
List of Tables	viii
1. Summary and Recommendations	1
2. Introduction	5
3. Innovation and the Technology Transfer Process	10
3.1 Invention and Innovation	16
3.2 Evaluation, Validation, and Implementation	18
3.3 The Adoption Process	19
3.3.1 Characteristics of the Innovation	20
3.3.2 Characteristics of the Adopter	20
3.3.3 Characteristics of the Change Agent	23
3.4 Innovation Diffusion Models	26
4. Candidate Economic Verification Experiments	43
4.1 U.S. Based Experiments	44
4.1.1 Applications to the Offshore Oil and Gas Industry	44
4.1.1.1 General Nature of Offshore SEASAT Experiment	47
4.1.1.2 Overview of Approach	47
4.1.1.3 Methods of Data Application	52
4.1.1.4 Experiment Test Areas	53
4.1.1.5 Experiment Duration	55
4.1.1.6 Work to be Done	55
4.1.2 Applications to the Marine Transportation Industry	56
4.1.2.1 An Ocean Routing Experiment	56
4.1.2.2 Tanker Routing, Valdez to West Coast	72
4.1.3 Applications to the Fishing Industry	78
4.1.3.1 A Tuna Fisheries Experiment	78
4.1.3.2 Alaskan Crab Fisheries Experiment	86
4.1.3.3 Menhaden Yield Forecasts Tied to Surface Water Transport	103
4.1.3.4 Marine Fisheries Upwelling Forecasts	113
4.1.4 Ice Monitoring Applications	117
4.1.4.1 Alaska Sea Ice Monitoring	117

TABLE OF CONTENTS  
(continued)

	<u>Page</u>
4.1.5 Coastal Zone Applications	125
4.1.5.1 Southeast and East Coast Hurricane Wind and Landfall Forecasts	125
4.1.6 Other Experiments	133
4.1.6.1 Surveillance of the 200-Mile Limit	133
4.1.6.2 Marine Mammal Management	134
4.1.6.3 Monitoring North American Goose Nesting Habitats	136
4.2 International Cooperative Experiments	146
4.2.1 Applications to the Offshore Oil and Gas Industries	147
4.2.1.1 Oil Exploration in the Beaufort Sea	148
4.2.1.2 Oil Exploration in the Labrador Sea	158
4.2.1.3 On-Ice Seismic Work	162
4.2.2 Applications to the Marine Transportation Industry	168
4.2.2.1 Polar Gas Transportation Routing	168
4.2.2.2 A Ship Routing Experiment in the Belle Isle Straits	168
4.2.2.3 The Agulhas Current and Associated Phenomena	184
4.2.3 Applications to the Ocean Fishing Industry	200
4.2.3.1 Crab Fisheries Off the Labrador Coast	200
4.2.4 Ice Monitoring Applications	201
4.2.4.1 Application to the International Ice Patrol	201
4.2.4.2 Application to Great Lakes Ice Monitoring	211
4.2.5 Other Experiments	216
4.2.5.1 Caribou Migration Monitoring	216
4.2.5.2 Monitoring the Canadian 200-Mile Economic Zone	216
4.2.5.3 Circulation Patterns in the Beaufort and Labrador Seas	217
4.2.5.4 Planning Data for the Design of Structures	218
4.2.5.5 Snow Water Equivalent Mapping	218
4.3 Targets of Opportunity	219
5. Experiment Evaluation and Ranking	222
5.1 Experiment Ranking	228
Appendix A Marine Data Products Available to the Eastern Tropical Tuna Fleet	230

## LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
3.1	The Process of Technological Innovation	12
3.2	Economic Invention and Technology Implementation	17
3.3	Adopter Categories	21
3.4	Typical Benefit Stream Resulting from Innovation Diffusion	27
3.5	Gompertz Curve Fit of Proportion of Corn Acreage Planted with Hybrid Seed in Wisconsin	29
3.6	Spring-Mass-Damper System	30
3.7	Typical SMD Model Responses	33
3.8	A Flow Diagram of Hagerstrand's Conceptualization of the Innovation Diffusion Process	34
4.1	SEASAT Offshore and Gas Verification Experiment	48
4.2	Overall Results, Benefits Due to SEASAT in Marine Transport, in 1975 Dollars	57
4.3	Flowchart of Operational Procedures, Ocean Routing Case Study	70
4.4	Data Flow and Computer Processing SEASAT Economic Verification Ocean Routing Case Study	73
4.5	Tanker Routing Within the Prince William Sound	76
4.6	Fishing Grounds for Eastern Tropical Pacific Tuna Fleet	80
4.7	King Crab Fisheries	88
4.8	Tanner Crab Fisheries	89
4.9a	Ice Accretion for Wind Speeds Between 41 and 55 Knots	98
4.9b	Ice Accretion for Wind Speeds 56 Knots or Greater	98
4.10	NWS Forecast Areas	100
4.11	Purse Boats Beginning a Set on a 70-ton School of Menhaden	105

LIST OF FIGURES  
(continued)

<u>Figure</u>		<u>Page</u>
4.12	Atlantic Menhaden Purse-Seine Landings--Actual and Estimated	107
4.13	Gulf Menhaden Purse-Seine Landings--Actual and Estimated	108
4.14	Relationship Between Surface Water (Eckman) Transport and Menhaden Recruits	111
4.15	Breeding Areas and Migration Corridors	138
4.16	Breeding Areas and Migration Corridors	139
4.17	Proposed Offshore Test Area for SEASAT-A Experiment.	150
4.18	One-Day Altimeter Coverage Over the Beaufort Sea Test Area	154
4.19	One-Day SAR Coverage Over the Beaufort Sea Test Area	155
4.20	One-Day Scatterometer Coverage Over the Beaufort Sea Test Area	156
4.21	One-Day SMMR Coverage Over the Beaufort Sea Test Area	157
4.22	Labrador Sea Test Area	160
4.23	Altimeter 3-Day Coverage Over the Labrador Sea Test Area	163
4.24	SAR 2-Day Coverage Over the Labrador Sea Test Area	164
4.25	Scatterometer One-Day Coverage Over the Labrador Sea Test Area	165
4.26	SMMR One-Day Coverage Over the Labrador Sea Test Area	166
4.27	VIR One-Day Coverage Over the Labrador Sea Test Area	167
4.28	Alternative Routes for St. Lawrence--European Traffic	170
4.29	Principal Ice Surveillance Areas	173
4.30	Typical IIP Surveillance Flight Patterns	174

LIST OF FIGURES  
(continued)

<u>Figure</u>		<u>Page</u>
4.31	Shoe Cove Reception for St. Lawrence Area	177
4.32	Typical One-Day Coverage for SEASAT-A Microwave Radiometer Sensor	178
4.33	Typical Two-Day Coverage for SEASAT-A Synthetic Aperature Radar Sensor	179
4.34	Characteristics of Control and Experimental Groups	182
4.35	Ocean Currents Around Africa	188
4.36	The Agulhas Current	189
4.37	Mean Southerly Current Speed Parallel to the Coast in m/s	190
4.38	Chart of South East Coast of South Africa Showing Continental Shelf, Shelf Edge and Continental Slope, Agulhas Current, Inshore Counter Current and Coastal Upwelling, Positions of Ships Which Have Encountered an Abnormal Wave, Depths in Metres	191
4.39	Coast of South Africa	195
4.40	Wave Height Probabilities in Marsden Square 441 (January Through June)	196
4.41	Wave Height Probabilities in Marsden Square 441 (July Through December)	197
4.42	Ice Conditions on February 28, 1973	206
4.43	Great Lakes--St. Lawrence Seaway Under Navigation Season Extension Investigation	212
A.1	Wind and Weather Analysis and Forecast	234
A.2	Sea and Swell Analysis and Forecast	235
A.3	Weekly Mean Sea Surface Temperature	236
A.4	Weekly Mean Mixed Layer Depth	237

## LIST OF TABLES

<u>Table</u>		<u>Page</u>
2.1	SEASAT Major Benefit Areas	6
3.1	Duration of the Innovative Process for Ten Innovations	14
4.1	Generalization Results for Offshore Oil and Gas Industry	46
4.2	General Operational Roles and Experiment Participants	71
4.3	King Crab Fishery 1976 Estimates	91
4.4	King Crab Production by Major Geographical Region for the Years 1946-1973	92
4.5	Shipments to North Slope Oil Operations 1969-1978	120
4.6	Goose Populations Based on Fall and Winter Surveys, 1955-1974	140
4.7	Expenditures of Waterfowl Hunters, United States, 1970	144
4.8	Duck Stamp Sales, 1934-1973	145
4.9	Responsibilities Associated with Experiments	185
4.10	Maritime Shipping Expressed in Gross Tons Benefiting from International Ice Patrol	204
5.1	Rating of Candidate SEASAT-A Economic Verification Experiments	223

## 1. SUMMARY AND RECOMMENDATIONS

During 1974-75, an economic assessment was performed to estimate the economic benefits of an operational SEASAT system. The economic assessment indicated substantial economic benefits, in excess of program costs, in the areas of marine transportation, offshore oil and natural gas exploration and development, ocean fishing, and Arctic operations. With the launch of SEASAT-A in 1978, the opportunity will exist to obtain experimental data on the economic performance of this ocean observation system. In 1976 preliminary studies were completed to define experiments which could be performed with SEASAT-A to demonstrate the scientific and economic features of the system. In the economic area, the purpose of these experiments is to provide data to help design the characteristics of follow-on SEASATs to meet civilian sector or commercial user economic needs.

This report provides a description of the candidate economic verification experiments which could be performed with SEASAT-A that have been identified in studies performed to date. Experiments have been identified in each of the areas of ocean-based activity that are expected to show an economic impact from the use of operational SEASAT data. Experiments have been identified in the areas of Arctic operations, the ocean fishing industry, the offshore oil and natural gas industry, as well as ice monitoring and coastal zone applications. Emphasis has been placed on the identification and the development of those experiments which meet criteria for:

- End user participation
- SEASAT-A data utility

- Measurability of operational parameters to demonstrate economic effect
- Nonproprietary nature of results.

Because of limitations of time and resources, not all of the candidate economic verification experiments have been developed to the same level of detail. However, it is now believed that the level of detail is sufficient to enable the preliminary selection of those experiments that could be implemented with the launch of SEASAT-A in 1978.

As a result of technical considerations and resource limitations, it is probably not desirable to perform all of the experiments that have been considered in this study. A subjective rating of the experiments has been performed to facilitate selection of experiments for implementation. The evaluation was accomplished by rating each of the experiments in each of eight attributes. The results indicate that U.S. offshore oil and gas experiments, an ocean routing experiment, and several experiments related to the improvement of U.S. fishing operations rate highly in each of the evaluation factors considered. Several potential experiments that could be performed cooperatively with Canada also rate highly; however, the highly rated Canadian experiments are dependent upon the need to process SAR data received at the proposed Canadian east coast reception station at Shoe Cove, Newfoundland.

While certain experiments can be recommended on the basis of this study, a specific strategy for the allocation of NASA resources to these and other possible experiments has not been considered. On the basis of this study, it is recommended that work continue on the experiments in support of U.S. offshore oil and gas industry, on the U.S. ocean routing experiment, on the U.S. Alaskan crab fishing experiment, on the U.S. tuna fisheries

experiment and on the marine upwelling experiment. Although it is somewhat difficult to perceive the economic significance of the experiment concerned with the monitoring of vessel traffic in the U.S. 200-mile zone at the present time, it is suggested that work on this experiment be continued as it has many other desirable attributes, and the economic significance will become apparent if a decision is made to enforce a U.S. 200-mile economic zone. Many of the proposed Canadian cooperative experiments are of great potential economic importance to both Canada and the United States. Since these experiments would be performed in Canadian territory, and would require a commitment of resources by the Canadian government, it is not possible for the United States to unilaterally select the Canadian cooperative experiment to be implemented. For this reason, it is recommended that NASA consider the advisability of negotiations with the government of Canada that could lead to the selection of Canadian cooperative experiments that could be implemented with SEASAT-A.

In addition to the above experiments which are recommended for further development and implementation, the results of this study indicate experiments of opportunity may occur during the life of SEASAT-A. For this reason, it is recommended that NASA consider the possibility of reserving some part of the resources available to support the conduct of economic verification experiments for the application to experiments of opportunity.

SEASAT-A is now scheduled for launching in April 1978. If this schedule is maintained, it is possible that selected economic verification experiments using SEASAT-A data could begin as early as August or September 1978. Some of the economic verification experiments also require the collection of at least one year of data prior to the launch of SEASAT-A in order to provide

a baseline against which improvements can be measured. Examples of this type of experiment are the ocean routing experiment, the Alaskan crab fisheries experiment, and the marine upwelling experiment. In these cases, it will be necessary for NASA to begin the experiment in 1977 in order to allow for the one year of baseline data collection before SEASAT-A data comes on line in 1978. If the baseline data are not obtained prior to the availability of SEASAT-A data, it may be necessary to forego the possibility of real-time experiments in many areas, and to use simulation techniques in conjunction with SEASAT-A data in order to experimentally verify the economic importance of SEASAT data. In addition to the need for baseline data, many of the experiments will require up to one year of intensive planning and preparation prior to implementation in September 1978. Thus, the time for decision is at hand. If real-time economic verification experiments are to be performed using SEASAT-A data, it will be necessary for the various government and industrial activities, both in the United States and Canada, to select the experiments and begin the process of implementation so that the experiments can be ready to begin operation shortly after the launch of SEASAT-A.

## 2. INTRODUCTION

The SEASAT Economic Assessment, completed in 1975, identified substantial potential benefits from the use of operational SEASAT data in areas that are extensions of current operations, such as marine transportation and offshore oil, and natural gas exploration and development. In addition, it was concluded that very large potential benefits from the use of SEASAT data could be possible in an area of operations that is now in the planning or conceptual stage, namely, the transportation of oil, natural gas and other resources by surface ship in the Arctic regions. A further area of large potential benefits that was identified stems from the use of SEASAT data in support of ocean fishing operations. Table 2.1 presents a summary of the major benefit areas attributable to the use of operational SEASAT data. For the sake of clarity, several smaller benefit areas have been omitted from this table. The interested reader is referred to the SEASAT Economic Assessment for a complete discussion of the case studies, their generalizations and the estimation of the benefits.\* For the purpose of the economic assessment, the operational SEASAT system was considered to begin in 1985. The economic benefits shown in Table 2.1 begin in 1985 and are accrued in the period from 1985 through 2000. The range of benefits estimated reflects present uncertainties in the future developments of the areas studied, as well as uncertainties in the expected performance of the operational SEASAT system. All benefits are stated in 1975 dollars at a 10 percent rate of discount, referenced to 1975.

---

\* SEASAT Economic Assessment, ECON, Inc., August 31, 1975.

Table 2.1 SEASAT Major Benefit Areas*	
Area	Present Value of the Benefit (\$ millions, 1975)
Arctic Operations	96- 288
Coastal Zones	3- 81
Marine Transportation	215- 525
Ocean Fishing	274-1432
Offshore Oil and Natural Gas	214- 344
*Benefits attributable to an operational SEASAT system, 1985-2000, at 10 percent discount rate, referenced to 1975.	

The benefit estimates made in the SEASAT Economic Assessment are largely based upon empirical evidence and best estimates of the expected impact of operational SEASAT data on operations in the areas of maritime activity considered in the assessment. The launch of SEASAT-A in 1978 will provide the first opportunity to obtain experimental evidence of the effects of SEASAT data on the economic performance of selected areas of maritime activity. Through the use of SEASAT-A data in a series of designed experiments, it should be possible to obtain information which will be useful in guiding the design of future oceanographic satellite systems to emphasize those characteristics that are of economic importance to civilian sector and commercial users. A secondary purpose of these experiments could be to begin the process of the transfer of the technology of the SEASAT system from NASA to the expected users of an operational SEASAT system.

This report describes a number of potential economic verification experiments that could be performed using SEASAT-A. The purposes of these experiments are:

1. To substantiate the economic justification for the SEASAT program
2. To improve technology transfer and accelerate the rate at which SEASAT benefits are obtained
3. To provide data to aid in the design of follow-on SEASAT satellites and systems to meet user economic needs.

A large number of potential economic verification experiments were considered in this study and, because of limitations of time and resources, not all of the potential experiments have been developed to the same level of detail. The absence (or presence) of detail at this time does not imply a prioritization or recommendation of specific experiments. It is hoped that the participants in this study will have further opportunity to develop additional information on many of the potential experiments that could only be described in a very preliminary manner for this report.

Four criteria were applied to the selection of the proposed economic verification experiments:

1. Is there industry interest in the experiment? Since the experiments are intended to obtain data to help design future oceanographic satellites to meet the economic needs of civilian sector (commercial) users, it is important to obtain the cooperation and/or participation of the user concerned in the performance of the experiment.
2. Can the experiment be supported with SEASAT-A data? Since SEASAT-A is not an operational system there will be system constraints on the collection, processing and distribution of the SEASAT-A data. Thus, a determination that SEASAT-A can provide data needed to support the experiment is a necessary criteria.
3. Is it a measurable experiment? In order to estimate economic impact it is necessary to be able to measure the operational characteristics of the systems involved. For example, in a ship routing experiment it is necessary to measure the transit time, fuel consumed, and losses incurred for a large number of vessels. In each experiment it is necessary that similar measurable operational parameters can be identified.

4. Can the results of the experiment be made available to the general body of interested users? It is conceivable that some experiments could produce results that are of proprietary importance to a single commercial user. Given that the purposes of the SEASAT-A experiments are to provide guidance to the characteristics of future systems and to begin the process of the transfer of SEASAT technology to users, it is important that the results of the experiments can be made available to all interested parties.

Although the above four criteria were applied to the selection of all of the proposed experiments, it must be realized that much further work remains to be done to make certain that these criteria can be fully satisfied before the final recommendation can be made for experiments to be implemented by NASA.

An important consideration in the development and selection of the economic verification experiments is the expected ability of SEASAT-A to produce nowcasts of ocean parameters such as ice, waves and winds, as well as to produce data for use in forecasts of weather and ocean conditions. Experiments which use both the nowcast and forecast capabilities of SEASAT-A data are contained in the candidate economic verification experiments. A further consideration is that some of the experiments involve the measurement of phenomena which may occur only a few times during the expected life of SEASAT-A while other candidate experiments involve many measurements, over an extended period of time, with both an experiment and control group of test subjects. Although estimates have not been made of the costs of implementing these experiments, it is believed that, in general, the experiments which must be supported by many measurements will require more time to perform and will be more costly than those experiments that deal with either unique events or events which occur seasonally.

Section 3 of this report discusses the process of technology transfer (innovation diffusion) as it relates to SEASAT-A. The purpose of this section is to provide insights into the technology transfer process as it could affect the selection of economic verification experiments.

Section 4 describes the candidate economic verification experiments. Some of the experiments involve the United States alone, while others require international cooperation.

Section 5 provides a preliminary assessment and rating of the candidate experiments, and makes recommendations for further action by NASA.

### 3. INNOVATION AND THE TECHNOLOGY TRANSFER PROCESS

The SEASAT-A system will provide types and amounts of data for the world's oceans which have not been hitherto available. NASA is concerned not only with ascertaining that these data are applied to yield new scientific results, but also with assuring that the widest possible use is made of this unique technological capability by the industrial sector. These data will permit industrial or commercial organizations to do things which were not possible before, or to accomplish existing operations in a more complete or less expensive way. Accordingly, it is of interest to consider the process by which new technology is applied to commercial or economic activities.

This process has been extensively studied during the past 15 years under the heading of innovation diffusion, and the results of this work can provide useful background for anyone concerned with the problem of fostering the use of SEASAT data by industry. Over 3000 papers have been published dealing with one part or another of the innovation process and more than a dozen books have appeared. There is currently a new technical society, the Technology Transfer Society, devoted to the study of the innovation process itself. A number of federal organizations, including NASA, are undertaking new initiatives in technology transfer. Also, the Congress has considered and is considering various measures for enhancing the transfer of existing federal technology. The Science and Technology Act of 1975 authorized the creation of a Technology Transfer Office at the White House level. This has not as yet been implemented but is currently under discussion.

It seems clear that the importance of the technology transfer problem is becoming more widely recognized and the mechanisms are being studied more carefully.

The general nature of the innovation process is indicated in Figure 3.1. Chronologically, the process starts with a conception or an invention. This is a bringing together of a technological capability with a perceived need or problem area. The concept is then evaluated in the light of market needs and, if it appears to be promising, then an investment may be made to verify the concept by a working model or small-scale trial. The results of this are again evaluated and, if they appear to be promising, a development may be undertaken to create a product suitable for wide-scale use. If this development program is successful, the product may be produced or the concept otherwise implemented. At this point there is a marketable product or process and the problem then is one of getting it used. If the product is successful in that it is widely adopted, there may follow another phase in which society adapts itself to the availability of the new product. Reorientation of U.S. housing patterns as a result of the availability of the automobile is an example of this sort of adaptation. This final phase, however, is not indicated in Figure 3.1. The entire development process is motivated and controlled by perceived market needs. This perception has frequently proved to be erroneous but it nonetheless must be viewed as a major underlying consideration.

The individual steps shown in Figure 3.1 are discussed in more detail in later subsections but, before proceeding with this, some general observations can be made about the process as a whole. The first is that the amount of time required for completion of this innovation process is often

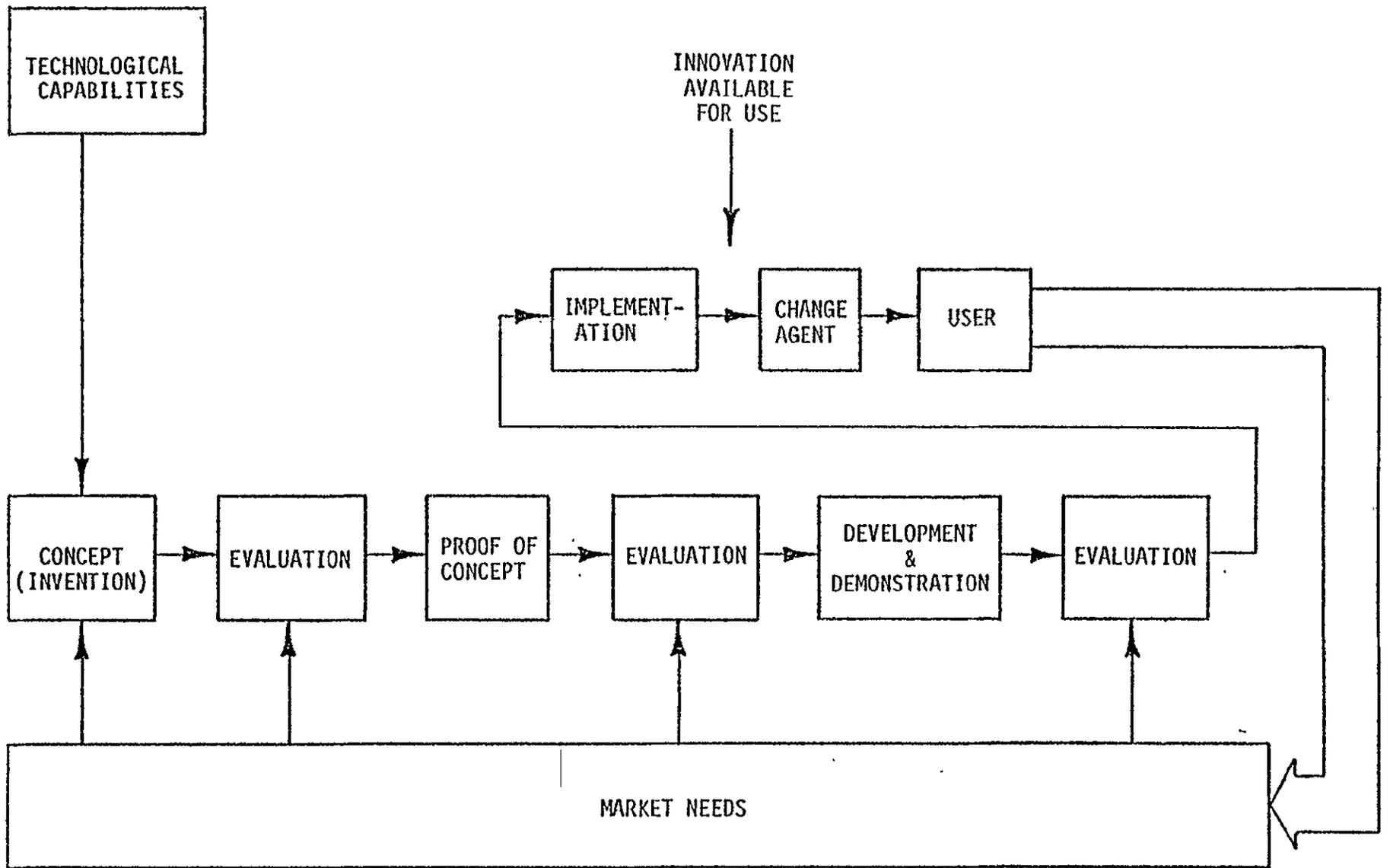


Figure 3.1 The Process of Technological Innovation

quite long, on the order of several decades. In a recent study by Battelle of the development process, that is the portion starting with the concept and ending with implementation, ten specific innovation processes were studied. The time required for the development process in each of these innovations is given in Table 3.1. The average time span for these ten innovations is 19.2 years. The diffusion process, that is to say, the adoption of the innovation once it has become available, takes a period of about the same magnitude. Thus, a time span of 40 years from conception to wide-scale adoption is by no means unusual. Very seldom is it less than 10 to 15 years. Time spans of this magnitude are larger than the planning horizons of most public or private organizations, and may cover several generations of decision makers. Many innovations fail simply because of a lack of continuity in the management structure.

The long time span is a major factor in the next general observation, which is that the failure rate in this process is extremely high, running from 98 to 99 percent depending on the definitions employed. The greatest number of failures occur in the earlier parts of the process, though failure in the marketplace, once an innovation has been implemented, is of the order of 50 percent. When the process is successful, the rewards both to the innovator and to society as a whole may be very large, but the possibility of failure is also quite high.

The second general observation is that most innovation processes show a merging of diverse streams of technology. That is to say, technologies which initially seem to be unrelated to the problem being considered are brought into the process. This happens throughout the process and not only in the early phases. In most cases this merging appears to have been largely

Table 3.1 Duration of the Innovative Process for Ten Innovations

INNOVATION	YEAR OF FIRST		DURATION YEARS
	CONCEPTION	REALIZATION	
HEART PACEMAKER	1928	1960	32
HYBRID CORN	1908	1933	25
HYBRID SMALL GRAINS	1937	1956	19
GREEN REVOLUTION WHEAT	1950	1966	16
ELECTROPHOTOGRAPHY	1937	1959	22
INPUT OUTPUT ECONOMIC ANALYSIS	1936	1964	28
ORGANOPHOSPHORUS INSECTICIDES	1934	1947	13
ORAL CONTRACEPTIVE	1951	1960	9
MAGNETIC FERRITES	1933	1955	22
VIDEO TAPE RECORDER	1950	1956	6
AVERAGE DURATION			<u>19.2</u>

fortuitous and has caused some investigators to wonder whether the process can really be managed at all. However, in some cases innovations have been developed by multidisciplinary teams convened specifically for the purpose of producing a desired innovation and, in these cases, the merging of technologies appears to be planned.

Finally, it has been observed that in most successful innovations there is an advocate. This is an individual, sometimes the inventor, sometimes not, who devotes a substantial number of years to furthering the idea. In some of the literature this person is called a technological entrepreneur. Because of the time span involved in innovation the technological entrepreneur may well devote his entire career to furthering a single idea. The presence of such an individual was observed in all but one of the innovations studied.\*

It should perhaps be mentioned that there are certain terminology problems in the discussion of technological innovation. There is as yet no standard terminology in this field and the new Technology Transfer Society has taken this as an item for early action. The terminology used here may differ in some respects from that found in certain other books and papers.

In the following sections some discussion is given of each of the steps in the process. The conclusions presented here are drawn from a wide variety of studies which have been made. Perhaps the best guide to the development process (from conception until the product reaches the market)

---

\* Science, Technology and Innovation. Battelle Columbus Laboratories. February 1973. PB 22859.

is the above mentioned Battelle study. For the remainder of the process a good summary and guide to the literature is given by Rogers and Shoemaker.\*

### 3.1 Invention and Innovation

Inventions or innovations can be aimed at either doing something new, for example, the airplane which made powered flight possible, or doing something "better." "Better" can mean faster, more accurately, more often, less costly, etc. Often, an activity may be possible, given a particular technology, and it may even be generally desirable, but it is not done. The reason may be that it is not "economic" to do; for example, the costs may exceed the benefits. In this case, inventions and innovations that result in a more cost-effective technology can result in performing new activities--activities that were not previously economic--or they can result in increased activities in areas where cost was previously a limiting factor. "Invention" can be viewed as a process of making something economic as well as making something possible.

The process of economic invention can be illustrated as shown in Figure 3.2. Any system can be defined in terms of its "capability." For an airplane, capability could be measured by speed, range, payload, etc., or some combination of these. For a remote sensing system, it could be area of coverage, spatial or spectral resolution, frequency of coverage, data lag, etc. The system provides its users with a benefit which is a function of its capability. The cost of the system is also a function of its capability.

---

\*Everett M. Rogers and F. Floyd Shoemaker, *Communication of Innovations, A Cross-Cultural Approach*, Second Edition, The Free Press, New York (1971).

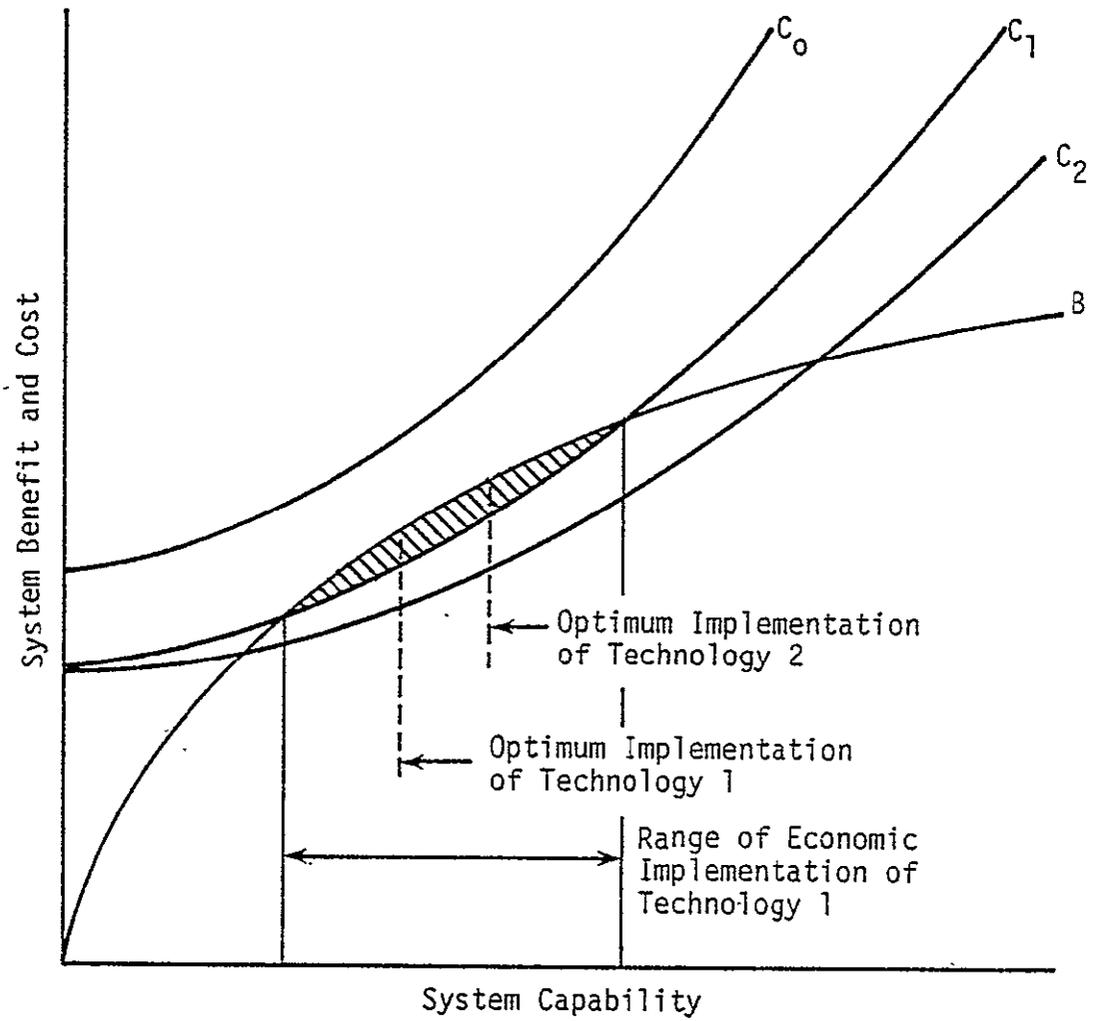


Figure 3.2 Economic Invention and Technology Implementation

If, as shown by Curve  $C_0$ , the system cost is greater than the system benefit, Curve B, for all levels of capability, then the system is not economic and it would not be (rationally) used. If a new technology, Curve  $C_1$ , is developed that does intersect the benefit curve, then this technology could be economically used over that range of capability for which the costs are less than the benefits. In the absence of constraints placed on technology implementation, the optimum capability at which to implement the technology would be that capability which maximizes the net benefit (that is, benefit less cost). Now, if a still more advanced technology is developed, Curve  $C_2$ , it would be logical to implement this technology in favor of the previous technology and also, possibly, to change (usually increase) the capability at which the implementation takes place.

Remote sensing activities are very much of the nature discussed above. Most all measurements could be made either on the ground or from aircraft. That, in many instances, such measurements are not made routinely from aircraft is an indication that the costs exceed the benefits. The introduction of satellite-based technologies offers to make many new activities cost effective and to increase the level of activity in other areas, perhaps even with an increase in expenditures. Such is the nature of the innovation provided by SEASAT.

### 3.2 Evaluation, Validation, and Implementation

During the remainder of the development process, the Battelle study identified a number of significant factors. Among the more significant were the following:

1. Internal R&D management
2. Availability of funding

3. . Presence of a technical entrepreneur
4. Interaction with in-house colleagues
5. Technology confluence
6. Presence of a technological gatekeeper.

Funding and management are obviously of importance. However, even when funding is available, it is rather remarkable how often erroneous decisions are made. Even when serious efforts are undertaken to collect relevant data and to weigh all significant factors, wrong decisions are more the rule than the exception. This area appears to offer considerable potential for improvement. It has also been found that frequently important contributions are made by employees of the developing organization who are not directly involved in the innovation in question. They assist in the technology confluence, which is a significant factor in most successful innovations. The technological gatekeeper is another contributor to this confluence. He is an individual who is widely acquainted with technological activities and technological capabilities and is able to assist in assuring that the relevant skills and data are assembled.

### 3.3 The Adoption Process

In some ways the most critical part of the innovation process is that of bringing about actual use of an innovation which has become available. This involves three interrelated components: the innovation itself, the potential user, and the change agent. The change agent can take a variety of forms, ranging from an informational pamphlet to an economic demonstration of the innovation.

There are mutual interactions among these three entities and in the following subsections brief descriptions are given of the characteristics which tend to promote or inhibit adoption of the innovation.

### 3.3.1 Characteristics of the Innovation

A number of studies have shown that the following attributes of an innovation are significant in influencing its adoption:

- ① Relative Advantage. Perhaps most significant is the degree to which the innovation offers an advantage over other techniques or equipment. How much money can be saved, how much time can be saved, what is the relative convenience, etc.
- ① Compatibility. If an innovation can be integrated smoothly into an existing operation its adoption potential is enhanced. If, on the other hand, new equipment must be purchased or new personnel must be hired with different skills, the innovation is less likely to be adopted or will likely be adopted more slowly.
- ① Complexity. If the innovation appears to the user to be unusually complex or difficult to understand he will have less tendency to adopt. The perception of complexity, of course, may be quite different for different individuals in a user community.
- ① Trialability. If an innovation can be tested on a small scale without making a full initial commitment it is more likely to be adopted. Space systems are difficult to try on a small scale. SEASAT-A will prove the technical attributes of such a system, but many operational and economic attributes will require an operational system to fully test.
- ① Observability. This is the degree to which the results of adopting an innovation can be seen by the user, by the user's customers, or by the user's competitors. In one case, a pesticide failed to be adopted because it killed rats in their holes. It was not possible to see the effects of the poison, and the pesticide was therefore deemed to be ineffective.

### 3.3.2 Characteristics of the Adopter

Perhaps one of the most interesting features of the adoption process is its time distribution. If the number adopting per unit time is plotted as a function of time the result is a bell-shaped curve, as shown in Figure 3.3. The first group to adopt is the group of innovators. These are individuals or organizations who enjoy innovation and are able to indulge their tastes. In terms of the overall process this is not a very significant group.

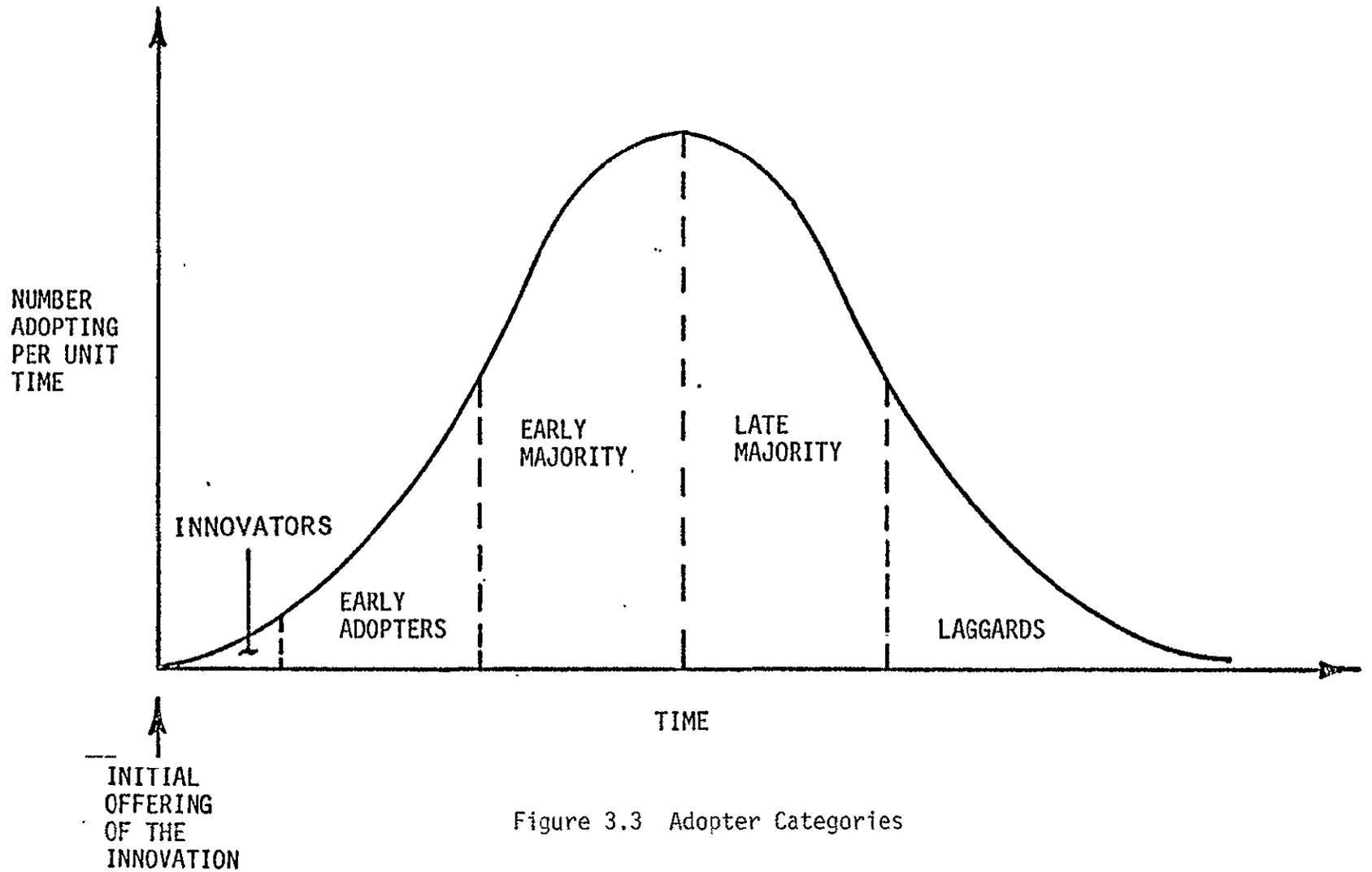


Figure 3.3 Adopter Categories

The next group, however, the early adopters, is quite different. These are people or organizations who are accustomed to innovation and are highly regarded by the user community. Others look to them for leadership. They are usually more open to communication of all types than are other members of the community. Studies indicate that once the early adopters have made a favorable decision the rest of the community will follow along without major activity on the part of the change agent. This suggests, then, that the early adopters should be the principal target for the change agent. It should perhaps be mentioned that a majority of the work that has been done on technology transfer has been in the agricultural field, where the adopters are typically individual farmers. It may be that the characteristics identified for early adopters in the technology areas studied to date are only relevant in part to the more common situation for NASA technology, in which the adopter is an industrial organization.

Turning now to the question of the adoption decision itself, there are some differences between individual adopters and collective adopters. If the innovation is to be adopted by single individuals, four stages have been identified. These are:

- Knowledge. In this period the user is generally aware of the existence of the innovation but knows little about it and has no particular opinion of its merits.
- Persuasion. In this phase the user becomes acquainted with the characteristics of the innovation and analyzes those characteristics in relation to his own needs. This is the phase in which the change agent is most effective.
- Decision. The user decides to adopt or to reject the innovation.
- Confirmation. Following his decision the user seeks additional information to determine whether or not he made the correct choice.

If the innovation is to be adopted by a group or organization then the process is somewhat different. The steps are the following:

- Stimulation. This is the phase in which the idea of the innovation is introduced to the organization, usually from the outside.
- Initiation. During this phase the innovation is studied and its relevance to the organization assessed, usually at lower levels in the hierarchy.
- Legitimization. In this phase the more influential members of the organization become persuaded that the innovation should be adopted. This usually causes an affirmative opinion to diffuse throughout the organization.
- Decision. Once the various levels within the organization have become persuaded that the innovation should be adopted a decision can be rendered.
- Action. The plan of action associated with adopting the innovation is executed. In many cases this may be a rather complex group of activities.

### 3.3.3 Characteristics of the Change Agent

The change agent is the link between the innovation and the user, and can be defined as a process, an organization, or an individual who attempts to bring about use of the innovation. It has been determined that the following characteristics are positively related to a change agent's success:

- Effort. As might be expected, the more contacts made by the change agent the more likely that his efforts will be successful. As mentioned above, this effort is most useful during the early adopter phase.
- Client Orientation. A change agent will be more effective if he identifies with his clients rather than with the change agency.
- Social Status. The higher their social standing, the more effective change agents appear to be. There are limits, however. Too great a gap between the change agent and the client may be counterproductive.
- Working Through Opinion Leaders. Change agents who concentrate on the opinion leaders in the client community are demonstrably more successful than those who do not.

- Credibility. A change agent who has established credibility with clients will be more effective. It appears that NASA may have a particular problem in this area, at least when dealing with industrial clients.

There are many ways in which the change agent function can be implemented. Some of the more frequently employed functions are listed below. Many of these have been or are currently being used by NASA, other federal agencies, and by sales forces for high technology industries.

- Dissemination of Literature. Perhaps the simplest change agent device is that of sending out literature describing the innovation and outlining the reasons why it should be adopted. This technique is widely employed, possibly because it is relatively inexpensive; it is done by NASA Code K, by NTIS, and by most high technology industries.
- Reference and Literature Search Services. An organization which can respond to user inquiries by locating and transmitting reference material can also function as a change agent. This is done by NASA Headquarters Code K, U.S. Department of Agriculture, NTIS, NIH, and others.
- Local Agents. The use of local agents to interface with users on a continuing basis can be a highly effective, though expensive, change agent mechanism. This is a feature of the system composed of the U.S. Department of Agriculture Extension Service, the state research organizations and the local county agents. This system, which is funded partly by the federal government and partly by the state and county governments, is widely viewed as the world's most successful technology transfer operation thus far achieved. It is given a major share of the credit in the outstanding productivity increase record of U.S. agriculture. It is true that the local agents are only one part of this system, but the success of their operation merits the close consideration of anyone involved in technology transfer. The NSF is currently conducting an experiment program in which technology agents are attached to city governments in a number of medium-sized U.S. cities. Their function is rather similar to that of the county agents and these technology representatives are supported by a back-up system of research institutions.
- Regional Centers. Some organizations make use of a permanent facility to foster technology transfer in a region, perhaps one state or several states. While not maintaining the close tie with individual users that is possible with the local agent system,

the regional centers can provide a wider spectrum of services and expertise. Such centers are operated by various high technology industries, by NASA Code K, by ERDA, and others.

- National Centers. Moving even further away from the close user interface, it is possible to operate technology transfer from a single center serving the entire nation. Industry seldom uses this approach, except when the number of potential customers is quite small. It is used by a number of federal agencies including NASA and NIH.

The selection among these various types of change agent configurations will be based on the nature of the innovation, the nature of the user community, and the importance which is attached to achieving a successful transfer. This last point can be translated into the question of how much money is allotted. If the potential users are very numerous and widely dispersed and if transfer is sufficiently important, the local agent configuration might be the best. If the number of potential users is very small, then a national center would be indicated. If limited funds are available, perhaps literature dissemination and literature search services are indicated. Some recent experiments have shown that literature dissemination can be reasonably effective if the literature is prepared and distributed in the proper way. Careful targeting of literature and distribution mechanisms, however, increases the expense.

The choice, then, depends on a careful analysis of the marketing problem being addressed. Even for a single technological innovation such as SEASAT there are many different potential user communities. They vary from user communities with only a few members, such as a single federal agency, to user communities of millions of members, such as recreational boat operators.

### 3.4 Innovation Diffusion Models

It is of general interest to model the innovation diffusion process in order to assess the potential effect of alternative market development strategies. Thus, much work has focused recently on the development of innovation diffusion models. A few such models are discussed in this section.

There are two basic approaches to quantifying innovation diffusion. The first simply recognizes that the adoption process, as a function of time, generally exhibits an S-shape as shown by the undiscounted benefit stream in Figure 3.4 and strives to find appropriate mathematical relationships for fitting to the data. The second approach is to attempt to model, in either a direct or general way, the physics of the diffusion/adoption process. Both methods have met with some degree of success and are briefly reviewed below.

The first method has resulted in the well-known Gompertz curve which takes the form\*

$$P(t) = K a^{b^{t-1}}$$

where  $P(t)$  is the accumulated adoption at time  $t$ .  $K$ ,  $a$  and  $b$  are constants such that

$$K > 0$$

$$0 < a < 1$$

$$0 < b < 1$$

In the case that  $P(t)$  is the fraction of the "market" penetrated,  $K = 1$  and  $0 < P(t) < 1$ . The relation simplifies to

---

\*Wentz, Walter B. and Eyrich, Gerald I., Marketing Theory and Application, Harcourt, Brace and World, Inc., New York, 1970.

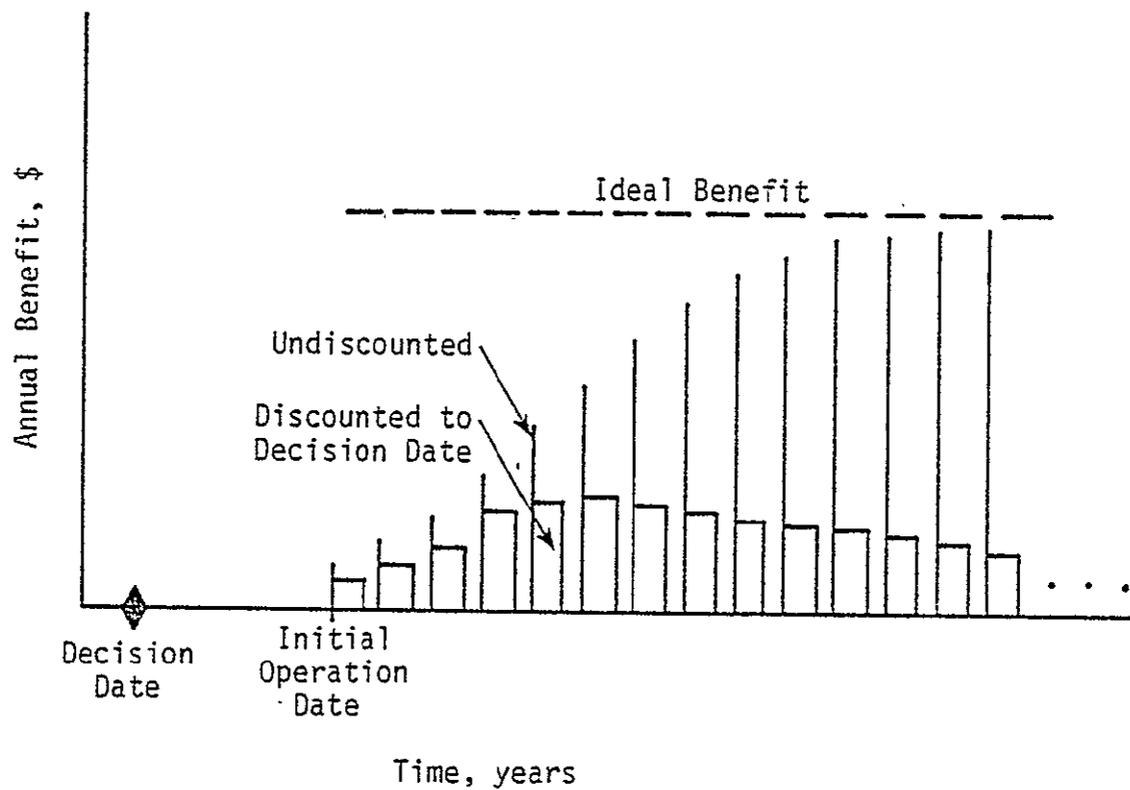


Figure 3.4 Typical Benefit Stream Resulting from Innovation Diffusion

$$P(t) = a b^{t-1}$$

In this case, this equation is generally easier to deal with in its logarithmic form

$$\ln P(t) = (\ln a) b^{t-1}$$

Noticing that both  $\ln P(t)$  and  $\ln a$  are negative,

$$-\ln P(t) = (-\ln a) b^{t-1}$$

allows a second logarithm to be taken.

$$\ln (-\ln P(t)) = \ln (-\ln a) + (t-1) \ln b$$

This form is linear in  $\ln (-\ln a)$  and  $\ln b$ . Thus, it is a simple matter to apply least squares curve fitting techniques. The result of such an exercise is shown in Figure 3.5 for the adoption of hybrid corn in Wisconsin. In the Gompertz curve form shown,  $K = 1$ , the fractional cumulative adoption may be interpreted as the fraction of the ultimate potential benefit achieved as a function of time.

Two forms of physical models are discussed below. The first is a deterministic model that draws an analogy between the adoption process and a spring-mass-damper system and the second is a stochastic model that models the adoption process in terms of communication and resistance to change. The spring-mass-damper (SMD) model is represented by the physical system shown in Figure 3.6. An heuristic interpretation of this model is as follows. The spring represents the motive force when stretched. It is the system economic driver--benefits or profit. The right hand end of the spring is moved according to a function which represents the aggregate motive force on the community. For example, its movement may be taken as a function of the aggregate perceived benefit of the innovation by the community. Thus, in the case shown, this function was taken to be the fraction of the community

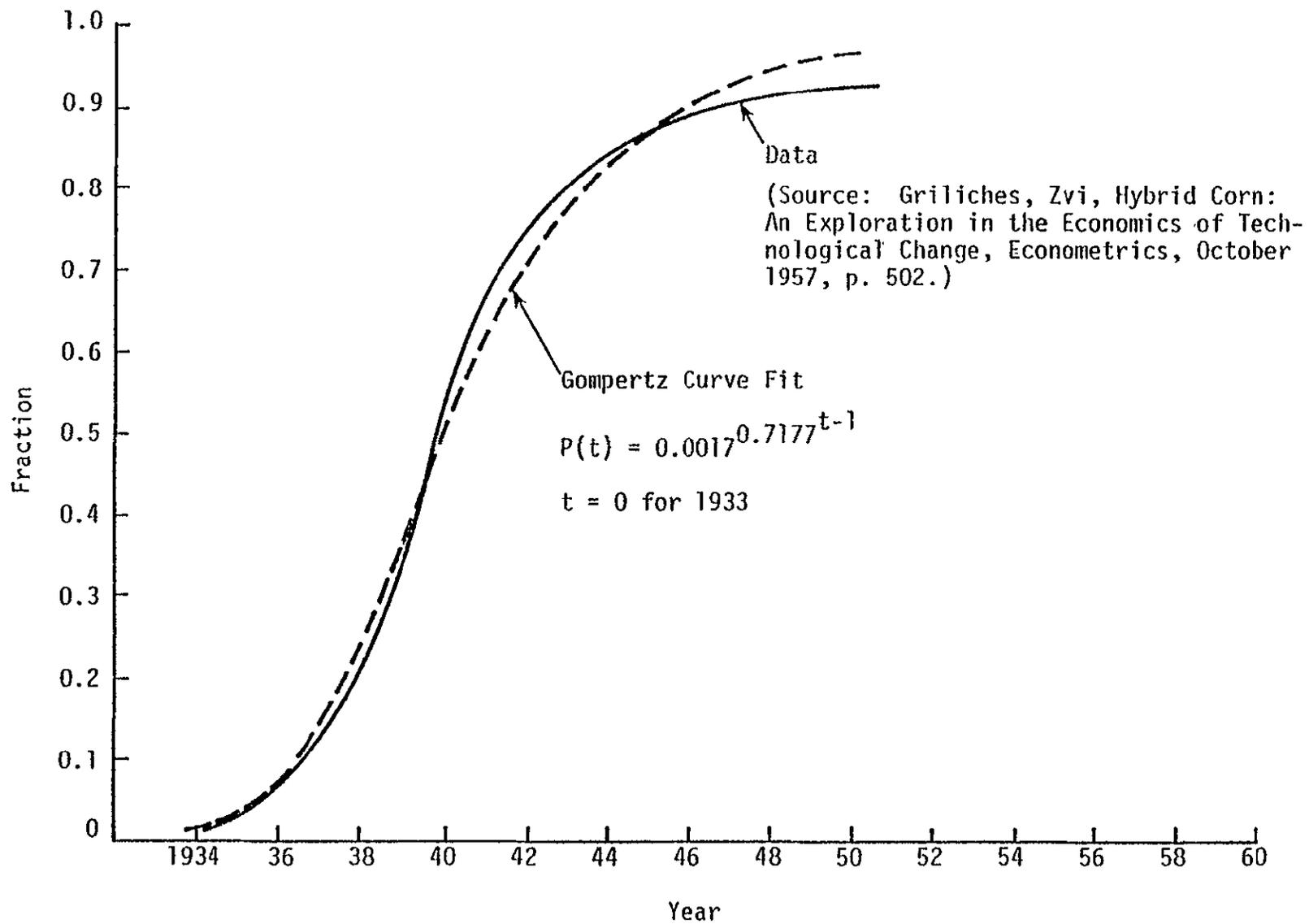


Figure 3.5 Gompertz Curve Fit of Proportion of Corn Acreage Planted with Hybrid Seed in Wisconsin

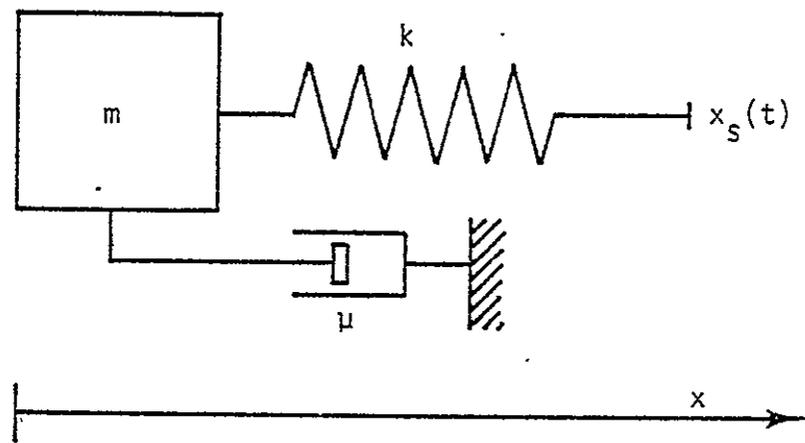


Figure 3.6 Spring-Mass-Damper System

that is aware of the new technology and perceives its benefits as a function of time. The mass represents inertia or resistance to change. This inertia is both psychological and economic. For example, a businessman who has just invested in a new piece of equipment cannot be expected to replace this equipment with a new technology product before it has been used to some extent. The damper simulates physical constraints on the system: availability of new hardware, services, etc. The motion of the mass,  $x(t)$ , is taken to be the response of the system to the new technology.

The equation of motion of the system is

$$m \frac{d^2x}{dt^2} + \mu \frac{dx}{dt} + kx = k x_s(t)$$

Without loss of generality, we can take  $m = 1$ . Then

$$\frac{d^2x}{dt^2} + \mu \frac{dx}{dt} + kx = k x_s(t)$$

Assuming that the rate at which people become aware of the new technology is proportional to the fraction of the community that is unaware of the technology at any point in time,

$$x_s(t) = 1 - e^{-t/\lambda}$$

where  $\lambda$  is a learning rate constant. Thus, the equation of motion becomes

$$\frac{d^2x}{dt^2} + \mu \frac{dx}{dt} + kx = k (1 - e^{-t/\lambda})$$

This equation has three different solution forms depending on the value of  $\mu$ . These are as follows:

$$\mu > 2 \sqrt{k} \quad \text{Overdamped}$$

$$\mu = 2 \sqrt{k} \quad \text{Critically damped}$$

$$\mu < 2 \sqrt{k} \quad \text{Underdamped}$$

The case of underdamping results in periodic motion. Such behavior has been shown to exist in certain market situations, but obviously cannot exist in the case of new technology adoption (more than 100 percent adoption is not

possible). The critically damped case results in effectively 100 percent adoption in a finite time. This is probably optimistic. Thus, only the overdamped solution is examined here. This solution allows that some individuals may never adopt the new practice. Figure 3.7 shows typical system responses possible with this model.

The overdamped solution to the SMD model is

$$x(t) = 1 + Be^{-\beta t} + Ce^{-bt} + De^{-at}$$

where

$$\beta = \frac{1}{\lambda}$$

$$\phi = \frac{\beta^2 - \mu\beta}{\beta^2 - \mu\beta + k}$$

$$a = \frac{\mu}{2} \left( 1 + \sqrt{1 - \frac{4k}{\mu^2}} \right)$$

$$b = \frac{k}{a}$$

$$B = \phi - 1$$

$$C = \frac{\phi(\beta - \mu + b) - \beta}{a - b}$$

$$D = \frac{\phi(\beta - \mu + a) - \beta}{a - b}$$

The variables to be fit in this model are  $\mu$ ,  $k$  and  $\lambda$ .

The final innovation diffusion model discussed here is the stochastic model. The primary architect of this theory is Torsten Hagerstrand. This theory is presently receiving the greatest attention by quantitative sociologists. A conceptualization of Hagerstrand's model is shown in Figure 3.8

The "basic tenet of Hagerstrand's conceptualization is that adoption of an innovation is primarily a learning (persuasion) process. This implies

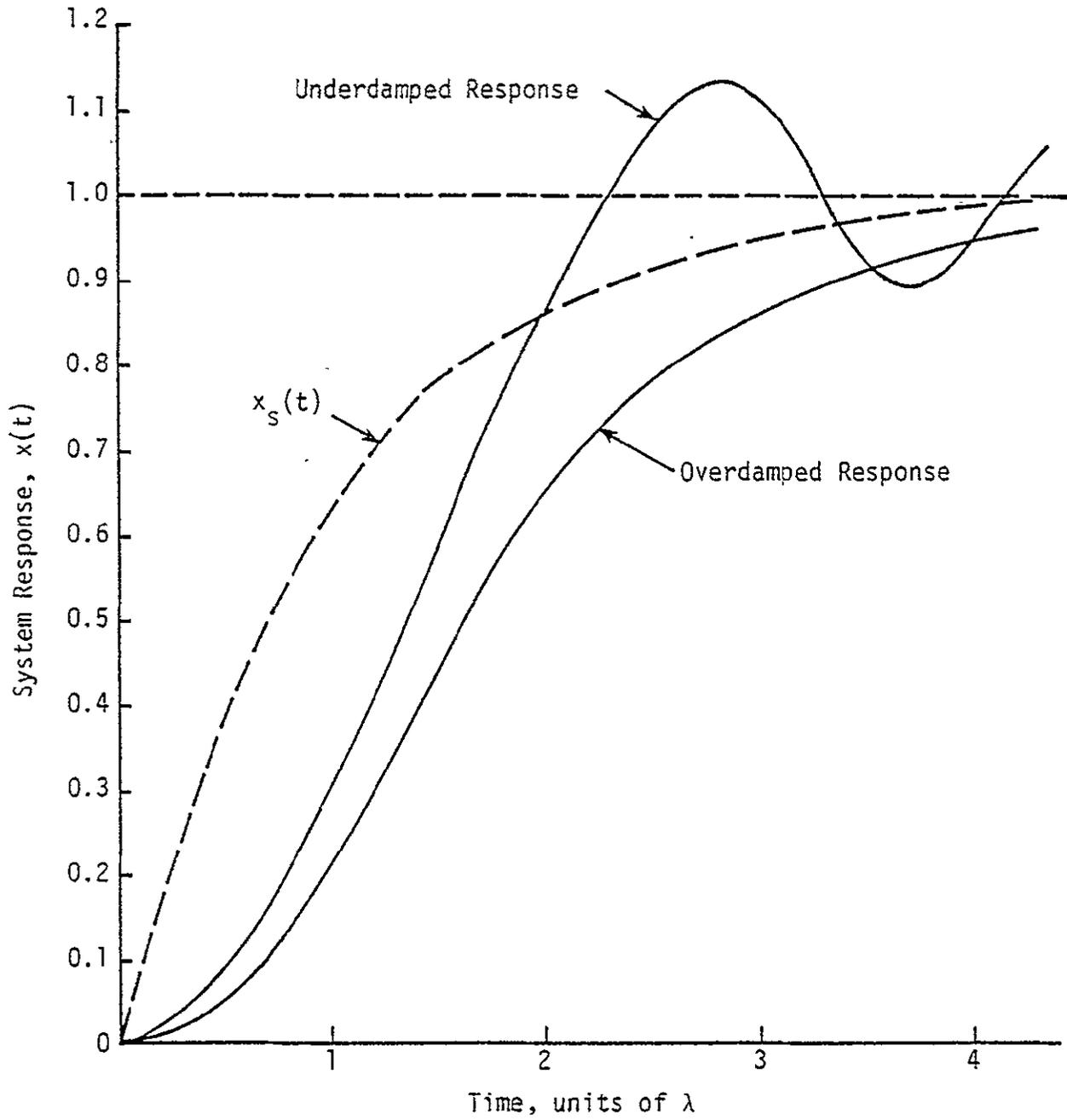


Figure 3.7 Typical SMD Model Responses

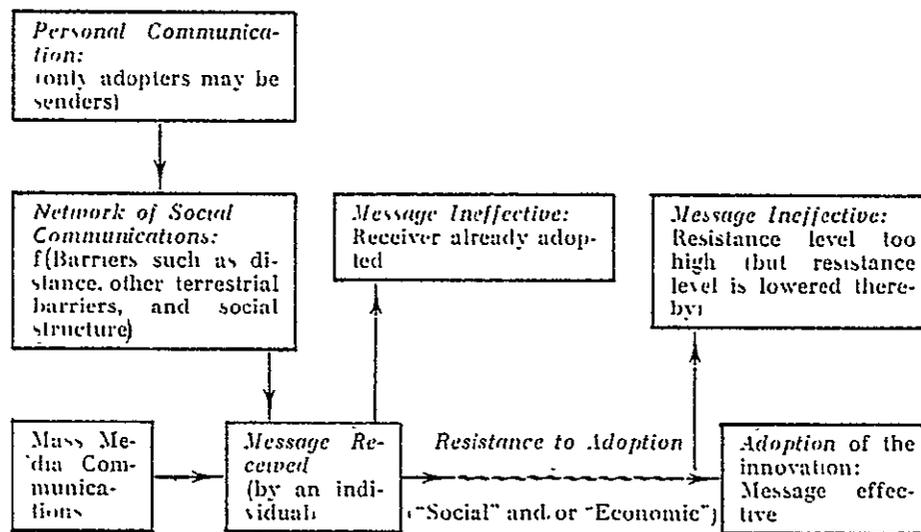


Figure 3.8 A Flow Diagram of Hagerstrand's Conceptualization of the Innovation Diffusion Process

(Source: Brown, Lawrence, Diffusion Dynamics - A Review and Revision of the Quantitative Theory of the Spatial Diffusion of Innovation, Royal University of Lund, Sweden, Department of Geography, Ser. B. Human Geography No. 29, 1968, p. 16.)

that a detailed theory need consider only factors related to the effective flow of information, e.g., personal characteristics which control the pattern of communication or the effect of a received message, intensity and frequency of messages and the relationships between exposure to 'information' about the innovation and reduction of resistance to adoption.\* However, the model put forth by Hagerstrand uses only that portion of a complete theory (under his tenet) which is relevant to the empirical situation examined. In part, this comes about because Hagerstrand proceeds inductively from empirical examples, rather than deductively from his basic tenet. His verbal statements, however, clearly indicate that his conceptualization of the process is much broader. For convenience in presentation, the components of the conceptualization may be divided into two groups: those related to the spread of information about the innovation and those related to deactivation of resistance to adoption.\*\*

A development of the Hagerstrand model as revised by Lawrence Brown\*\*\* is presented below. The formal development of the model employs the following terms and relationships.

---

\*"Effective" as used here signifies that adoption results upon receiving the information.

\*\* Brown, Lawrence, Diffusion Dynamics - A Review and Revision of the Quantitative Theory of the Spatial Diffusion of Innovation, Royal University of Lund, Sweden, Department of Geography, Ser. B. Human Geography No. 29, 1968, p. 11.

\*\*\* Ibid., pp. 44-48

$A_{it}$  is the probability that a resident of place  $i$  adopts for the first time during time  $t$ . Thus, in the case in which diffusion ultimately reaches the whole population,

$$\sum_{t=0}^{\infty} A_{it} = 1 \quad (1)$$

$a_{it}$  is the probability that a resident of place  $i$  adopts by time  $t$ . In all cases, therefore,

$$a_{it} = \sum_{k=0}^t A_{ik} \quad (2)$$

i.e.,  $a_{it}$  equals the probability of first-time adoption by a resident of place  $i$  in time 0 or time 1 or ... time  $t$ .

$C_{ij}$  is the probability that a resident of place  $i$  will choose place  $j$  as the destination for any single shopping trip.\*

$B_{jt}$  is the probability that a person shopping in place  $j$  at time  $t$  comes into contact with a merchant distributing the innovation.

$L_{it}$  is the probability that a resident of place  $i$  gains sufficient information from the mass media in time  $t$ .

$W_i$  is the probability that a resident of place  $i$  confronts the innovation in the marketplace and, thereby, gains sufficient information.

$I_{it}$  is the probability that a resident of place  $i$  gains sufficient information about the innovation during time  $t$ .

$F_{it}$  is the probability that a resident of place  $i$  gains sufficient information about the innovation from another resident of place  $i$  during time  $t$ .

$M_{it}$  is the probability that a resident of place  $i$  has sufficient contact with a distributor of the innovation during time  $t$ .

$r_i$  is the probability that a resident of place  $i$  is resistant to adoption.

$q_i$  is the number of acquaintances with whom a resident of place  $i$  has contact within the duration of a single time interval.

---

\* With respect to subscripts,  $t$  in all cases refers to a time interval, whereas all other subscripts ( $i$ ,  $j$ , etc.) refer to place or location.

$s_i$  is the number of acquaintances with whom a resident of place  $i$  has contact within the duration of a single time interval.

$v_{it}$  is the number of shopping trips taken by the resident of place  $i$  within the duration of time  $t$ .

$N$  is the number of places  $i$  which are considered in the empirical application of the model.

The model is designed to treat adoption of an innovation as a once-in-a-lifetime act, which is characteristic of the most common situation treated in research. Accordingly, its basic statement is: The probability that a randomly selected resident of place  $i$  adopts the innovation in time  $t+1$  equals the probability that adoption did not occur by that individual before time  $t+1$ , that he receives sufficient information about the innovation during time  $t+1$ , that this information is accepted because he is neither socially or economically resistant to adoption, and that during time  $t+1$  he comes into sufficient contact with a distributor of the innovation, thus acting upon the received information. Furthermore, the event of receiving sufficient information about the innovation during time  $t+1$  is realized by the occurrence of any one of three independent subevents: sufficient information is gained from another resident of place  $i$ ; or sufficient information is gained through the mass media; or sufficient information is gained upon contact with the innovation in the market.

The first event, that a randomly selected resident of place  $i$  did not adopt the innovation before time  $t+1$ , is gauged by

$$1 - a_{it} \tag{3}$$

or by substituting from equation (2)

$$1 - \sum_{k=0}^t A_{ik} \tag{4}$$

This assumes, of course, that adopters within place  $i$  are randomly distributed throughout its population.

The second event, that the randomly selected resident of place  $i$  receives sufficient information about the innovation during time  $t+1$ , must consider three subevents, as delineated above. In defining the first of these, gaining information from another resident of place  $i$ , the following assumptions are made for the initial formulation: that contact among residents of a place  $i$  is at random, that the distribution of adopters among the residents of place  $i$  is also at random, that all members of an acquaintance circle reside in the same place  $i$ , that only new adopters pass on information about the innovation, and that only a single contact with a new adopter is necessary.\* Then, the probability of contact with another resident of place

---

\* As a consequence of these assumptions, contact with any one acquaintance is an independent event, i.e., other acquaintances may also be contacted during the same interval with the same probability. In such a case, the characteristic probability relationship is

$$\lambda = \gamma_1 + \gamma_2 + \gamma_1\gamma_2$$

where  $\lambda$  is the probability of contact with at least one acquaintance and  $\gamma_i$  is the probability of contact from acquaintance  $i$ ,  $i = 1, 2$ . However, since this formulation becomes quite cumbersome when applied to many observations  $i$ , it is more convenient to focus upon the probability that no contact with an acquaintance occurs.

$$1 - \lambda = 1 - \gamma_1 - \gamma_2 + \gamma_1\gamma_2 = \prod_{i=1}^2 (1 - \gamma_i)$$

and it may be shown that a corresponding relationship holds for  $n$  events. Since several events in the model are designated to be of this type, this relationship will be employed frequently.

$i$  is  $s_i/q_i$ , the joint probability of contact with a resident of place  $i$  who is a new adopter in time  $t$  is  $s_i A_{it}/q_i$ , so that the probability of no contact during time  $t+1$  with a single resident of place  $i$  who passes information about the innovation is

$$1 - s_i A_{it}/q_i$$

the probability of no contact with any resident of place  $i$  who passes on information during time  $t+1$  is

$$(1 - s_i A_{it}/q_i)^{q_i} \quad (5)$$

and, finally,

$$1 - (1 - s_i A_{it}/q_i)^{q_i}$$

is the probability that a place  $i$  resident comes into contact with at least one other resident of place  $i$  who passes on information about the innovation during time  $t+1$ .<sup>\*</sup> The second and third subevents, gaining sufficient information from the mass media and gaining sufficient information as a result of contact with the innovation in the market, are represented by  $L_{i,t+1}$  and  $W_i$ , respectively. Now, incorporating these, we may define the whole of the second event, that sufficient information about the innovation is received during time  $t+1$ :

$$I_{i,t+1} = (1 - s_i A_{it}/q_i)^{q_i} (1 - L_{i,t+1}) (1 - W_i) \quad (6)$$

The third event, the the information is accepted because the resident is neither socially nor economically resistant to adoption, is opposite to and

<sup>\*</sup>Rapoport uses the expression

$$1 - (1 - 1/q_i)^{A_{it} q_i}$$

to express a parallel element in his acquaintance circle net model, assuming therefore that  $s_i = 1$ . From tests with arbitrarily chosen

mutually exclusive of the probability that the resident is resistant to adoption. This event may thus be gauged by

$$1 - r_i \quad (7)$$

numbers, however, and still assuming that  $s_i = 1$ , it appears that formulation would overestimate the desired probability. Note the formulation which describes different social situations. If on the average one acquaintance is encountered per time interval (i.e.,  $s_i = 1$ ), component (5) is

$$1 - (1 - A_{it}/q_i)^{q_i}$$

which evidently may be approximated by

$$1 - e^{-A_{it}}$$

If on the average all acquaintances are encountered per time interval (i.e.,  $s_i = q_i$ ), component (5) is

$$1 - (1 - A_{it})^{q_i}$$

which evidently may be approximated by

$$1 - e^{-q_i A_{it}}$$

If on the average more than one but less than all acquaintances are encountered per time interval ( $1 > s_i > q_i$ ), component (5) is

$$1 - (1 - s_i A_{it}/q_i)^{q_i}$$

which evidently may be approximated by

$$1 - e^{-s_i A_{it}}$$

In defining the fourth event, that the resident of place  $i$  has sufficient contact during time  $t+1$  with a distributor of the innovation, the following assumptions are made for the initial formulation: that only a single contact with a distributor of the innovation is necessary, that an individual's choice of market is independent of whether that market has the innovation, and that the act of shopping in one marketplace  $j$  neither influences nor precludes the possible act of shopping in some other marketplace, i.e., that contact with any single market is an independent event. Then,  $B_{j,t+1}c_{ij}$  is the joint probability that the market of place  $j$  distributes the innovation during time  $t+1$ , and that this market is contacted on a single shopping trip by a representative resident of place  $i$ ;

$$(1 - B_{j,t+1}c_{ij})^{V_{i,t+1}}$$

is the probability that a representative resident of place  $i$  has no contact with the distributor of the innovation located in place  $j$  during time  $t+1$ ;

$$\prod_j (1 - B_{j,t+1}c_{ij})^{V_{i,t+1}}$$

is the probability that during time  $t+1$  a place  $i$  resident contacts no distributor of the innovation in any market; and

$$M_{i,t+1} = 1 - \prod_j (1 - B_{j,t+1}c_{ij})^{V_{i,t+1}} \quad (8)$$

is the probability that during time  $t+1$  a place  $i$  resident contacts at least one distributor of the innovation.

Now, to define the probability that a randomly selected resident of place  $i$  adopts the innovation in time  $t+1$ , it remains only to combine (3), (6), (7) and (8) as joint and independent events, i.e.,

$$A_{i,t+1} = (1 - a_{it}) I_{i,t+1} (1 - r_i) M_{i,t+1} \quad (9)$$

a recursion formula from which  $A_i$  for any  $t$  may be computed given the values of  $A_{i,0}$ ,  $s_i$ ,  $q_i$ ,  $L_{i,t+1}$ ,  $W_i$ ,  $r_i$ ,  $c_{ij}$ ,  $v_{it}$ , and the pertinent values of  $B_{jt}$ . Also, the values of  $A_i$  for every  $t$  may be substituted into equation (2) in order to compute  $a_{it}$ , the probability that a randomly chosen resident of place  $i$  adopts by time  $t$ , a property of the system which is of general interest.

As can be seen from the foregoing discussion, the innovation diffusion process can be modeled. It may be possible to use these models to gain insight into the effects of alternative development strategies on the rate of technology transfers from the developer to the end user of a new technology such as SEASAT.

#### 4. CANDIDATE ECONOMIC VERIFICATION EXPERIMENTS

In this section, a variety of potential economic verification experiments are proposed. It is recognized that the costs to perform the full set of proposed experiments would probably exceed the resources available from the SEASAT-A program. Thus, it will be necessary to select a subset of these experiments to perform. A ranking of the experiments for aid in their selection is provided in Section 5.

Throughout this section, the reader should keep in mind the differences between an economic verification experiment and a technical verification experiment. Both seek to demonstrate a measurement capability, but an economic verification experiment has two important added features:

1. It places emphasis on verification of technical capabilities that are of economic value.
2. In addition to demonstrating a technical capability, it demonstrates a potential use of that capability in an economic process.

Thus, whereas a technical verification experiment objective could be to demonstrate the ability of SEASAT sensors to measure wave height, the corresponding economic verification experiment objective might be to demonstrate the potential use of SEASAT data in a wave height information system and the value that the resulting improved information could have in, for example, offshore drilling operations. It is not always necessary to conduct an economic verification experiment in real-time in order to obtain valid results nor is it necessary to provide improved information for every decision (that is, it should not be implied that an operational system is necessary to conduct an economic verification experiment). It is necessary, however, to collect data from which the

economic value of improved information can be implied and this is what is usually missing in a technical verification experiment. In special cases, it may be possible to directly impact an operation and obtain an actual benefit. These cases are always the most impressive demonstrations of economic value but they also tend to be associated with relatively small benefits and, while of some importance, they should not be emphasized to the total exclusion of other experiments associated with potentially larger benefits.

The proposed economic verification experiments are detailed below in two sections. Section 4.1 outlines U.S. based experiments and Section 4.2 outlines international cooperative experiments. Most of the latter involve cooperation with Canada.

#### 4.1 U.S. Based Experiments

##### 4.1.1 Applications to the Offshore Oil and Gas Industries

By any standard, offshore oil and gas exploration and production constitutes the largest segment of economic activity in the world's oceans. It has been estimated\* that the economic value to the United States alone of offshore oil and gas was \$3.2 billion in 1973, and will grow to \$18.9 billion by the year 2000 (in 1973 dollars). The next largest segment is that of transportation, for which the comparable figures are \$2.5 billion and \$11.4 billion, respectively.

The shortages in available energy supplies and in known proven reserves have increased the interest in exploration for hydrocarbon

---

\*"The Economic Value of Ocean Resources to the United States," prepared for the Committee on Commerce, U.S. Senate, pursuant to Senate Resolution 222, National Ocean Policy Study, 93rd Congress, 2nd Session, December 1974.

resources in offshore areas around the world. This expansion has led industry into much harsher environments and more remote locations. Harsher environments increase the desirability of obtaining environmental data. In general, there is usually a paucity of data in report areas with severe environments, and the expense of obtaining data in these regions often precludes the initiation of any measurement programs unless there is some substantial expectation of economic returns. Unfortunately, many years of data are required to determine valid design and operational criteria. Furthermore, forecasting accuracy cannot be assessed where there is a limited amount of verification data. SEASAT will probably be helpful in solving some of these problems associated with environmental data needs. Global coverage of the oceans at frequent intervals and reasonable cost can provide estimates of such parameters as: (1) significant wave height and direction, (2) current speed and direction, (3) wind speed and direction, and (4) ice coverage and movement. It is hoped that data from operational SEASAT systems with the capability of wide area coverage will provide a more economic and reasonably accurate alternative to present methodologies.

The size of this industry, together with the fact that there is a clear need for improved technology in offshore exploration and operation, suggests that this industry segment presents a major opportunity for application of the new and unique capabilities of SEASAT-A for generating data for all the world's ocean regions, with particular emphasis on the waters surrounding North America.

Preliminary assessment of the benefits to the offshore oil and gas industry from an operational SEASAT was made during 1974-1975.\* The annual worldwide benefits were estimated at \$658 million between 1985 and 2000. Table 4.1 shows the integrated benefits of the generalization results for the offshore oil and gas industry at several discount rates.

A number of initiatives are now being pursued with organizations involved in offshore oil and gas operations with the objective of defining possible experiments which these organizations might undertake utilizing SEASAT-A data to investigate the practical benefits of a SEASAT system. For the most part, the organizations contacted have been highly receptive to the general idea of using SEASAT data and to the development of suitable experimental programs. However, a number of details remain to be worked out. The purpose of this section is to outline the general character of the potential experiments which are emerging from this negotiation process.

Table 4.1 Generalization Results For Offshore Oil and Gas Industry				
Discount Rate %	0	5	10	15
	Integrated Benefit 1985-2000 (\$1975 Millions)			
SEASAT Exclusive	464-2656	195-1113	87-501	43-244
SEASAT Exclusive Most Likely	1136-1824	476-765	214-344	104-168
All Sources	1547-8853	650-3710	290-1670	143-813
All Sources Most Likely	3787-6080	1587-2550	713-1147	347-560

\* Offshore Oil and Gas Industry Case Study and Generalization, Vol. III of SEASAT Economic Assessment, prepared by ECON, Inc., for the National Aeronautics and Space Administration, under Contract No. NASW-2558, October 1975.

#### 4.1.1.1 General Nature of Offshore SEASAT Experiment

In contracts with the offshore industry, interest has been expressed in all the SEASAT sensors and in several geographical regions. There is interest in both real-time and historical data. In some cases, potential participants have predictive models to which SEASAT data could make a contribution. In all geographical regions, the interests of the users are roughly similar. They are interested in:

1. Verification of SEASAT data against in situ measurements in the region of interest
2. Use of SEASAT data in "nowcast" and predictive models and verification of the model outputs
3. Use of data obtained to guide field operations.

There will be a requirement for the most recent possible data for "nowcast" and forecasting purposes, very likely less than twelve hours between sensing and data available to the user. Collection of historical data in certain regions has been indicated to be quite useful for generating exceedance statistics.

#### 4.1.1.2 Overview of Approach

The objectives of an experiment in offshore oil and gas industries would be to:

1. Assess the technical capabilities and economic benefits of SEASAT data for offshore oil and gas industry operations in selected test areas, and
2. Generalize the results to worldwide industry operations.

An overview of the approach for a SEASAT verification experiment that can achieve these objectives is shown in Figure 4.1.

The approach selected involves a single management organization, serving a variety of offshore oil and gas organizations. The first step

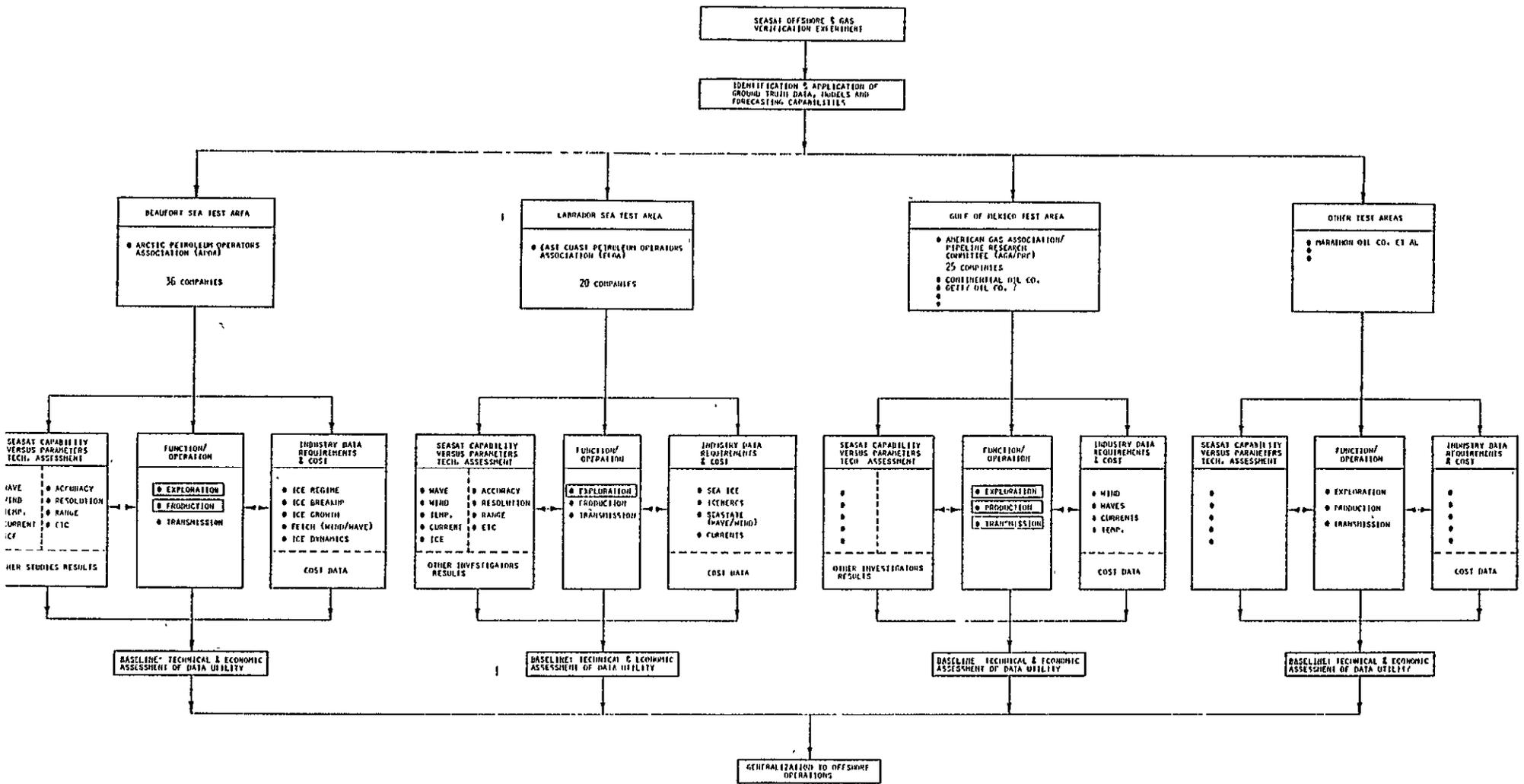


Figure 4.1 SEASAT Offshore and Gas Verification Experiment

in this approach (identification and application of ground truth data, models and forecasting capabilities) emphasizes those major common data requirements that apply to most of the industry. For example, modeling and forecasting capabilities are used by most operators, either directly or through their contractors, and these could probably be provided by a single SEASAT data system. This suggests that, once this system is designed, it could be made available to the entire industry and that a considerable number of users could benefit, at minimal cost.

Four test areas with unique characteristics have been selected to provide the necessary baseline evaluation that can be generalized to the rest of the industry on a worldwide basis. These four test areas are:

1. Beaufort Sea
2. Labrador Sea
3. Gulf of Mexico
4. Other test area (to be selected).

Areas 1 and 2 would involve international cooperation with Canada and are discussed in Sections 4.2.1.1 and 4.2.1.2. Areas 3 and 4 would be U.S. based experiments and are discussed below. In all these test areas both technical and economic verification procedures will be applied to the three major phases of the offshore oil and gas industry operations to the extent possible:

1. Exploration
2. Production
3. Transmission.

The emphasis will be on the technical verification of SEASAT during its early stages. This seems to be desirable on the part of the offshore oil and gas industry participants who have expressed the need for the technical verification before they can make judgments on future economic benefits. Although many representatives have expressed great interest in the type of data that can be provided by SEASAT, they are still skeptical about the capability of SEASAT (for example, precision/accuracy achievable, resolution, coverage, etc.) in meeting their requirements. Therefore, one of the aims of this experiment is to demonstrate and validate SEASAT capability against the ground truth data which will be provided by the industry in the selected test areas. SEASAT-A will be a predecessor of the operational SEASAT system and will more or less be a verification experiment to evaluate instrumentation and to determine whether or not data obtained are, in fact, a reliable guide for operational decisions.

At this point, it is important to mention that even if the instruments are capable of the resolution and accuracy specified, consideration must be given to sampling interval, timeliness of data, and areal extent of coverage when evaluating operational usefulness.

The purpose of the verification procedure is to determine:

1. Resolution and accuracy achieved
2. Limitation of SEASAT instrument capabilities to sense the desired parameters
3. Capability of the models and relationships to describe the end parameters and results accurately
4. Economic benefits that can be realized from an operational SEASAT system for predicting and describing environmental and ocean dynamic parameters.

Though many types of weather conditions hamper offshore operations, winds and waves are common hazards to all offshore operations. Through close coordination with potential users, wind and wave conditions could be categorized with respect to their effect upon operations. For example, if positioning a drilling rig requires winds not greater than 10 knots and seas not greater than 3 feet, then these criteria describe one (probably the optimum) operational category. Categories could be numbered consecutively from the most to the least desirable wind and wave conditions. Thus, the category number would define which operations could and which could not be performed. Furthermore, a change of category would always have an operational effect upon the user.

Other parameters of offshore gas and oil interest include surface current speed and direction, ice data, deep ocean tide data, and ocean surface temperature. Verification of the SEASAT data obtained on these parameters could be made from offshore platforms and vessels.

The number of surface measurement locations available varies considerably from one experiment region to another. In the case of the Gulf of Mexico, a substantial number of measurement sites can be used, but for the arctic regions, the number may be very small. Narrow-swath instruments like the altimeter and the SAR will seldom provide data for direct comparison with data from a given surface site. The scatterometer determination of wind speed, on the other hand, represents an average over distances of some hundreds of kilometers. This too is difficult to compare with data from a single point.

In most cases, therefore, it seems advisable to consider the introduction of nowcasting models into the comparison process. This will

introduce modeling errors, but without the model, other assumptions would have to be used which would raise even greater questions. In any event, an operational system would have to make use of some type of model, so it is not unreasonable to introduce one into the SEASAT-A tests. Naturally, verification of the model then becomes part of the process.

#### 4.1.1.3 Methods of Data Application

##### Comparison with Ground Truth

As an initial step in any experiment, users will want to verify SEASAT-A data against other measurements, especially those being made at existing facilities in the areas of operational interest. For this purpose, real-time data are not necessary. If agreement with ground truth data is not obtained, it will be necessary to investigate the causes for this disagreement before proceeding.

##### Use of SEASAT Data in Models

Some prospective participants have used or are developing predictive models for ice movement, wave height and weather. Once SEASAT data are verified, they can be put into these models along with data from other sources. It may be possible to arrange to run predictions with and without the SEASAT data but user motivation to do this may not be high. Also, for the most part, these models are proprietary. It may prove more efficient for NASA to do the modeling and prediction for all users, as the techniques required are quite similar. In any case, model prediction will be compared with operating experience.

Again, if verification is not obtained, it will be necessary to investigate the discrepancy before proceeding.

### Operational Use of Data

If the preceding step is successful, the final portion of the experiment could be to make use of the data and predictive models to guide operational decisions. A number of months would be required to carry this out. In view of the limited SEASAT-A experiment period, and the fact that there will be only a single satellite, it may not be possible to reach the stage of operational data use, except possibly with certain data types in certain regions. Even then, it will probably not be possible to compare the results with SEASAT against those without, but it will be possible to keep track of operational decisions in which SEASAT data played a significant role.

### Use of Historical Data

As a possible adjunct to SEASAT data it may be of interest to make use of other available satellite measurements. For example, GEOS-3 data could be used to estimate wave height in regions of interest for the years in which these data are available.

#### 4.1.1.4 Experiment Test Areas

The data requirements are generally similar for all geographic regions but there are some differences in emphasis. The regions discussed below are the ones in which the greatest interest has been expressed by U.S. offshore oil and gas operators. Regions of interest to the Canadians are discussed in Sections 4.2.1.1 and 4.2.1.2.

### Gulf of Mexico

Several industry representatives are interested in the Gulf of Mexico test area. The principal organizations, so far, that have expressed interest in this area are the American Gas Association/Pipeline

Research Committee (AGA/PRC), and Continental Oil Company. Other companies, such as Getty Oil, are expected to communicate their preference soon. Interest in this area appears to be in monitoring and prediction of winds, waves, and temperature, especially in relation to major storms.

#### Preliminary Objectives

The overall objective is to evaluate SEASAT capability as an aid in establishing improved design criteria for offshore pipelines and gathering systems as well as assisting in oil and gas operations. Specific objectives are to:

1. Validate sensor data by direct comparison with corresponding in situ data obtained by ground truth stations in the Gulf of Mexico.
2. Correlate surface environmental conditions such as winds, waves, and currents with subsurface characteristics affecting pipeline design and operations.
3. Provide valuable supplemental information for improving the accuracy of prediction of severe storm size, intensity, and path which are critical for the design of offshore pipelines.
4. Provide a broad range of environmental data for improving the capability for real-time prediction of oceanographic and meteorological conditions which affect offshore operations such as pipe laying, diving, drilling, helicopter and vessel operation, and the loading and unloading of equipment and supplies from offshore platforms.

Additional work (still in progress) for defining the test area and the parameters involved will be required.

#### Other Test Areas

Marathon Oil Company is in the process of defining a test area involving several oil companies. Other organizations such as the American Petroleum Institute and Brown and Root are being considered for the possibility of participation in the verification experiment.

#### 4.1.1.5 Experiment Duration

It seems probable that the time span of one and one-half to two years will be required to reach the point at which operational use could begin. Once SEASAT-A data become available, perhaps three months would be required to get the data channels working, assuming good advance planning. In the Arctic locations (see Sections 4.2.1.1 and 4.2.1.2), probably a full operating season would be required for each of the two validation steps, assuming all goes well. If discrepancies are found, additional time will be required to find the causes.

At least another year would be required before a reasonable opinion could be developed as to the operational usefulness. Thus, a total program of the order of three years could be involved, possibly longer if problems are encountered. It remains to be seen how much of this will be possible within the SEASAT-A lifetime.

#### 4.1.1.6 Work to be Done

There remain several activities that must be completed before a final experimental program could be designed and readied for SEASAT. These activities, which should be completed by October 1977, include the following:

- Continuation of efforts that have already started (see above) with various industries to formulate experiment team and generate interest and support
- Development of a technical plan for the experiment in the selected test areas for further definition of data sources and requirements, test site locations and parameters, analysis procedures and the development of validation plans including appropriate ground-truth data (to be provided by the industry) to demonstrate SEASAT instrument accuracy, coverage, and potential benefits

- Development of management plan including functional requirements of the proposed experiment for the various phases of SEASAT-A (prelaunch, launch, and post-launch); organization of experiment team efforts and assignment of responsibilities among team members and NASA
- Development of detailed costs for the experiment including cost to government and those costs that will be shared by the industry
- Preparation and execution of a suitable agreement between NASA and the experiment team.

#### 4.1.2 Applications to the Marine Transportation Industry

##### 4.1.2.1 An Ocean Routing Experiment

The purpose of the SEASAT-A Ocean Routing Economic Verification Experiment is to obtain experimental data in support of previous empirical estimates of the economic benefits of a SEASAT system which generates ocean condition information and which, along with conventional ocean condition information, is useful in routing vessels on ocean crossings. The aim of the ocean routing process is to assist vessels in their efforts to avoid adverse weather and the resulting problems:

- Loss of time
- Greater fuel consumption
- Casualties with loss of life and/or vessel damage.

The experiment will attempt to quantify the incremental reduction in time loss, fuel consumption and casualties when SEASAT information is added to the conventional information available. For a preliminary assessment of the usefulness of SEASAT-A for ocean routing see: Marine Transportation Case Study.<sup>\*</sup> The results of this study are presented in Figure 4.2. Undiscounted benefits on U.S. trade routes alone might be \$27 million in the first

---

<sup>\*</sup>Marine Transportation Case Study, Volume VII of the SEASAT Economic Assessment, prepared by ECON, Inc., for the National Aeronautics and Space Administration under Contract No. NASW-2558, October 1975.

		Dry Cargo				Tankers		Totals Estimated	
		All U.S. Trade Routes		Canadian Trade Routes		World Fleet All Major Routes			
		Source of Benefits	1985 Undiscounted Benefits	1985-2000 Cumulative Discounted Benefits*	1985 Undiscounted Benefits	1985-2000 Cumulative Discounted Benefits*	1985 Undiscounted Benefits		
Direct Operating Costs	Delay Time	20,660,000	86,620,000	6,440,000	25,200,000	3,430,000	19,400,000	30,530,000	131,220,000
	Cost Savings			to 7,220,000	to 43,800,000	to 16,680,000	to 94,250,000	to 46,560,000	to 224,670,000
Marine	Prevention of Catastrophic Losses	(not estimated)		5,000,000	24,500,000	5,830,000 to 19,420,000	32,930,000 to 109,800,000	17,230,000	84,270,000
Insurance	Reduction in Casualty Costs (Hulls)	6,400,000	26,840,000	to	to	(not estimated)			
Costs	Reduction in Casualty Costs (P&I cargo)	(not estimated)		39,900,000	163,600,000	(not estimated)		to	to
	Totals Estimated	27,060,000	113,460,000	11,440,000 to 44,120,000	49,900,000 to	9,260,000 to	52,330,000 to	47,760,000 to	215,490,000 to

\* Discount Rate - 10%

Source: VII - SCASAT

Figure 4.2 Overall Results, Benefits Due to SEASAT in Marine Transport, in 1975 Dollars

full operating year, 1985. U.S. flag ships carry about 7 percent of the cargo on U.S. trade routes.

The experiment will be conducted through an actual monitoring of selected ocean crossings in a case study framework. The dollar value of the incremental gains will be estimated for the case study experiment, and the results will be generalized to all vessel ocean crossings on the U.S. trade routes for the time period 1980-2000.

#### Background--The Present Weather Routing System

There is no single weather routing system today. Rather, there are the Navy's Fleet Numerical Weather Center (FNWC), Norfolk, Virginia and Monterey, California; and a number of commercial services such as Louis Allen, Washington, D.C.; Bendix Commercial Service Corporation, South Hackensack, New Jersey; Ocean Routes, Inc., Palo Alto, California. In addition, there are weather routing services operated by foreign individuals and governments. Bracknell, a government-owned routing service in England, is an example of the latter.

The charge per ocean crossing for these routing services may run from \$95 to \$300, but is generally in the \$200 to \$250 range. The charge may be for simply recommending the entire route in one analysis before the crossing begins or it may involve a more complete service. In its most thorough form the weather routing might involve a discussion with the captain before departure to gather such information as: cargo to be carried; any cargo stored on deck; special reason for speedy crossing if necessary. A recommended route will then be selected based on the information gathered from the captain, from weather forecasts, from information about the ship's rated speed and ability to handle heavy seas, etc.

Once the voyage is begun the weather router may contact the ship with revised information or suggestions as to the route as often as twice a day. FNWC runs its forecasting program and ship routing program twice a day. Navy ships often have a radio operator on duty continuously. However, for commercial vessels route recommendations are usually restricted to one contact per day, since most commercial vessels have one radio operator who will on duty nine hours per day (usually in three-hour daylight shifts with one hour between shifts). When the voyage is completed, the routing service may also involve a postvoyage consultation and analysis. The ship's log book may be examined in conjunction with a record of the router's recommendation, to ascertain the cause of a slow crossing time or failure to avoid a heavy storm, or the reason for the departure from the recommended route.

The above description pertains to a complete weather routing service. Often contact is made only every few days, whenever a major change in weather conditions on the route takes place, and there may not be a postvoyage analysis.

Weather routing became available in the early 1950s, but the expansion of the weather routing services did not occur until the mid-1960s. Presently, on a given day, Ocean Routes, Bendix, Louis Allen, Inc., FNWC Monterey, and FNWC Norfolk may handle 850 ships. Their numbers may vary considerably day to day. For example, Ocean Routes may handle 1000 ships on a given day and FNWC Monterey may handle 200 plus ships during a major military supply effort. Since 11,000 to 12,000 of the world fleet of approximately 21,000 ships may be on the ocean on a given day, the U.S. commercial and government weather routing services could be guiding approximately 7 percent of all ships on the oceans.

### Overview of Approach to Experiment

The experiment will seek three representative sample groups of ocean crossings from the vessel types and routes of interest. These three sample groups will be unrouted vessels, vessels routed without SEASAT, and vessels routed with SEASAT. The sample vessels will be provided ocean routing information (if required) and monitored with respect to crossing time, fuel consumption and adverse weather related damage.

An extensive ocean routing industry exists today, and the SEASAT information will be an additional input to the procedures used by the industry. The ocean routing industry will provide the routing service where required. The ship owners will be approached to seek their cooperation in the monitoring effort. Ship owners will be asked to provide enough prevoyage information to identify potential sample crossings and to provide desired postvoyage information.

ECON will collect the postvoyage information and subject it to a screening process to determine if it is a representative sample. Those ocean crossings which pass the screening process will be entered in the sample data base. The differences in the performances of unrouted vessels, vessels routed without SEASAT, and vessels routed with SEASAT will be computed and analyzed. Dollar benefits for the use of SEASAT information in the ocean routing procedure will be derived from the analysis of the experiment results.

### Methodology Proposed

In order to provide an accurate assessment of the impact of a SEASAT system on ocean routing a sound methodology must be developed and implemented. In this section a methodology is presented which is intended to

measure the incremental dollar benefits derivable from reduced ocean crossing time, fuel consumption, and adverse-weather related casualty damage.

The elementary unit in the experiment will be a single one-direction ocean crossing by a vessel of a given type or subtype. The variables to be measured include: crossing time, distance traveled, fuel consumed, and any casualty causes and costs. The physical field within which the experiment is to be conducted will be identified by: port of origin, port of destination, minimum distance possible (Great Circle route distance), ocean to be traversed, and time of year. The population of elementary units for this experiment will be all ocean crossings on the U.S. trade routes for the years 1977 to 1980 inclusive.

This population will be divided into three groups:

1. Unrouted vessels
2. Vessels routed without the use of SEASAT data
3. Vessels routed with the use of SEASAT data.

Representative samples will be drawn from each of these three population groups. The first sample group, the unrouted vessels, will be the Control Group, the second and third sample groups will be the Experimental Groups I and II respectively. The goal of the experiment is to quantify the difference in the measurement variables (crossing time, distance traveled, fuel consumed, and any casualty causes and costs) between:

- Control Group (unrouted vessels) and Experimental Group I (vessels routed without SEASAT data)
- Control Group and Experimental Group II (vessels routed with SEASAT data)
- Experimental Group I and Experimental Group II.

The success of the experiment will depend on the ability of the sample selection procedure to yield representative samples. This is especially difficult in this case because many factors affect ocean crossing time. These factors are discussed, as well as a method for obtaining representative samples given many such variable factors.

#### Factors Affecting Vessel Performance

The factors which affect a vessel's ocean crossing performance may be grouped into three categories:

- Vessel specifications
- Geographic specifications
- Trip specifications.

Vessel specifications include all the physical characteristics of the ship which affect its performance. Among these are: age, where it was built, gross tonnage, deadweight tonnage, speed, draft, engine type, beam length, etc. It is imperative that representative sample groups include vessels which are similar or nearly similar with regard to the variables which impact on the ocean crossing performance.

Geographic specifications include: the ocean of operation (and the specific path across that ocean), the port of destination, intermediate stops if any, direction of sailing, time of the year and direction of currents at that time of the year.

Trip specifications encompass the myriad of variables which change in the environment surrounding a given physical vessel in a given geographic setting. A sampling of these are: weather conditions, wave height, changes in crew, machinery failure, cargo type carried, load factors, on-deck cargo, etc. It is, of course, trip specifications which presents the greatest control problem for this experiment.

### Selecting a Representative Sample

Selecting representative sample groups involves selecting elementary units (ocean crossings) which are similar or nearly similar with respect to vessel specifications, geographic specifications and trip specifications. In an ideally controlled case the only difference among the control and experimental groups would be the availability or lack of routing information. The sample design should approximate this ideal as closely as possible.

The first step will be to stratify vessels by type and physical characteristics. This involves some subjective judgment. For example, a generally used broad classification by vessel type is:

- Liquid bulk (e.g. tankers)
- Dry bulk (e.g. ore carriers)
- Break bulk (e.g. freighters)
- Containers.

The Maritime Administration has adopted a slightly more defined broad classification for most of its analysis which includes nine vessel types:\*

- General cargo
- Partial container
- Full container
- Barge carrier
- Neo bulk
- Dry bulk
- Liquified gas carrier

---

\* A Study of the Future Requirements for Ships That Will be Engaged in the U.S. World Trade for Both the Short and Long Term, prepared by Temple, Barker & Sloane, Inc., for the Office of Maritime Technology, Maritime Administration, March 1976.

- Liquid bulk
- Combination carrier.

An example of a very detailed classification can be found in the 99 vessel type classifications employed by the U.S. Salvage Association in its casualty survey procedure.\* A level of detail of vessel type will be selected so that, together with the physical characteristics selected, the vessels within each vessel type can be expected to perform similarly with respect to the measurement variables (ocean crossing time, fuel consumption, and cost of repair for weather related casualty damage).

Physical characteristics of vessels can be looked at in greater or lesser detail also. The characteristics used to physically describe a vessel will first be listed, then ranked according to their impact on the measurement variables. Ranges of values for each physical characteristic will be defined so that ships within a range can be said to be similar with respect to that characteristic alone. Ranges will be defined most narrowly for those characteristics ranked highest.

The aim of this effort will be to select strata of vessels, with each strata distinguished by type and physical characteristics, such that the vessels within each strata can all be expected to perform similarly with respect to the measurement parameters if they are placed in the same geographic situation and trip specific situation. These vessels within each strata will be called vessel subtypes.

Since it will be possible to perform a thorough analysis on only a few of the vessel subtypes, two criteria will be used to select the vessel subtypes to be analyzed:

---

\* U.S. Salvage Association, Inc., Damage Survey Analysis Coding Manual, January 1968, revised, April 1971.

- Vessel subtypes selected for analysis should be fairly representative of the broader vessel type within which they are found.
- The population of vessels for the chosen subtype should be sufficiently large that adequate samples can be drawn.

The second step in selecting representative samples will be proper definition of geographic specifications. This is the simplest and most direct task and involves defining the ocean crossing of interest by:

- Port of origin
- Ocean to be crossed and general path to be followed
- Port of destination
- Time of year.

The first three define what will be called a route. The criteria for selecting the geographic area for the sample will be that a chosen route must be heavily traveled by the vessel subtype of interest, and the time of year must be such that adverse weather is an important consideration for the crossing. There are several published sources which can serve as a guide to vessel traffic by route.

Once the vessel specifications of the subtypes are selected and the geographic specifications defined, all elementary units falling within these specifications will be considered potential sample units. Data will be sought from as many of these units as possible. Scheduled ocean crossings by as many such vessels as possible will be considered for monitoring. The crossing will be identified as a potential sample element before the sailing, cooperation of the vessel owner will be sought, and a postvoyage analysis will be performed by the shipping company which is expected to yield all the relevant trip specifications (i.e., load factor, type cargo, etc.). This

implies it would be best to obtain the cooperation of a set of companies operating on the routes of interest.

Thus, the third step in selecting a representative sample involves defining as many quantifiable trip specifications as are relevant to the measurement variables and preparing a form which enables consistent information to be gathered. Space must be provided for entering qualitative information which impacts on the measurement variables. Ships' owners will be briefed before sailings on the quantitative and qualitative information sought and its ultimate use.

Postvoyage trip specifications will be screened in order to eliminate those crossings which cannot be included in the sample (e.g., vessel left route for reasons unrelated to adverse weather) or to further stratify the sample (e.g., into vessels with high, medium, low load factors).

#### Experiment Operational Considerations

Implementation of the proposed methodology involves identifying the appropriate source of data, designing an operational procedure for gathering the data and analyzing it, and developing the necessary computer processing software through which the data must flow. These considerations are discussed in this section.

##### 1. Sources of Data

Vessel specifications can be found in the Maritime Administration's Ship Description System (SDS) file.\* This magnetic tape file contains specifications for 22,400 vessels or the bulk of the world fleet. The information on each vessel includes:

---

\* Ship Description System, magnetic tape file maintained by the Office of Management Information Systems, Maritime Administration, U.S. Department of Commerce, Washington, D.C.

- Vessel name and flag
- Vessel number (Marad identification number)
- Vessel type
- When and where built
- Gross tons, deadweight tons, bale cubic
- Speed
- Draft
- Engine type
- Beam length
- Refrigerated capacity.

This information has been compiled by the Maritime Administration from the ship registries such as Lloyd's Register of Shipping and the American Bureau of Shipping. A computer program will be created to cluster the vessels into the appropriate groups according to the vessel specification ranges provided. The program can be rerun with various vessel specifications until a satisfactory stratification is achieved.

Geographic specifications such as general weather conditions by time of year, ocean conditions and currents can be obtained from ocean routers such as Fleet Numerical Weather Center, Ocean Routes, and Bendix Commercial Services Corporation. Traffic on routes by vessel type can be obtained from:

ECON, Inc., Marine Transportation - Case Study and Generalization, Volume VII of SEASAT Economic Assessment, prepared for the U.S. National Aeronautics and Space Administration, May 1976. (Includes forecasts.)

Temple, Barker & Sloane, Inc., A Study of the Future Requirements for Ships That Will Be Engaged in the U.S. World Trade for Both the Short and Long Term, prepared for the Office of Maritime Technology, Maritime Administration, March 1976. (Includes forecasts.)

Maritime Administration, Essential U.S. Foreign Trade Routes, annual.

Trip specifications can be obtained from the ship owners.

Weather routing without and with SEASAT will be provided by the ocean routing services in the normal course of their operations in the period 1977 to 1980 (1977 and part of 1978 without SEASAT, part of 1978 through 1980 with SEASAT). Routed vessels will necessarily be restricted to the customers of the routing service. Sample crossings of vessels routed without a SEASAT system will be drawn from the 1977 to mid-1978 population. Sample crossings of vessels routed with a SEASAT system will be drawn from the world 1978 through 1980 population. Since it will be necessary to gather the data for the two experimental groups in sequence rather than in parallel (once SEASAT-derived information becomes available it would not be ethically acceptable to withhold that information from some vessels since the safety of lives and property are at stake) extra care must be taken that all other specifications are as similar as possible. SEASAT information will be provided directly to the Fleet Numerical Weather Center and distributed by them to ship routers who will use this information in their routing recommendations.

The trip specification data will be keypunched (if it passes the final screening) and entered into a main data base. A computer program will be created to process and analyze this data and calculate the benefits of the SEASAT information.

## 2. Operational Procedures

The operational procedures described in the methodological discussion and data sources description are summarized here.

- Select vessel type and physical characteristics for experiment.
- Select route and time of year in which to conduct the experiment.
- If the vessel is routed the ocean router takes ocean condition forecast (using SEASAT information if available) and vessel data, prepares routing instructions, and provides the routing instructions to the ship before departure.
- After departure ship reports are received along with updated ocean condition forecasts, and the route selection is updated; this process is repeated as often as necessary until the vessel arrives at its destination.
- After the voyage is completed the trip specifications are entered on a form provided to the ship owners by ECON and the completed form is sent to ECON.
- The forms are analyzed by ECON and the ocean routers, and if the ocean crossing is deemed representative the crossing is included in the sample data base; and the general results are calculated when the sample sizes permit significant results to be derived.

These operational procedures are illustrated in Figure 4.3, Flowchart of Operational Procedures. The roles of the experiment participants in each of the operational steps is given in Table 4.2, General Operational Roles of Experiment Participants.

### 3. Data Flow and Experiment Results

The data flow and processing described throughout the methodological discussion and data sources description are summarized here.

- Identify general vessel types (four to nine types).
- Identify a representative or significant (in terms of volume of cargo) vessel subtype.
- Select identifying vessel specifications ranges for the empirical subtype.
- Write computer program to cluster vessel names from Maritime Administration's SDS file into subtypes identified by ranges of vessel specifications.

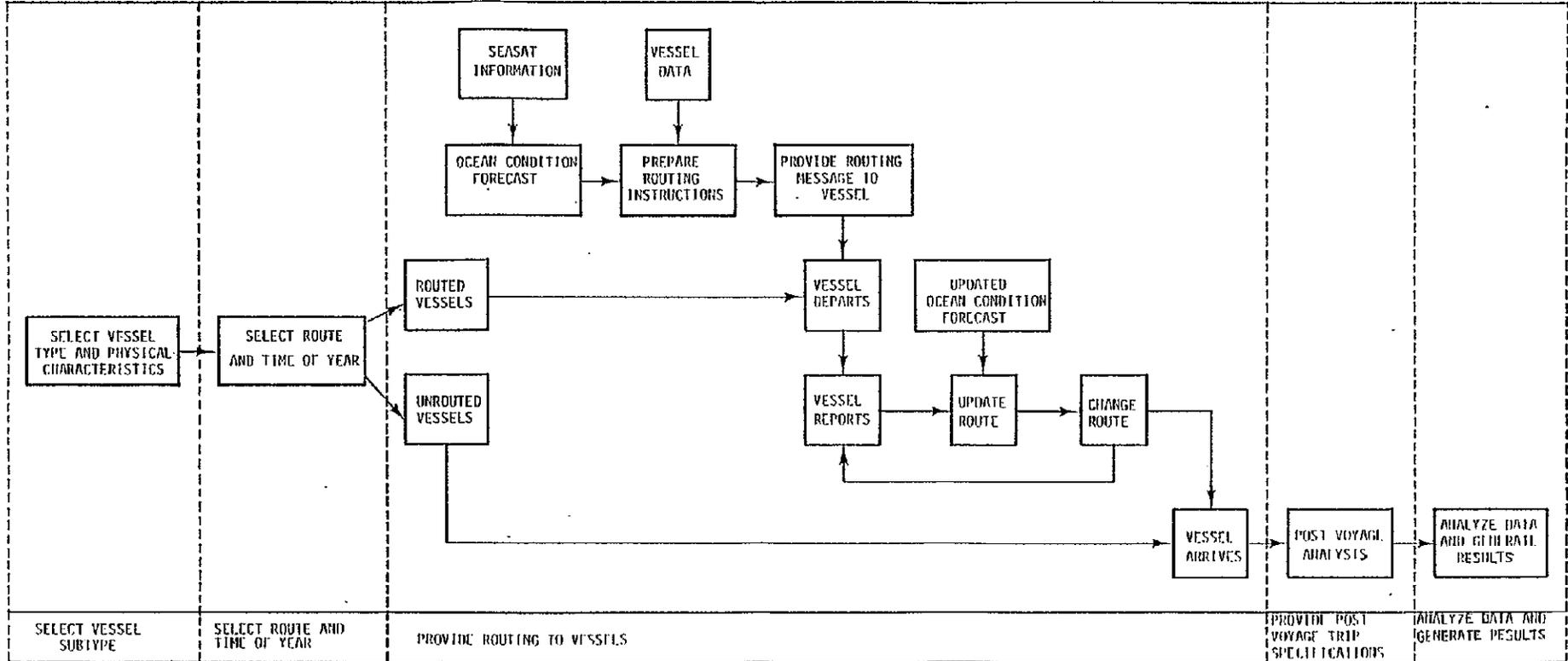


Figure 4.3 Flowchart of Operational Procedures, Ocean Routing Case Study

Table 4.2 General Operational Roles and Experiment Participants

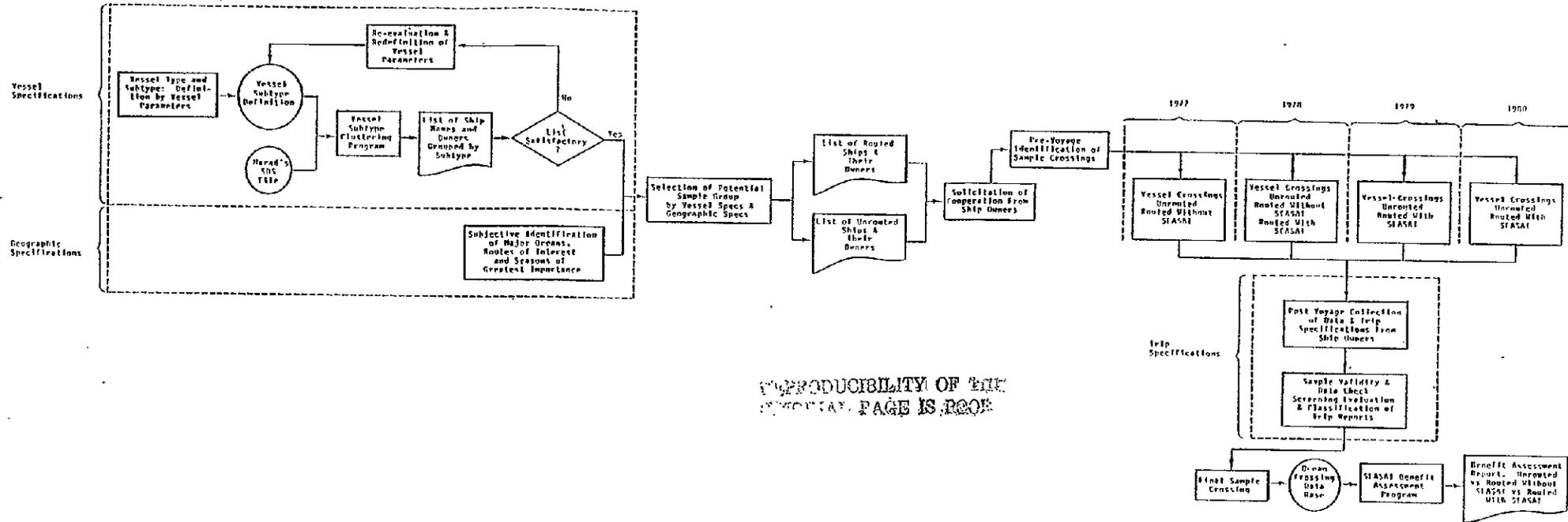
Operational Steps	ECON	Ship Routers	Ship Owners
Select Vessel Subtype (vessel specifications)	✓ (with SDS file provided by Maritime Admin.)	✓ (technical assistance to ECON)	
Select Route & Time of Year (Geographic Specifications)		✓	
Routing Provided to Vessels		✓	
Provide Post Voyage Trip Specifications			(to ECON on ✓ form devised by Ship Router and ECON)
Analyze Data & Generate Results	✓		

- Run cluster program with Maritime Administration's SDS file as input and list of vessel names grouped by subtype as output.
- Identify oceans, routes, and time of year of interest.
- Ship routers select tentative sample from the cluster list where it overlaps their customer list and solicit cooperation of the shipping companies.
- ECON contacts and solicits the cooperation of shipping companies whose ships are on the cluster list and who do not receive ship routing.
- Check sample ships for any major modifications (eliminate if yes).
- Select potential sample crossings (elementary units) in advance of sailings.
- If a routed ship, provide ship routing for the crossing (some without SEASAT data, some with SEASAT data).
- After voyage collect all trip specifications for all sample ocean crossings.
- Eliminate unrepresentative elementary units (e.g., vessel departs from test route for reasons unrelated to weather).
- Further group elementary units according to trip specifications.
- Enter representative elementary units into data base.
- Run program to perform quantitative and economic benefit analysis.
- Perform generalization of sample results to population.

This procedure is illustrated in Figure 4.4, Data Flow and Computer Processing.

#### 4.1.2.2 Tanker Routing, Valdez to West Coast

The shipping of crude oil from the Valdez Terminal of the Trans-Alaska Pipeline to west coast ports in the United States is scheduled to begin in July 1977. This transport operation will necessarily cross the Gulf of Alaska which is frequented by poor sea and weather conditions such as high waves and winds. In addition, fog is quite often a problem encountered both at the entrance to the port of Valdez and along the ocean route.



REPRODUCIBILITY OF THE ORIGINAL PAGE IS NOT GUARANTEED

Figure 4.4 Data Flow and Computer Processing SEASAT Economic Verification Ocean Routing Case Study

An experiment is proposed to estimate some of the potential economic benefits of SEASAT along this route. However, after close study it is felt that the area is not suitable for a SEASAT-A economic verification experiment as a result of a lack of interest on the part of the intended participants in the experiment.

#### Background

With the beginning of oil movement through the Trans-Alaska Pipeline from Prudhoe Bay to Valdez, oil tankers will begin transport of crude oil from Valdez to the west coast ports of Juan de Fuca and Coos Bay. This transport is scheduled to begin with the opening of the pipeline in July of 1977. The port of Valdez was selected because its channel is deep enough to support the traffic and because it is ice free throughout the winter.

The fleet of tankers which will be used in this transport will be owned or leased by the oil companies involved. The three companies with major involvement with Alaskan oil to date are Mobile, Exxon and Arco. The tankers involved will vary in size from 50,000 to 150,000 dead weight tons.

The land leg of the oil transport, that is, the pipeline itself, is managed by Alyeska Pipeline Supply which is responsible for the construction and operation of the line. In this role, Alyeska is responsible for the management of the terminal storage units and the loading berths at Valdez. Their primary concern is to keep oil flowing through the pipeline at capacity. In order to do this they must schedule tanker loadings at Valdez in order not to exceed their storage capacity. Initially, this capacity will be for storage of eight days of oil at a delivery rate of 1.2 million barrels a day. (There are plans for increasing both the delivery rate and the storage capacity.) There will be four berths, thus allowing the

simultaneous loading of four tankers (of at least 165,000 tons) at rates up to 110,000 barrels per hour. The total turnaround time (docking, ballast discharge, loading, undocking and other related activities) is expected to be about 24 hours.

The entrance into Port Valdez, the Valdez Narrows, will only allow one-way tanker traffic. Therefore, tanker traffic will be controlled outside of the port in the Prince William Sound. Figure 4.5 shows the shipping lanes for tankers inside the Prince William Sound.

The berths, including the floating berth, are constructed to withstand extremely high winds and sea conditions. It is, however, important to note that the berths will tolerate roughly twice the wind and sea conditions if they are free than they would if a tanker is moored alongside.

#### Experiment Description

The oil transport experiment would be proposed to provide tankers with SEASAT data on sea conditions and to measure the benefits from such a program. It would be a year-round operation with primary experimental emphasis on the late fall, winter and early spring months when poor weather conditions are the most troublesome in the Gulf of Alaska.

Since the tankers are so large and require deep passage, alternate routes which would follow the shoreline rather than crossing the Gulf are not feasible. Numerous studies by the oil companies, ship routing companies and others have indicated that changing a route based on weather or sea conditions is not likely to be practical. All other possible routes seem to require more additional transit time than would be wasted due to weather conditions. This is particularly true as the size of the vessel increases. While the oil tankers can be slowed by poor weather, in general they are not sensitive to other weather related loss or damage.

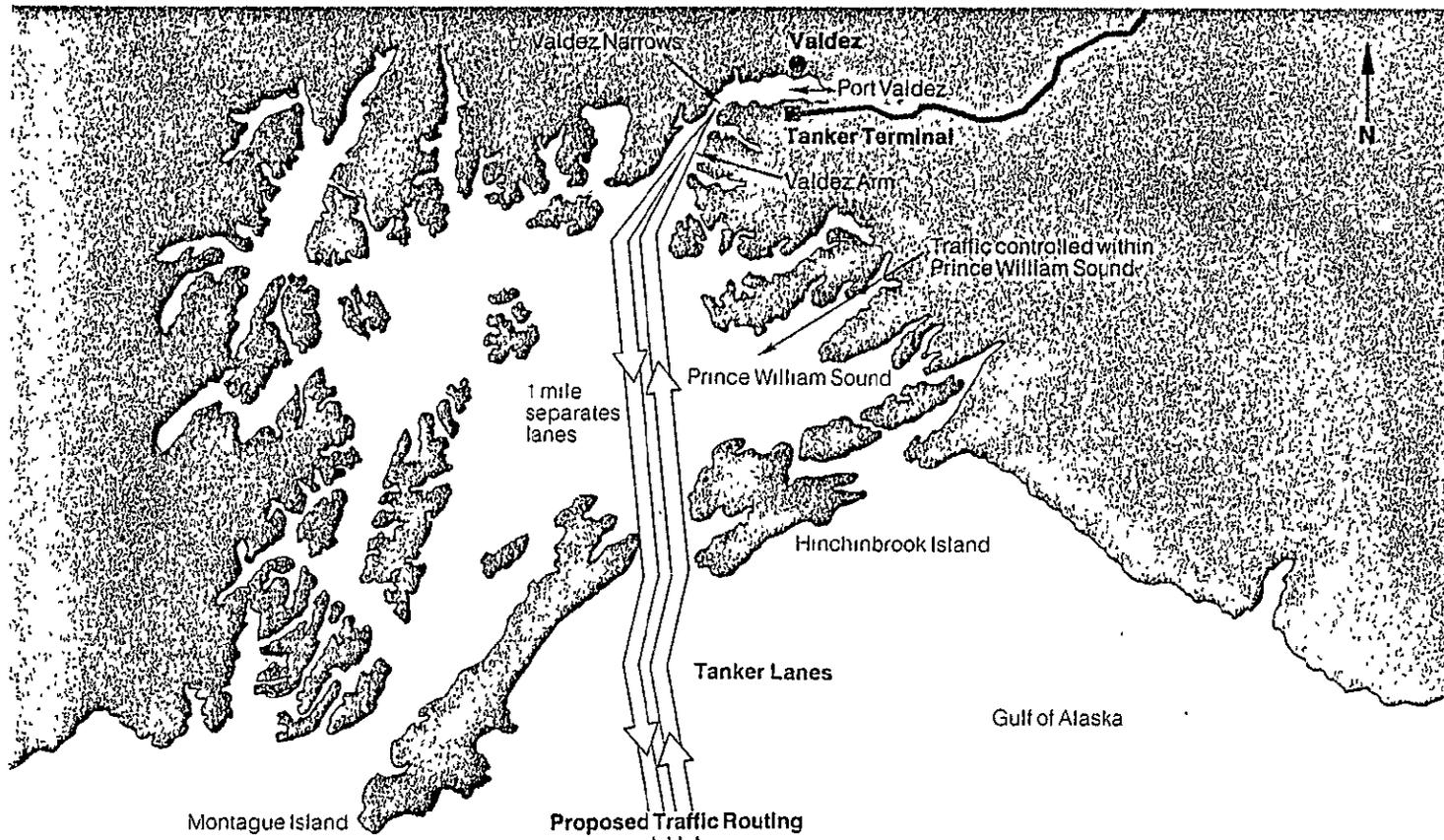


Figure 4.5 Tanker Routing Within the Prince William Sound

Source: Summary, Project Description of the Trans-Alaska Pipeline System, September 1975

Therefore, the only apparent benefit from SEASAT in this transport area would be in the scheduling of ship traffic. Because of the constraints mentioned above, that is, 1) storage capacity versus optimum oil flow, 2) one-way traffic into Port Valdez, and 3) the berth ability to withstand wind and sea conditions with and without a tanker alongside, Alyeska will be unwilling to reschedule tankers if such a process requires the slowdown of tankers either entering or leaving the berths. The oil companies themselves will be able to change the timing on the routes. It is generally agreed, however, that in most cases, since the danger of damage due to weather is not extreme, any progress that can be made is preferable to "waiting out" a storm. The exceptions to this may be when entering a narrow passage or one that is difficult to navigate in fog or other poor weather conditions. Therefore, even though the vessel captains would be interested in SEASAT data, it is felt that such information would have little effect on the operation of oil transport and therefore be of little benefit. In addition, an experiment would be somewhat limited by being forced into the first year of the transport operation. Thus, in addition to the expected learning curve associated with the installation of SEASAT-A there would be a complicating learning curve associated with the beginning of tanker operations. These problems have been well perceived by those in Alyeska and the oil companies and have been manifest in a seeming lack of interest and cooperation. On this basis it is not recommended to proceed in the development of an Alaskan Oil Transport economic verification experiment.

### 4.1.3 Applications to the Fishing Industry

#### 4.1.3.1 A Tuna Fisheries Experiment

A potential Economic Verification Experiment in ocean fisheries involves the eastern Pacific tropical tuna fleet. Although this industry is important, its existence is currently threatened by enforcement of the Marine Mammals Protection Act of 1972. Tuna fishermen now use environmental information from the National Weather Service and the National Marine Fisheries Service, including NOAA satellite data products. An experiment in this area is recommended based upon the improved quality of data and all-weather capability of SEASAT-A.

##### 4.1.3.1.1 Background

###### The Industry

The American tropical tuna fleet represents an economically important industry in the United States economy. Total dockside value of the catch for this fishery in 1973 was \$85.6 million (1973\$), representing 356 million pounds by approximately 140 vessels. This fleet is generally recognized as the most sophisticated of all United States fishing fleets. "Typical" vessels are capable of holding up to 1000 tons of catch and are on the sea for one to seven months at a time, making perhaps three or four trips per year. A day's operations at sea costs approximately \$2000.\* Vessel owners in general are innovative and have been very receptive to technology advances in the past. Most of the U.S. fleet (about 60 percent) are represented by the American Tunaboat Association (ATA).

The primary decision faced by vessel operators is where to fish. Success is very dependent on individual skills of the captain and good operators are

---

\* Michael Zolezzi, Assistant General Manager, American Tunaboat Association. Personal communication. November 4, 1976.

said to have a developed "fish sense." It appears that most decisions are based heavily on past experience, tempered by information about current environmental conditions. Once a general area for fishing has been selected, the operator looks for local indicators of fish schools such as disturbances on the water, birds, floating objects or, notably, porpoises. Once a school has been located, it is assessed as to size to determine whether the expected catch warrants setting up nets. The industry almost entirely uses purse seine net methods for catch.

The fleet covers roughly the entire ocean area shown in Figure 4.6, and somewhat beyond. Fishing in the shaded region is regulated by the Inter-American Tropical Tuna Commission (IATTC) which is supported and funded by the Departments of State of eight American countries. The IATTC is responsible for setting catch quotas, determining the open season for IATTC waters and performing biological studies to support these fishery conservation efforts.\*

The existence of the American tuna fleet is currently threatened by the enforcement of the Marine Mammals Protection Act of 1972. The economic viability of the tuna industry appears dependent upon using porpoises to locate tuna schools and, as the nets bring up the tuna, porpoises are caught as well, frequently resulting in their death, although attempts are made to save them. By court order based on the Marine Protection Act, incidental killing of porpoises associated with tuna catch must totally cease as of

---

\*William Bayliff, Inter-American Tropical Tuna Commission. Personal communication. September 20, 1976.

Merritt Stevenson, Inter-American Tropical Tuna Commission. Personal communication. November 5, 1976.

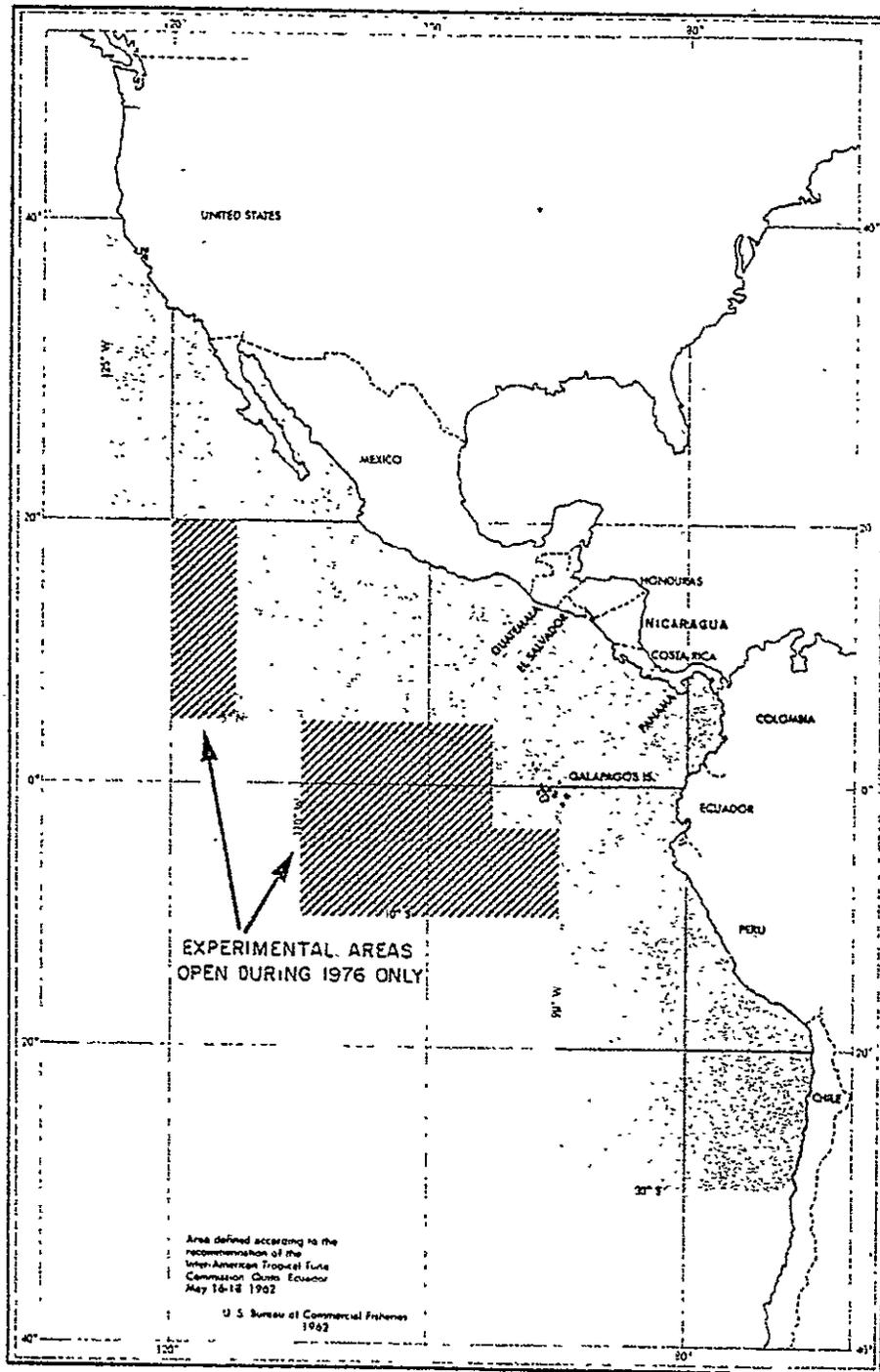


Figure 4.6 Fishing Grounds for Eastern Tropical Pacific Tuna Fleet

January 1, 1977. (Requests by the Commerce Department have resulted in a stay of a similar, previous court order, setting a ceiling of 78,000 for porpoise deaths for 1976; this limit has already been reached.) This situation is expected to put the U.S. tuna fleet out of business,\* selling out to Russians and Japanese whose activities are not regulated and who will end up with approximately the same catch, with no porpoise conservation efforts. Should the fleet survive this situation, it is likely to be searching for alternate methods to assist in locating tuna schools.

#### The Physical Processes of Interest

There are several environmental factors of interest to tuna fishermen. The location of tuna schools is related to surface water temperature. Seventy-five percent of yellowfin tuna catch has been found in waters between 79°F and 83°F.\*\* (This figure is not as significant as it appears, since most of the fishery waters frequently fall within this range.) Tuna particularly appear to favor boundaries between water masses (thermal fronts), since these fronts often concentrate forage and fish are frequently found in or adjacent to fronts.\*\*\*

A second environmental parameter of interest is the mixed layer depth, giving the vertical location of different water masses. This factor is important in setting of the nets, for if the layer of warm water extends too deep, much of the school may swim under the nets resulting in unprofitable efforts.

---

\* Wall Street Journal. October 21, 1976.

\*\* Michael Laurs, Southwest Fisheries Center, National Marine Fisheries Service, NOAA. Personal communication. November 5, 1976.

\*\*\* Merritt Stevenson. "A Review of Some Uses of Remote Sensing in Fishing Oceanography and Management" IEEE Ocean, 1975.

Forecasts of weather and sea state are also important because, under certain adverse circumstances, the setting of nets is not possible. Fishermen wish to know of these conditions ahead of time so as to avoid traveling to areas where fishing is not possible.

#### Current Information System

Tuna fishermen already receive environmental information provided by the National Weather Service (NWS), Redwood City, California, and the National Marine Fisheries Service (NMFS), both of the National Oceanic and Atmospheric Administration (NOAA), Department of Commerce. Appendix A provides details and some samples of these products. This information is broadcast over radio station WWD, operated by NMFS, La Jolla. Some 70 vessels are equipped with radio facsimile machines to receive the map products. Weather information is obtained by NOAA satellites. Sea surface temperature and mixed layer depth information are provided by ship reports. Tuna fishermen are not satisfied with the products they are receiving. Sea surface temperature products, in particular, are felt to be highly inaccurate, and the ATA receives complaints regularly about this information; these reports are not currently used by fishermen due to their low credibility.\*

Sea surface temperature data are also available from another source: the Very High Resolution Radiometer (VHRR) now aboard some NOAA satellites. NMFS feels that the accuracy of such a system ( $\sim \pm 2^\circ\text{C}$ ) is insufficient for use in the tuna fishery.\*\* IATTC, however, feels that although the

---

\* Michael Zolezzi, Assistant General Manager, American Tunaboat Association. Personal communication. November 4, 1976.

\*\* Michael Laurs, Southwest Fisheries Center, National Marine Fisheries Service, NOAA. Personal communication. November 5, 1976.

VHRR data has low absolute accuracy, its relative temperature accuracy is considerably better and would be more than adequate for the tuna fishermen; relative accuracy is more important for identifying temperature fronts.\* Additionally, VHRR data would provide complete contour mapping, not just isolated points currently received, and could be obtained daily.

#### SEASAT-A Information System

SEASAT-A has the capability of supplying data that would be of considerable assistance to the tuna fishermen. Cloud-free temperature data comparable to that available from the VHRR could be obtained. In addition, an important all-weather capability would be added by the Microwave Radiometer; this latter capability is significant because important areas of the eastern tropical Pacific are chronically cloud covered. Improved weather and sea-state information would be available from SEASAT-A and this too would be important to the fishermen.

NMFS, however, feels that the temperature accuracies afforded by SEASAT-A are entirely inadequate. As already mentioned, though, IATTC feels differently about such capabilities and additionally feels that the all-weather sensor will be an important contribution.

#### 4.1.3.1.2 Possible Experiment Design

Having investigated the performance of a tuna fisheries experiment, it is possible to make a few statements about the design of such an experiment, should it be performed.

---

\* Merritt-Stevenson, Inter-American Tropical Tuna Commission. Personal communication. November 5, 1976.

### Establishment of a Control Group

Whereas it is easy to identify some group that could receive SEASAT-A obtained information, it is difficult to discover the way this experimental group would be isolated from a control group. Currently, the information is broadcast over a public radio station (WWD) to about 70 vessels with facsimile devices. It would be necessary to send the experimental information in a form such that it is not receivable by the control group. This would be possible via a specialized receiver or using a coded signal with decoder aboard the experimental vessels. A much greater problem, though, is the maintenance of independence between the operation of the two groups. Representatives of the ATA indicate that vessel captains are heavily influenced by the operations of others, and that any true separation would be nearly impossible.\*

A second alternative would be to use a temporally separate control group, that is, compare the fleet's performance with SEASAT data for one year (or more) to its performance without. Such a procedure is possible although extreme complexity is introduced by the need to remove performance differences based on institutional and environmental differences between experimental year(s) and control year(s). Such complications arise due to change in quotas, season specifications, fish availability and weather. These differences would have to be factored out to arrive at meaningful results.

---

\* Michael Zolezzi, Assistant General Manager, American Tunaboat Association. Personal communication. November 4, 1976.  
Manuel Silva, President, American Tunaboat Association. Personal communication. October 4, 1976.

### Measurement of Performance

In principle, it is possible to measure the direct economic performance difference between the two groups. The differences could be measured as a function of some catch-per-unit-effort measure. To do this requires boat-specific data about catch and time at sea, as well as vessel characteristics and, perhaps, region where fishing was done. The IATTC already gathers and has historical files for this type of data. The great complexity involved in deriving meaningful catch-per-unit-effort measures has been documented,\* however, the IATTC already has considerable experience in this area.

#### 4.1.3.1.3 Conclusions and Recommendations

Although there are several difficulties associated with this experiment, ECON feels that it could be a valuable contribution to the SEASAT program. Some of the key points are noted below:

1. The tuna fishermen are very disappointed with the sea surface temperatures they are currently receiving.\*\* The resulting threat is that they will have little confidence in similar products. It is felt, however, that SEASAT-derived information would be of considerably superior quality than that currently in use\*\*\* and that the fishermen would be obliged to experiment with it for economic reasons.

---

\* Michael Laurs, Harold Clemens, and Larry Hreha. "Nominal Catch-Per-Unit-Effort of Albacore, Thunnus Alalunga (Bonnaterre), Caught by U.S. Jig Vessels During 1961-1970." Marine Fisheries Review, 38(5).

\*\* Michael Zolezzi, Assistant General Manager, American Tunaboat Association. Personal Communication. November 4, 1976.

\*\*\* There is some difference of opinion on this point among those familiar with the existing information products.

2. SEASAT-A sea surface temperature data appears to be only marginally superior to that currently available from the VHRR, but SEASAT could add additional frequency, an all-weather capability and real-time and forecast information about sea-state condition.
3. The experiment can effectively make use of equipment, data and experience already available in the facsimile machines on board the tuna boat and the existing IATTC historical data and familiarity.
4. More than one year (probably three) of experiment will be required to obtain a sufficient number of observations and experimental conditions.

#### 4.1.3.2 Alaskan Crab Fisheries Experiment

The crab fishery in Alaska is subject to hazards due to sea conditions and sea ice. These may be detectable by the synthetic aperture radar, microwave radiometer and visual and infrared radiometers carried on board SEASAT-A. An experiment is proposed to disseminate nowcasts and forecasts of these conditions to the vessels fishing in the Bering Sea and Cook Inlet areas of Alaska. It is believed that such information would allow fishermen to remove gear from and otherwise avoid areas where conditions indicate fishing would be treacherous. Economic verification would be carried out by measuring and evaluating reduced losses in terms of reduced gear loss, reduced hull damage or vessel loss and increased personal safety or reduced loss of life caused by sea ice and vessel icing. The experiment would run through the king and tanner crab seasons of 1977-1978 and 1978-1979 for comparison of losses with and without SEASAT.

---

\*Michael Zolezzi, Assistant General Manager, American Tunaboat Association. Personal communication. November 4, 1976.

### Background - The Industry

The crab fishery in Alaska has three products, king crab, tanner crab and dungeness crab. Of these, the king crab has been historically the most valuable and while it continues to be so, the tanner crab fishery is making strong gains. (This is due at least in part to the proposed 200-mile limit, since this fishery in the past has been primarily Japanese but is now moving toward American operation.) King crab is fished from approximately the first of August until mid-March, depending on the area. The length of the season is specified by date in some areas and in other areas it is opened by date and closed by emergency order. An emergency order is issued when sea and weather make fishing too dangerous or other conditions warrant closing. For each specific area for king and tanner crab fisheries pictured in Figures 4.7 and 4.8 respectively, the following are noted:

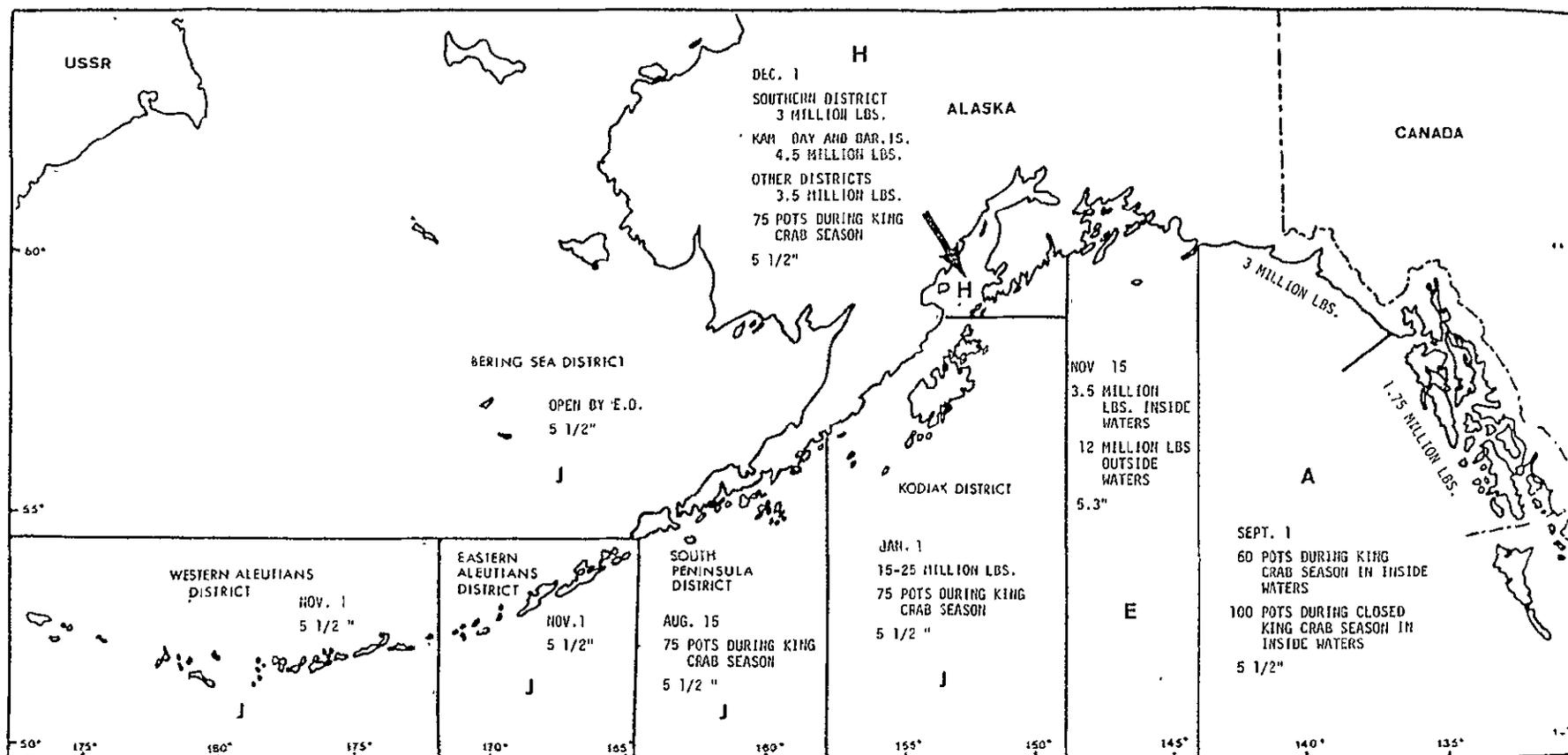
- Opening dates
- Guideline harvest levels
- Pot limits when applicable
- Minimum legal size
- Emergency order.

These areas provide the basic regulatory unit. A vessel must be registered to fish in an area and often must be registered within a subsection of this area. There are legal restraints to registrations in certain multiple areas; that is, it is not possible to register in every area. However, for example, it is possible to register in Dutch Harbor or Kodiak and the Bering Sea.

The Alaska Department of Fish and Game sets a quota for each area. These are based on the population of crab in each area and the expected growth of that population. The quota set in each region for king crab in the 1976

22





NOTATIONS INDICATE. OPERING DATES  
GUIDELINE HARVEST LEVELS  
POT LIMITS, WHEN APPLICABLE  
MINIMUM LEGAL SIZE  
E.O. = EMERGENCY ORDER

Figure 4.8 Tanner Crab Fishery (Source: "1976 Alaska Shellfish Commercial Fishing Regulations", Alaska Department of Fish and Game)

season is noted in Table 4.3. Along with the quota is the expected catch and its value. The prices quoted here are the prices negotiated between the processors and the fishermen. It is possible for these prices to rise or fall during the season. For example, instances of prices reaching 75 cents per pound have already been noted in Kodiak this season. Therefore, the expected value of the total catch may vary considerably.

Since total catch is set by quota, each vessel's share of the total value is directly related to the number of pounds it is able to bring in before the quota is reached or the season is otherwise closed. This makes for fierce competition among the vessels. In some areas the number of pots per vessel is also regulated. For instance, a vessel in Kodiak may only fish with 75 pots. In the Bering Sea however, the number of pots is not limited and vessels will fish with 300 to 400 pots. Several trips may be required in order to move this number of pots since a vessel can generally only carry 100 to 300 pots on deck at one time.

All total, there are about 450 boats and vessels in the king crab fleet, ranging from 32 to 125 feet in length. The smaller boats generally fish within a day or so of their unloading port while the larger vessels may be several days away. Many of the same vessels are part of the 300 or so fishing for tanner crab in the spring. Some of the vessels can also be used in shrimp or bottom fishing. In the crab industry, as in many others, a large percentage of the catch is taken by a few of the larger vessels and many smaller ones split the remainder.

Production of king crab in Alaska has been steadily increasing over a long period of time except during the late 1960s and early 1970s, during which time major reductions were seen. Table 4.4 lists Alaskan production by major areas from 1946 to 1973.

Table 4.3 King Crab Fishery 1976 Estimates

Area	Season	Quota*	Expected Harvest*	Price/lb.	Value
A-SE Alaska	9/1 thru 1/15	1.2	.6	.65	\$ 310,000
E-Prince Wm Sd	8/1 thru 3/15	.5	.2	.65	130,000
H-Cook Inlet	8/1 thru 3/15	5.0	5.0	.63 1/2	3,175,000
K-Kodiak	See note **	14.0 to 24.0	21.0	.63 1/2	13,335,000
M-AK Peninsula	8/1 thru close E.O.	2.2 to 5.3	2.5	.63 1/2	1,587,500
O-Dutch Harbor	11/1 thru close E.O.	12.0 to 14.0	14.0	.58 1/2	8,190,000
R-Adak	open by E.O.	0	0		
S-W. Aleutian	open by E.O.	0	0		
Q-Bering Sea	8/15 thru close E.O.	45.0 to 72.0	55.0 to 60.0	.58 1/2	33,637,500
Total		79.9 to 122.0	97.3 to 103.3		\$60,445,000

Lettered areas refer to Figure 4.7.  
E.O. = Emergency Order

Notes: \* = Millions of pounds  
\*\* = Split season - 7" crab, 9/1 through close by E.O. and 8" crab only from 12/1 through close by E.O.

Source: Alaska Department of Fish and Game

Table 4.4 King Crab Production by Major Geographical Region for the Years 1946-1973\*

Year	Southeast Alaska	Central Alaska	Western Alaska	Total
1946	13,400	9,200		22,600
1947	17,500	521	734,597	752,668
1948		--	2,133,354	2,133,354
1949		--	1,206,945	1,206,945
1950		64,882	1,454,367	1,519,249
1951		202,281	1,791,631	1,993,912
1952		779,611	1,993,222	2,772,833
1953		2,614,277	1,998,932	4,613,209
1954		6,356,827	2,514,243	8,871,070
1955		5,951,120	2,211,800	8,162,920
1956		6,899,795	1,896,227	8,796,022
1957		12,488,131	588,434	13,076,565
1958		11,211,554	--	11,211,554
1959		18,839,470	--	18,839,470
1960	3,424	27,878,630	687,962	28,570,016
1961	429,600	38,854,800	4,127,200	43,411,600
1962	1,289,600	44,653,000	6,839,600	52,782,200
1963	1,112,200	50,786,600	26,841,500	78,740,300
1964	820,500	51,638,600	34,261,600	86,720,700
1965	579,300	94,505,800	36,585,600	131,670,700
1966	105,899	117,305,088	41,790,708	159,201,695
1967	599,078	83,010,695	44,106,117	127,715,890
1968	2,199,772	37,559,518	42,278,206	82,037,496
1969	1,895,168	20,274,859	35,559,781	57,729,808
1970	577,802	19,587,102	31,896,126	52,061,030
1971	571,062	20,220,631	49,911,412	70,703,105
1972	952,602	21,722,072	48,751,982	74,426,656
1973	874,180	23,610,989	52,338,934	76,824,103

Source: Background Paper: Vessels in the Alaskan King Crab Fishery, University of Washington

\* Measurement in pounds live weight.

It is interesting to note that the 20 percent reduction from 1966 to 1967 brought only 4.5 percent reduction in revenues to fishermen. While price increases have not continued at this incredible rate, they have continued and presently the 100 million pound catch per season is worth about \$60 million.

Losses within the industry are typically quite high. In the 1973-1974 season, major losses to crab vessels totaled \$4.5 million,\* many other vessels had smaller losses. In addition, 13 lives were lost last season alone. While not all of these losses would have been reduced or eliminated by SEASAT information, a large part were ice and weather related losses where accurate nowcasts and forecasts might have allowed loss avoidance or reduction.

In general, hull damage is insured and information on such claims exists but tends to be fragmentary. In addition to hull damage and personal injury, the crab fleet expects about 10 percent gear loss per year. Thus, if vessels carry an average of 100 pots (quite a low estimate), approximately 4,500 pots are lost annually at a replacement cost of roughly \$500 for each pot, line and bouy. This (uninsured) loss amounts to \$2.25 million per year and remains quite constant from year to year. Since sea ice cutting the lines or carrying pots into deep water is responsible for a large portion of these losses, they are potentially largely impactable by SEASAT information.

#### The Operations

The exact location of daily fishing operations depends on the migration of the crab. The fishermen prospect for the crab by placing a line of test pots in an area. By noting the number of crabs caught in individual pots, along a line, the skipper is sometimes able to determine the direction the

---

\* Report of the 1976 Policy and Planning meeting of the Alaskan Fisheries Safety Advisory Council.

crabs are moving. Because the crabs are able to travel quite large distances in a single day, it is not easy to follow their movements and difficult to predict where the best fishing will be. The fishermen usually fish the same area year after year but because they follow the crabs (which don't follow any regular pattern) the specific area and the timing of the trips may vary extremely. For instance, a fisherman may plan to fish Dutch Harbor until the quota is reached and then move to the Bering Sea each year but the time of the move may vary by several weeks or months depending on the movement of the crabs and general fishing conditions.

In the course of a trip the vessel will bait and put out the pots in lines using LORAN A or C to locate the lead pot. The number of pots per line may vary from 12 to 30 or more. A vessel will work a number of lines within an area but will generally try to remain clear of all pots whenever possible. The crab pots are lifted with hydraulic winches, emptied, replaced and returned to the same spot if the line is not being moved. If the line is to be moved, they are lifted and stacked on deck. A moderately large vessel can carry 100 to 200 pots at one time. These can be boarded at a rate of about 10 per hour.

Crab vessels are tanked vessels, meaning that they have large tanks where the crabs are placed in circulating sea water to be kept alive until they are sold. Full load on the larger vessels (96 feet to 120 feet) will be about 150,000 to 180,000 pounds of crab. Only the crabs which are alive when unloaded at the processor are sold. The amount of dead loss varies with the length of the trip and sea conditions. The length of the trip varies depending on the size of the vessel's tanks, the number of pots worked, weather conditions, the fishing location and the fishing conditions. Trips are

generally four to eleven days long except in the case of the very small boats which are generally not out over two or three days.

The phenomena which cause the most severe losses are sea ice and super-structure icing. Sea ice (pieces of ice floating in the water) is particularly a problem in the spring during the season known as breakup. This is the period during which the ice pack melts back from its winter lengths. In the Bering Sea, the ice pack extends into the Aleutian Islands. The extent may vary as much as several hundred miles from year to year but usually reaches Cape Sarchef in the Bering Sea. When temperatures rise, large pieces of ice break off and move south, gradually disappearing into the sea. (Breakup also occurs in Cook Inlet where in the winter the ice pack generally extends to Cape Douglas, but the size of the icebergs which break off are considerably smaller.)

While some sea ice conditions are of concern in the Bering Sea during king crab season when the ice pack is forming, the largest problem occurs during the tanner crab season. The best fishing tends to be north of the winter ice line in the Bering Sea. Consequently, fishermen like to fish an area as soon as the danger from sea ice has past. The problem then comes when an area is relatively clear of sea ice and is subsequently iced in by ice that has broken off and floated into the area. Some effects have been made in modeling the direction of these ice movements but no accurate information on ice conditions is available to fishermen.

Floating ice is quite dangerous to fishermen. It can cause hull damage and, although floating ice is rarely responsible for the loss of an entire ship, costly damage to vessels is frequent. There are also conditions caused by the ice which lead to other types of damage and personal injury. At times, floating ice that was not expected has been known to force vessels

very close to shore. This leads to risks of grounding which often causes severe damage, or forces navigation through the ice which may also cause hull damage and other unsafe conditions. Many times sea ice conditions as described above can trap a vessel during the night in the few hours when the crew is asleep. If ice movements could be accurately predicted, the vessel could remain under power and avoid the area which will become iced in.

Another more frequent loss which results from such ice movements is the loss of gear. Ice pieces moving through a line of pots can either cut the lines or break the bouys and cause the pots to be lost, or drag the pots into deeper water and deposit them so the buoy is under water. When this occurs, the pots can no longer be spotted and are lost. It is not unusual for a vessel to loose 10 to 40 pots in a season in this manner. If ice forecasts were available, the fishermen could reduce this loss substantially by retrieving the pots before the ice reaches them. The length of time required for this would vary depending on the number of pots and distance from the vessel to the pots when the forecast is received. Many fishermen stay within two or three hours of their gear while others tend to stay much further away. When a vessel has left its fishing area for port to unload generally a much longer time would be required to reach the line. If the vessel were within two hours of a lead pot, a six-hour warning (for example) would allow him time to recover 40 pots. A longer forecast may allow him time to move more pots; however, if the number to be moved is extremely large the savings will be limited by the number the vessel can safely carry under the given weather and sea conditions and the distance necessary to transport the gear to safe waters.

The second condition, possibly impracticable with SEASAT-A gathered data, is that of vessel superstructure icing. This occurs when wind, sea

temperature and air temperature are such that ocean spray freezes on the vessel (high seas and the increased spray that results from such conditions also add to icing conditions). If conditions exist such that severe icing occurs, tons of ice build up on the vessel reducing freeboard and stability and can cause it to capsize or sink. Figure 4.9 depicts the relationship between sea surface temperature, air temperature and ice buildup for specified wind speeds.

The ice accretion is particularly dangerous to small boats and vessels with a relatively large area of superstructure surface. A crab vessel with gear aboard is particularly susceptible since the pots, with 8 x 8 x 3.5 feet metal frames and rope webbing on all sides, can accumulate ice quickly. If icing conditions could be predicted a crew might be able to throw the gear over board and lose it, if necessary, rather than risk having it frozen together (so that it can not be moved) and collect the weight of ice, which could sink the vessel.

A vessel with proper warning may also be able to more accurately decide if a port is within reach before conditions become too dangerous or whether to head for sea where, due to generally warmer air temperatures, icing conditions are not likely to be as severe.

#### Experimental Purpose

The purpose of the proposed experiment would be to present SEASAT-A information on ice conditions and sea surface temperature obtained with the synthetic aperture radar, microwave radiometer, and visual and infrared radiometers to fishermen in the Alaskan crab fishery and to measure some of the economic benefits of the information.

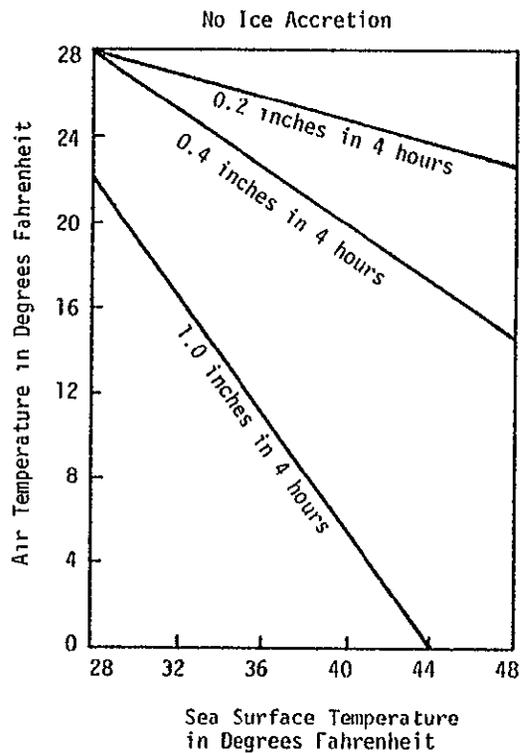


Figure 4.9a Ice Accretion for Wind Speeds Between 41 and 55 Knots

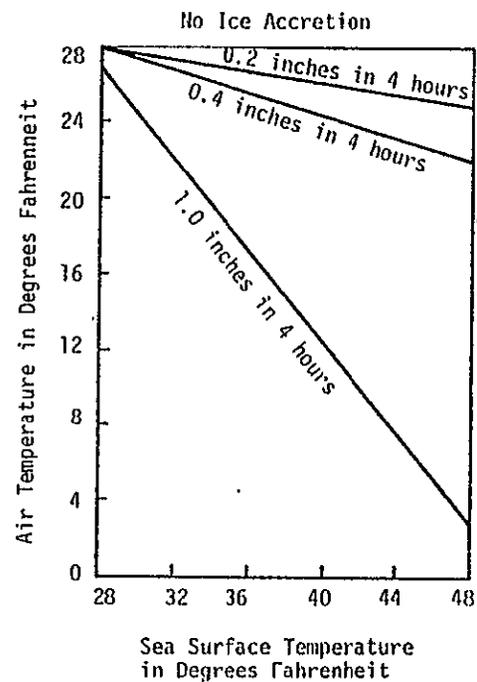


Figure 4.9b Ice Accretion for Wind Speeds 56 Knots or Greater

(Source: "Ice Accretion--Hazard of Significance to Seafarers", W. S. Korsch)

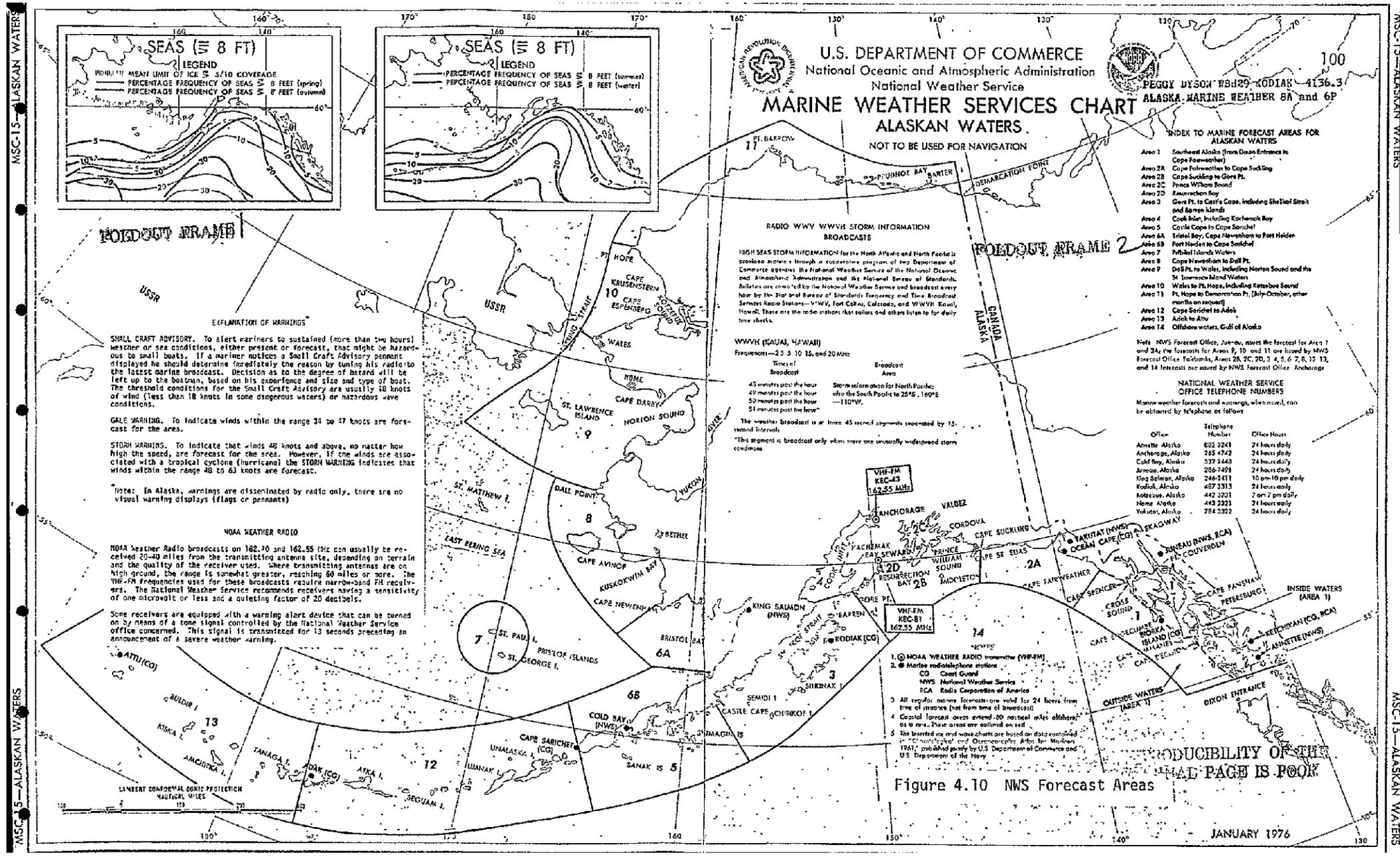
The benefits of ice movement information, sea surface temperature and sea conditions leading to nowcasts and forecasts of dangerous conditions will be measured in terms of:

- Reduced gear loss
- Reduced hull damage
- Reduced vessel loss
- Increased personal safety and reduced loss of life.

It is expected that there will also be benefits in terms of increased yields but these benefits are not likely to be measureable and therefore will not be included in the purpose of this experiment. It is also expected that this experiment will indicate some of the benefit areas of a fully operational SEASAT system.

#### Experiment Description

The Alaskan crab fisheries experiment would consist of the dissemination of SEASAT-derived information through the current NWS channels. The crab fleet obtains weather forecasts on the radio (4 MHz) from a woman contracted by NWS in Kodiak. She receives feedback from the fishermen on actual weather conditions which are then used to revise the forecast if necessary. She is also available to the fishermen for special questions. Almost every vessel in the fleet listens to her twice daily for broadcasts. The experiment would be run by feeding the information to her and having her broadcast the information immediately following her normal weather program. Information could be broken down into districts as are the weather forecasts. Figure 4.10 shows the districts covered by the weather service. Broadcasts are only made for those regions in which vessels are likely to be. In addition, radio facsimile can be sent to certain vessels which already have the necessary receiving equipment

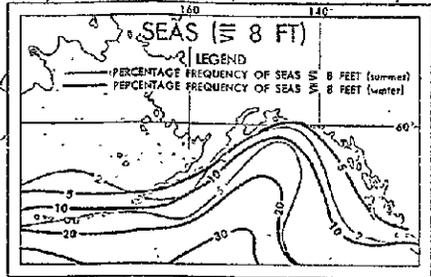
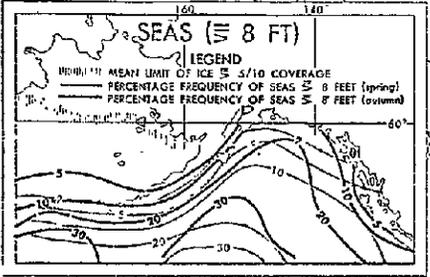


U.S. DEPARTMENT OF COMMERCE  
National Oceanic and Atmospheric Administration  
National Weather Service

**MARINE WEATHER SERVICES CHART**  
ALASKAN WATERS

NOT TO BE USED FOR NAVIGATION

PEGGY DYSON 98129 KODIAK 4136.3  
ALASKA MARINE WEATHER 8A and 6P



INDEX TO MARINE FORECAST AREAS FOR ALASKAN WATERS

- Area 1 Southeast Alaska (from Dixon Entrance to Cape Romanof)
- Area 2A Cape Fairweather to Cape Suckling
- Area 2B Cape Suckling to Gore Pt.
- Area 2C Prince William Sound
- Area 2D Koonuck Bay
- Area 3 Gore Pt. to Cape Crater, including the Shelikof Strait and Adak Islands
- Area 4 Cook Inlet, including Kachemak Bay
- Area 5 Central Cape to Cape Sarahel
- Area 6A Bristol Bay, Cape Newenham to Port Heiden
- Area 6B Port Heiden to Cape Sarahel
- Area 7 Pribilof Islands Waters
- Area 8 Cape Newenham to Dall Pt.
- Area 9 Dall Pt. to Wales, including Norton Sound and the St. Lawrence Island Waters
- Area 10 Wales to Pt. Hope, including Kotzebue Sound
- Area 11 Pt. Hope to Demarcation Pt. (July-October, other months as season)
- Area 12 Cape Sarahel to Adak
- Area 13 Adak to Atka
- Area 14 Offshore waters, Gulf of Alaska

Note: NWS Forecast Office, Juneau, issues the forecast for Area 1 and 2A. The forecasts for Areas 2, 10 and 11 are issued by NWS Forecast Office Fairbanks, Areas 2B, 2C, 2D, 3, 4, 5, 6, 7, 8, 12, 13, and 14 forecasts are issued by NWS Forecast Office Anchorage.

NATIONAL WEATHER SERVICE OFFICE TELEPHONE NUMBERS

Marine weather forecasts and warnings, when needed, can be obtained by telephone as follows:

Office	Telephone Number	Office Hours
Anchorage, Alaska	622-3241	24 hours daily
Central Fairbanks, Alaska	265-4742	24 hours daily
Juneau, Alaska	537-5443	24 hours daily
King Salmon, Alaska	256-7491	24 hours daily
Kodiak, Alaska	246-4111	10 am-10 pm daily
Kotzebue, Alaska	457-3313	24 hours daily
Nome, Alaska	442-2021	7 am-7 pm daily
Valdez, Alaska	443-2323	24 hours daily
Valdez, Alaska	784-3322	24 hours daily

RADIO WWV WWVB STORM INFORMATION BROADCASTS

HIGH SEAS STORM INFORMATION for the North Pacific and North Pacific is available through a cooperative program of the Department of Commerce, the National Weather Service of the National Oceanic and Atmospheric Administration and the National Bureau of Standards. Bulletins are compiled by the National Weather Service and broadcast every hour by the National Bureau of Standards Frequency and Time Broadcast Service Radio Stations—V-VW, Fort Collins, Colorado, and WWVH, Kona, Hawaii. These are the radio stations that sailors and others listen to for daily time checks.

WWVH (KAUAI, HAWAII)

Frequencies—2.5, 5, 10, 15, and 20 MHz

Time of Broadcast	Broadcast Area
45 minutes past the hour	Storm information for North Pacific, also the South Pacific to 25°S, 160°E
49 minutes past the hour	—110°W
50 minutes past the hour	
51 minutes past the hour	

The weather broadcast is in three 45 second segments separated by 15 second intervals.

This segment is broadcast only when there are unusually widespread storm conditions.

FOLDOUT FRAME 1

EXPLANATION OF WARNINGS

**SMALL CRAFT ADVISORY.** To alert mariners to sustained (more than two hours) weather or sea conditions, either present or forecast, that might be hazardous to small boats. If a mariner notices a Small Craft Advisory pennant displayed he should determine immediately the reason by tuning his radio to the latest marine broadcast. Decision as to the degree of hazard will be left up to the boatman, based on his experience and size and type of boat. The threshold conditions for the Small Craft Advisory are usually 18 knots of wind (less than 18 knots in some dangerous waters) or hazardous wave conditions.

**GALE WARNING.** To indicate winds within the range 34 to 47 knots are forecast for the area.

**STORM WARNING.** To indicate that winds 48 knots and above, no matter how high the speed, are forecast for the area. However, if the winds are associated with a tropical cyclone (hurricane) the STORM WARNING indicates that winds within the range 48 to 63 knots are forecast.

Note: In Alaska, warnings are disseminated by radio only, there are no visual warning displays (flags or pennants)

NOAA WEATHER RADIO

NOAA weather radio broadcasts on 162.10 and 162.55 MHz can usually be received 20-40 miles from the transmitting antenna site, depending on terrain and the quality of the receiver used. Where transmitting antennas are on high ground, the range is somewhat greater, reaching 60 miles or more. The VHF-FM frequencies used for these broadcasts require narrow-band FM receivers. The National Weather Service recommends receivers having a sensitivity of one microvolt or less and a quieting factor of 20 decibels.

Some receivers are equipped with a warning alert device that can be turned on by means of a tone signal controlled by the National Weather Service office concerned. This signal is transmitted for 13 seconds preceding an announcement of a severe weather warning.

1. NOAA WEATHER RADIO transmitter (VHF-FM)
2. Marine radiotelephone stations
  - CG Coast Guard
  - NWS National Weather Service
  - RCA Radio Corporation of America
3. All regular marine forecasts are valid for 24 hours from time of issuance (see time of broadcast)
4. Coastal forecast areas extend 50 nautical miles offshore, as shown. These areas are outlined on sea
5. The forecast sea and wave charts are based on data contained in "Coastal and Offshore Forecasting for the Northern Hemisphere, 1961," published jointly by U.S. Department of Commerce and U.S. Department of the Navy.

Figure 4.10 NWS Forecast Areas

REPRODUCIBILITY OF THIS CHART PAGE IS FREE

and to a few others on which the experiment might warrant such installation. Participating vessels would be asked to keep a log of daily operations, fishing locations and depth, whether or not the broadcasts were heard, whether they were believed, and decisions made on the basis of the information. Marketing information would also be required. Participating vessels would supply information on pounds caught, number of pots, prices, dead loss, time spent per trip, days lost to weather, etc. Information on the industry as a whole concerning catch, fishing location and depth, gear used and prices would be obtained. The price and market information would be collected through the processors. The yield information is collected by and available (in aggregate form) from the Alaska Department of Fish and Game. The industry interest in the possibility of such an experiment is high and selecting an adequate sample of cooperating fishermen does not appear to be a problem.

Since sea ice and vessel icing conditions are most severe in areas of the Bering Sea and Cook Inlet, the experiment should include a sample of vessels from Dutch Harbor and from Kodiak. (However, it is possible that this division may become too cumbersome for the experiment, in which case it may be necessary to limit the experiment to the Dutch Harbor area since most fishermen in the Bering Sea are from this area.) The vessels would be classified as they are for insurance purposes by the following characteristics:

- Size of vessel
- Area of operation
- Age of vessel
- Season of operation
- Method and gear types
- Construction materials and design

- Tanking
- Propulsion and auxiliary power.

A sample, representative of the fleet based on these characteristics, would be selected for participation in the experiment.

The experiment would run from the beginning of king crab season in August, through its close and again from the reopening of the tanner crab season in the spring through its close (tanner crab season also overlaps most of the king crab season in many areas). It is expected that two seasons of data collection would be necessary to establish firm economic benefits. The first year's data would be collected before SEASAT is launched (the 1977-1978 winter season) and would model the specific losses which result from given conditions. The second season, 1978-1979, would be used to compare the same operations with the benefit of SEASAT-A.

#### Participants and Data Flow

Most of the vessel operators belong to either a vessel owners or marketing association. These organizations (26 total), particularly the United Fish Marketing Association in Kodiak and the North Pacific Fishing Vessel Owners Association in Seattle, seem quite willing to support an experiment and aid in sample selection and experiment coordination. In addition, cooperation would be required from the National Weather Service for aid in disseminating the information. Before the information is disseminated it will be either passed through one of the universities which conducts ice modeling and forecasting or through another agency for similar treatment. Forms which are not too time consuming for the fishermen to fill out will be designed and distributed. These will be collected by the marketing association or

returned directly for processing and analysis. NASA's efforts would be required to organize and coordinate the implementation and running of the experiment.

Other information useful in completing an adequate data base is available from the Alaskan Department of Fish and Game which maintains detailed records on the areas of catch and gear required, the North Pacific Vessel Owners Association, various insurance companies providing hull insurance and the National Marine Fisheries Service.

Modeling, processing and analysis of the results would be necessary. When estimates of the value of the reduced losses in terms of reduced gear loss, hull damage and loss of life have been completed for the experimental areas, extrapolation to other fishing and transport operations could be made based on the similarity of operations and environmental conditions encountered. It is believed that these estimates will indicate some of the economic benefits of SEASAT-A and provide a guide to the benefit areas and likely magnitudes of the benefits from an operational SEASAT system.

#### 4.1.3.3 Menhaden Yield Forecasts Tied to Surface Water Transport

Forecasts of fish catch are used by the marketplace and in industry operations; indications are that predictions of menhaden fishery yields can be improved with the use of SEASAT-obtained surface water transport data. Although a direct measurement of the economic effects of this information is not possible, an experiment is recommended in this area which promises to demonstrate the utility of SEASAT in fisheries management and to estimate the economic value of this utility.

#### The Industry

The menhaden fishery is the largest fishery by volume in the United States. Landings in 1974 were 967,000 tons with a dockside value of \$75

million (1974 dollars). In the two decades between 1952 and 1974, menhaden accounted for 33 to 45 percent of the total annual U.S. fish catch. Yields are from two geographically but not industrially separate regions: the Atlantic and the Gulf. Prior to World War II, the fishery was principally conducted along the Atlantic coast. Since then, however, the Gulf fishery has flourished and its product has exceeded that of the Atlantic since 1963. Relative catch for the two regions in 1974 was 322,000 tons for the Atlantic and 647,000 tons for the Gulf.\*

The fishing is done on approximately 120 vessels, most of which are owned by 17 reduction plants (10 on the Gulf coast, 7 on the Atlantic) that process the catch, primarily into fish meal and oil. The meal goes principally for high protein animal feed, while most of the oil is exported to Europe and used there for the production of margarine. There exists an active futures market for menhaden catch and about two thirds of the catch products have already been sold during the previous winter.\*\*

Fishing mostly 2 to 3 miles offshore, vessels operate all but a few winter and early spring months in the Atlantic and from April to October in the Gulf. The fishery is dominated by purse seine methods (see Figure 4.11). Additionally, the industry employs some 60 light aircraft for spotting surface fish schools. The spotter aircraft have been credited with increasing industry efficiency by at least one third.\*\*\*

---

\* Fred June and John Reintjes, "The Menhaden Fishery," in Industrial Fishery Technology, Maurice Stansky [Ed.], 1976.

\*\* Robert Chapoton, Atlantic Estuarine Fisheries Center, National Marine Fisheries Service, NOAA. Personal communication, October 27, 1976.

\*\*\* Fred June and John Reintjes, "The Menhaden Fishery," in Industrial Fishery Technology, Maurice Stansky [Ed.], 1976.

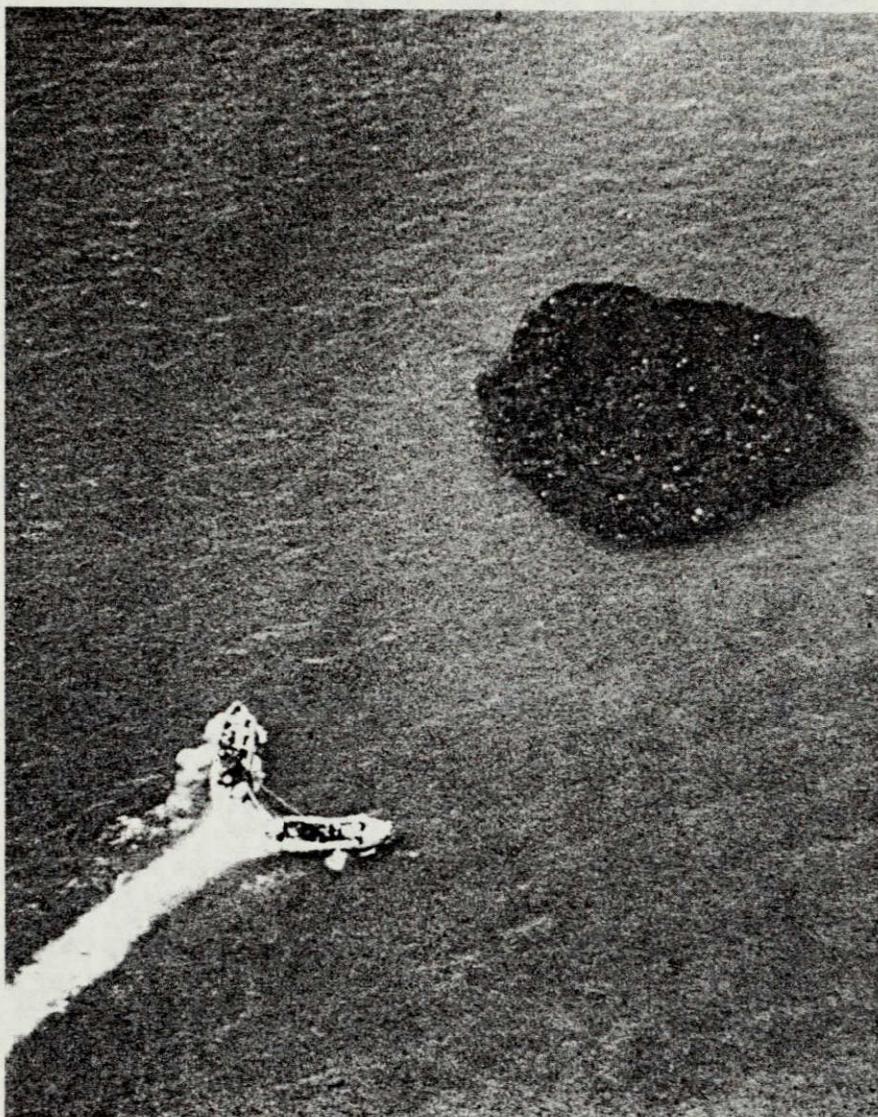


Figure 4.11

Purse Boats Beginning a Set on a 70-ton School of Menhaden. (Photograph by Hall Watters, Standard Products Co., Southport, North Carolina.) (Source: William Schaaf, "Status of the Gulf and Atlantic Menhaden Fisheries and Implications for Resource Management," Marine Fisheries Review, September 1975.)

### Forecasting Menhaden Catch

Forecasts of menhaden catch for the Atlantic and Gulf fisheries have been made since 1973 by the Atlantic Estuarine Fisheries Center (NMFS, NOAA), Beaufort, North Carolina. The forecasts are based on a multiple regression analysis which relates catch to fishing effort. Forecasts are made for assumptions of constant and  $\pm 10$  percent effort and are produced in November of the preceding year. Figures 4.12 and 4.13 show time series of actual and estimated catch for the Atlantic and Gulf fisheries, respectively; estimates for 1973 through 1976 represent forecasts.

These forecasts are used by the menhaden industry and the marketplace in partial determination of futures prices for fish meal and oil. The use of forecasts to derive more optimal consumption patterns of commodities has already received substantial attention in other ECON reports relating to agricultural commodities<sup>\*</sup>; the effects of improved forecasts here are analogous.

Industry also makes use of these NMFS forecasts, heavily tempered by its own forecasts, in planning the next season's operations. The level of fishing effort is not a constant, as there is little cost involved in retiring fishing vessels. Crews are typically not guaranteed wages and are paid on a per catch basis. Anticipation of a poor year could result in foregoing work on some vessels over the winter or perhaps suspending orders for new boats. If a particularly good year is anticipated, efforts might be increased to insure

---

\* John Andrews, The Value of Domestic Production Information in Consumption Rate Determination for Wheat, Soybeans and Small Grains, ECON, Inc., Princeton, New Jersey, Report No. 75-127.3, October 31, 1975.  
Keith Lietzke, The Value of Volume and Growth Measurements in Timber Sales Management of the National Forests, ECON, Inc., Princeton, New Jersey, Report No. 76-111-2, August 31, 1976.

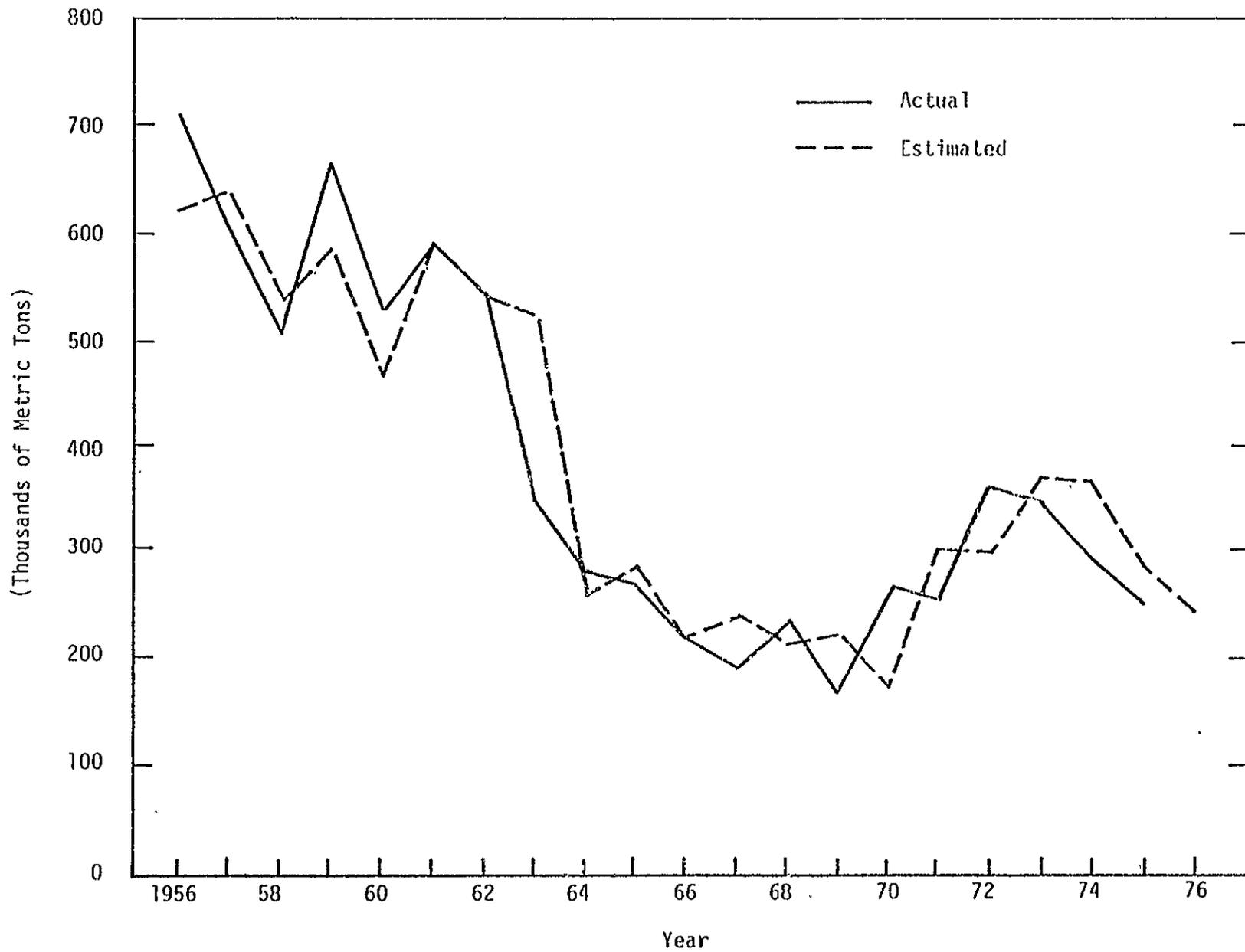


Figure 4.12 Atlantic Menhaden Purse-Seine Landings--Actual and Estimated  
 (Source: Atlantic Estuarine Fisheries Center, Beaufort,  
 North Carolina.)

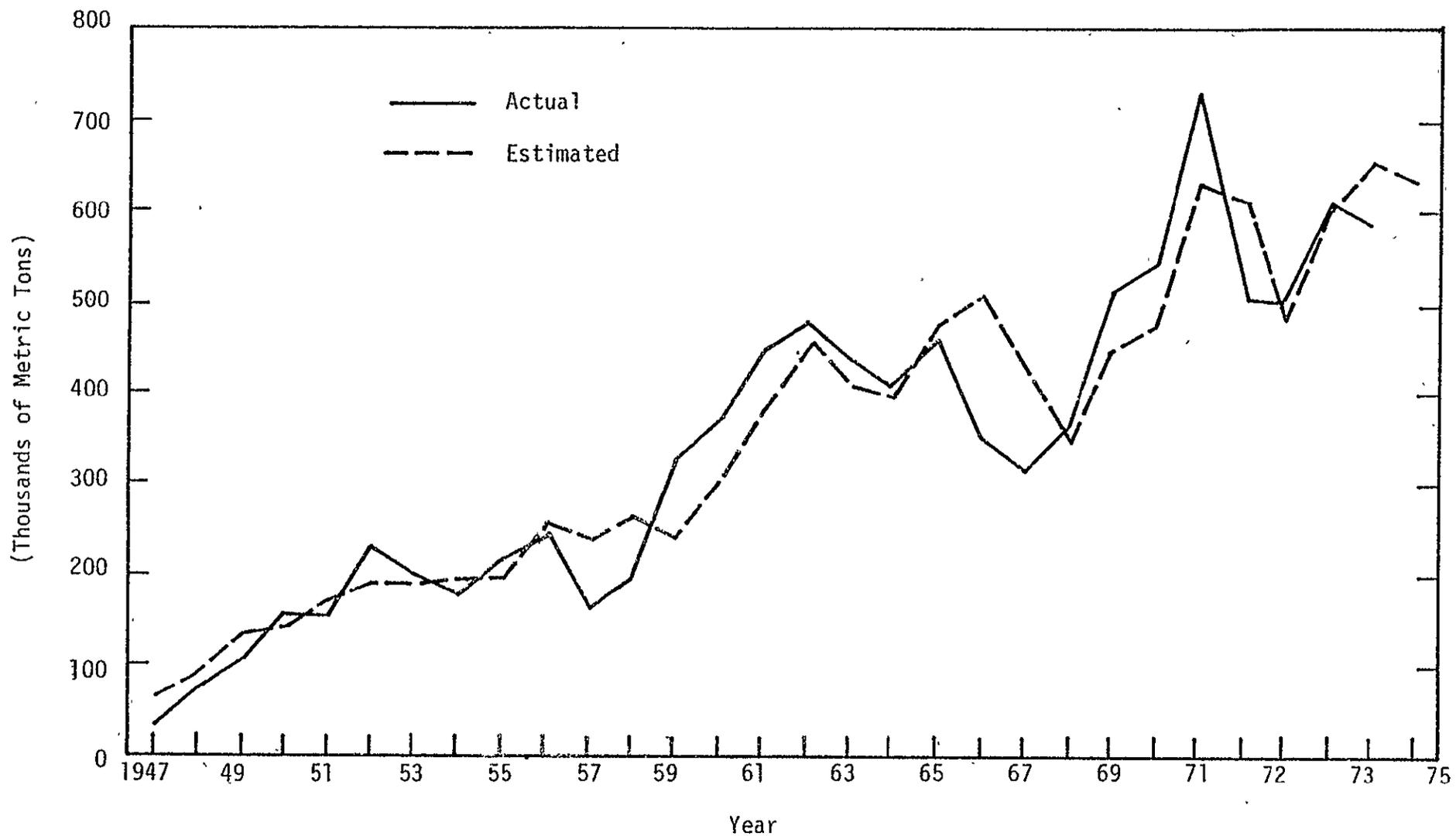


Figure 4.13 Gulf Menhaden Purse-Seine Landings--Actual and Estimated  
 (Source: Atlantic Estuarine Fisheries Center, Beaufort,  
 North Carolina.)

preparation by the beginning of the season. Anticipated long run increases in yield might result in orders for new boats. Finally, expected relative changes between fisheries could result in a change in allocation of resources between them. Although the operators are very interested in receiving the NMFS forecasts, they do not accept them outright for they are aware of the attendant forecast errors.\* Industry and NMFS would like to see improvements made in these forecasts.

#### The Physical Processes of Interest

The forecasts currently used make use of information related to fish density (previous catch and previous effort). However, there are factors not related to fish density, notably environmental conditions, that affect fish population and, thus, fish yield. In the menhaden fishery one such factor of importance is surface water transport (SWT). Adult menhaden spawn offshore, but larvae need to be transported inshore in order to survive. Recently, research efforts have focused on the relation between surface water transport and the numbers of menhaden recruits entering the population. A study performed at the Atlantic Estuarine Fisheries Center and the Atlantic Environmental Group of NMFS has shown that surface water transport data can be used to explain substantial amounts of variation in population not accounted for by fish density data.\*\* Multiple regressions relating an Ekman transport

---

\* Robert Chapoton, Atlantic Estuarine Fisheries Center, National Marine Fisheries Service, NOAA. Personal communication on October 27, 1976.  
Tom Reynolds, National Fish Meal and Oil Association. Personal communication on November 2, 1976.

Ed Swindel, Wallace Menhaden Inc. Personal communication on November 2, 1976.

Joseph Schollenberger, Seacost Products. Personal communication on November 2, 1976.

\*\* Walter Nelson, Merton Ingham and William Schaaf, Larval Transport and Year-Class Strength of Atlantic Menhaden, MARMAP Contribution No. 88, 1976.

index to a recruit survival index shows that approximately 62 percent of the former can be explained by the latter. Figure 4.14 shows the relation between recruits and Ekman transport. It is felt that the incorporation of this type of information into making catch forecasts could substantially improve these forecasts. Whereas, it is not currently known how this recruit information can best be used to improve forecasts, it is expected that such information will be used within the next two years.\*.

#### Information Systems

The only surface water transport data currently obtainable is produced by the NMFS Pacific Environmental Group. These data are derived from atmospheric pressure observations provided by Fleet Numerical Weather Central.\*\* The primary problem with these SWT estimates is that they are extremely "coarse", that is, there is only one estimate per 3° grid (roughly, 150 miles square). A secondary problem is that they are based on samples of single-pointed observations, with the attendant sampling errors.

SEASAT-A offers the possibility for providing surface water transport data more accurately, more frequently and with much greater resolution. Experiments are currently underway to demonstrate the ability of a scatterometer in measurement of SWT. Other SEASAT instruments, such as the radiometers and the imaging radar, may also be useful in this application. Whether SEASAT-A can dependably provide useful SWT data is not yet known and tests concerning this capability would be a part of this experiment.

---

\* Robert Chapoton, Atlantic Estuarine Fisheries Center, National Marine Fisheries Service, NOAA. Personal communication on November 18, 1976.

\*\* Andrew Bakun, Coastal Upwelling Incides, West Coast of North America, 1946-71, NOAA Technical Report NMFS SSRF-671, 1973.

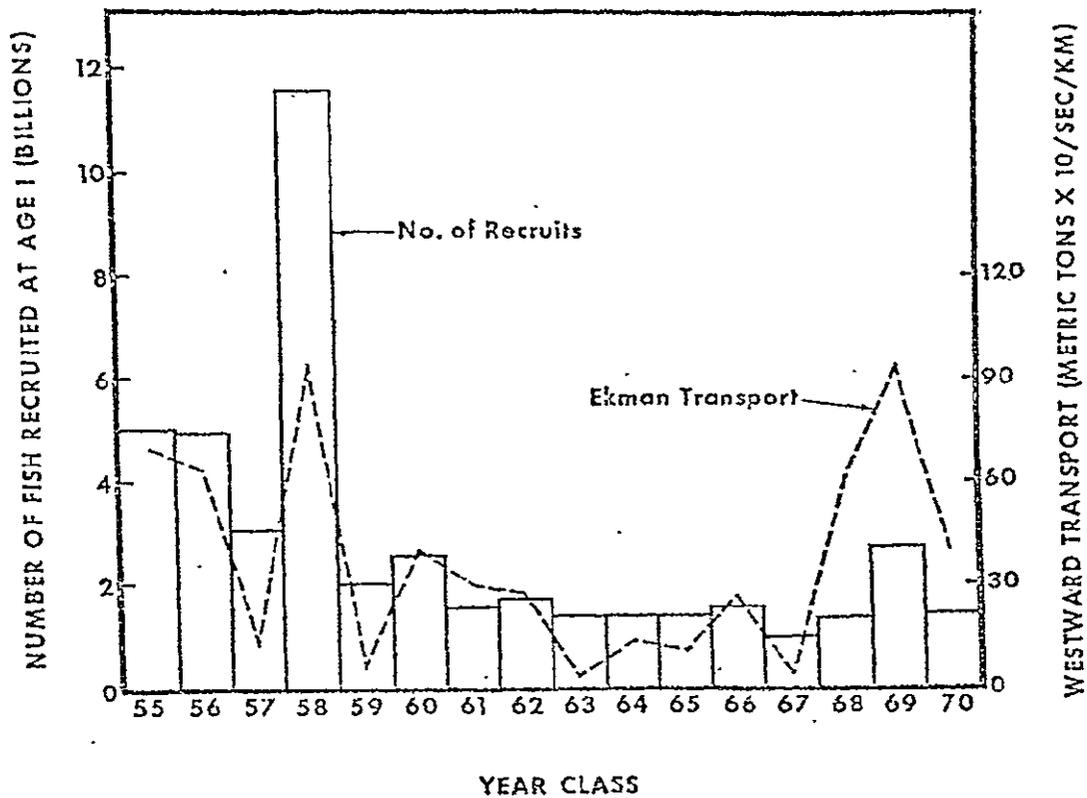


Figure 4.14 Relationship Between Surface Water (Ekman) Transport and Menhaden Recruits (Source: Walter Nelson, Mertin Ingham and William Schaaf, Lawal Transport and Year-Class Strength of Atlantic Menhaden, Contribution No. 88, 1976.)

### Experimental Design

The economic value of improved fish yield forecasts can only be verified over many years of observation of the market and of operators' responses to the forecasts. Thus, it is not possible in the envisioned length of time of an experiment to directly measure the economic impact of SEASAT in this application.

A possible experiment for this application would be to estimate the accuracy of SEASAT-A in measuring SWT and compare this with the accuracy of SWT data produced by the current, conventional means. This work could be done alongside efforts to be performed in the calibration of SEASAT instruments in measuring SWT by the Fisheries Engineering Laboratory, NMFS, Bay St. Louis, Mississippi. This analysis could be done with little additional effort.\* Such an experiment could hopefully be performed in the Atlantic fishery, where research has already demonstrated the nature of the connection between SWT and recruit survival. Logical participants would be the Fisheries Engineering Laboratory and the Atlantic Estuarine Fisheries Center of NMFS.

The link between SWT accuracy (estimated experimentally) and catch forecast accuracy can be derived analytically. The final connection between forecast accuracy and economic benefit can be completed by economic modeling of the fish meal and oil futures markets and boat owner's operations. This type of analysis is far from trivial, but is not unlike work previously performed by ECON.

### Conclusions and Recommendations

In spite of the fact that an experiment in this area would not result in direct measurement of economic benefits, performance of an experiment similar

---

\* Andy Kemmerer, John Brucks and Tom Leming, Fisheries Engineering Laboratory, National Marine Fisheries Service, NOAA. Personal communication on October 26, 1976.

to that outlined above is recommended. This recommendation is based on the following points:

1. It is very "do-able".
2. Both industry and government are very interested in seeing improvements in the existing menhaden catch forecasts.
3. The link between data of the type SEASAT proposes to obtain (surface water transport data) and improved forecasts has already been established.
4. Most of the effort required on the technical side of this experiment will be performed independent of the experiment.
5. The benefits of this SEASAT information could extrapolate nicely into the extremely valuable shrimp industry, and also to the anchovy industry.

#### 4.1.3.4 Marine Fisheries Upwelling Forecasts

A further possible experiment in marine fisheries would be designed to assess the potential for SEASAT to assist in detecting and forecasting areas of ocean upwelling. This experiment would involve the U.S. albacore fishing fleet.

The U.S. albacore fleet is very large--of varying size, but up to 2000 boats--and highly varied in sophistication. The albacore season starts in late June and runs through late November. The fishery covers the entire Pacific coast of the United States and extends a little south off Mexico. Over the last ten years, the dominant part of the fishery has moved from the southern half of this region to the northern half.\*

Albacore fishermen are interested in the existence and positioning of thermal fronts, for these are usually associated with nutrient-rich upwelling areas and--working up the food chain--with albacore tuna. The NOAA

---

\* Michael Laurs, Harold Clemens and Larry Hrea. "Nominal Catch-Per-Unit-Effort of Albacore, *Thunnus alalunga* (Bonnaterre), Caught by U.S. Jig Vessels During 1961-1970", Marine Fisheries Review, 38(5). May 1976.

recently began a program to provide charts to the fishermen\* depicting these thermal fronts. Thermal infrared images from NOAA satellites (currently VHRR from NOAA-3, soon AVHRR from NOAA-5) are manually analyzed for the existence of thermal boundaries, and charts of these fronts are made on a spatially-adjusted, mercator projection map. These charts are then posted in 18 ports along the northern Pacific coast. Maps are produced by the National Environmental Satellite Service (NESS) of NOAA at the Satellite Field Service Station (SSFS), Redwood City, California and are disseminated by the Marine Advisory Extension Service of the University of California.

It appears that the albacore fishermen have responded very favorably to this project, many having had great success at finding fish at locations to which they have gone after consulting the thermal front charts provided by NOAA. The fishermen are also interested in the actual satellite photographs for they appear to be willing to go to locations identified on the image which NESS was unwilling to interpret as a thermal front.\*\*

Recently, the dissemination procedure was improved by telecopying the charts to the ports instead of mailing them. There seems to be some demand for sending the charts to vessels directly by radio facsimile as some vessels can be out one or two months; but the number of vessels which can receive facsimile transmission is small and it appears that there are no plans currently to do this. New charts are prepared approximately once a week during the season.\*\*\*

---

\* Larry Breaker, Satellite Field Services Station, NESS NOAA. Personal Communications. November 3 and November 19, 1976.

\*\* Tom Thompson, Marine Advisory Extension Service. Personal communication. November 8, 1976.

\*\*\* Fred Jurich, Marine Advisory Extension Service. Personal communication. November 8, 1976.

SEASAT offers three very important capabilities to this program:

1. The use of the visible and infrared radiometer (VIR) in conjunction with the VHRR offers the sea surface temperature images at greater frequency.
2. The addition of the microwave radiometer adds an all-weather capability which NESS feels is very important to the programs, since cloud cover is a serious problem. Currently, they are using the geo-synchronous SMS-2 imagery to "mop up" where possible when VHRR imagery has been blocked by cloud cover. But SMS-2 does not have cloud-penetrating capabilities and it offers very poor resolution for this application.
3. The scatterometer will produce information that, hopefully, can be used in an upwelling-prediction model developed by NMFS, Pacific Environmental Group, Monterrey. These predictions, if they could be accurately made, would be extremely valuable to the fleet, particularly for vessels which are out for extended periods.

#### Experiment Design

There are two possible approaches to an experiment for this application. The first is one pursued in a research study called the Coho Project. This project provided aerially obtained temperature maps to salmon fishermen and attempted to measure the effect of this information upon fish yields. The researchers obtained an experimental group separate from the control group simply by asking the fishermen if they made use of the information and then double checking by noting if they caught salmon in areas indicated by the information\*.

This procedure has several serious drawbacks. First, a typical problem in evaluating the use of technology is that the innovators that readily accept new techniques are usually (on the average) better producers than those who are reluctant to use the new methods. This introduces a bias in the results

---

\* O'Brien, Woodworth and Wright. The Coho Project. Florida State University and Oregon State University. 1974.

of this procedure. Secondly, although this procedure is designed to measure the potential value of the information, it is not likely to be a good estimation of the ultimate program benefit because a certain part of the community may never make use of the information--because they are unwilling to recognize the value of the information or are simply set in their ways or because they already have techniques superior to those provided by the new technology, perhaps a highly developed "fish sense".

The alternative procedure is to temporally separate the experimental and control groups. The problems of this approach have already been mentioned in Section 4.1.3.1 and deal with having to factor out environmental influences which are different between the experimental and control years. Nevertheless, it is felt that this could be done if intelligently and knowledgeably approached.

Data by which catch-per-unit-effort measurements can be obtained appear to be already available.\* It also appears that there would be enough observations to establish statistical significance; one study obtaining historical catch-per-unit-effort figures made use of approximately 5,000 observations per season, 1961 to 1970.\*\*

#### Conclusions and Recommendations

ECON does not wish to recommend a particular experiment design at this time, but feels that an experiment which would meet NASA's requirements is possible in this area. The performance of an experiment here is recommended for the following reasons:

---

\* Fred Jurich, Marine Advisory Extension Service. Personal Communication. November 8, 1976.

\*\* Michael Laurs, Harold Clemens and Larry Hrea. "Nominal Catch-Per-Unit-Effort of Albacore, *Thunnus alalunga* (Bonnaterre), Caught by U.S. Jig Vessels during 1961-1970", Marine Fisheries Review, 38(5). May 1976.

1. SEASAT information would link into an existing and (apparently) highly successful program.
2. SEASAT would provide additional information considered to be very important to this application, not only operationally but also experimentally (in predicting upwellings).
3. The necessary data for performance evaluation appear to be available without special effort to obtain them.
4. This experiment provides an opportunity to directly measure the economic impact on user operations.
5. Results of this experiment extrapolate to other fisheries, notably salmon and anchovy.

#### 4.1.4 Ice Monitoring Applications

##### 4.1.4.1 Alaska Sea Ice Monitoring

Marine transportation of logistics support and supplies to oil operations along the North Slope of Alaska is subject to many complications due to sea ice and poor weather conditions. It is believed that information from SEASAT would be useful for nowcasting and for incorporation into ice models. Better information on ice breakup and movement as well as iceberg and floe location and ice pack movement would allow more efficient transportation, reduced hull damage and increased personal safety.

An experiment is proposed to estimate the economic benefits of SEASAT data obtained by microwave radiometer and synthetic aperture radar. The benefits of the resulting improved ice information are to be measured through reduced transit time, reduced fuel consumption and reduced hull damage and injury.

#### Background

The barges which supply the North Slope with supplies originate in Seattle and follow a northwestern course which takes them through the Gulf of Alaska. The other possible route is to travel up the United States and

Canadian shores and follow the Alaskan coast line around the Gulf of Alaska. This route, while generally safer because of the sheltered weather conditions, requires a few extra days transport time. From the western portion of the coast of the Gulf of Alaska, either route requires passage through the Aleutian Chain and up the western coast of Alaska in the Bering Sea. From there, a landing is made at Point Barrow and the shipping continues along the North Slope to exploration and drilling sites in the Beaufort Sea. In addition, barges carry equipment and supplies along the same route to the Distant Early Warning (DEW) System posts located along the northern coast of Alaska. The route remains ice free most of the year for the sections from Seattle up to areas on the western side of the Aleutian Chain near the Pribelof Islands. The extent of the ice pack varies from year to year.

Because of ice conditions, ship movement is necessarily limited to the summer months. Barges depart from Seattle about the first of July and are expected to reach Point Lay or Say Cape about the first of August. From this point, depending on the year, five to six weeks are available for barge movement along the north slope of the state. During this time transit must be made from Point Barrow to Barter Island and the destination points between, and the barges returned to the western coast to begin their return to Seattle. The length of time available for these operations is dictated by the thaw of the ice pack. During most of the year the ice pack covers the sea up to the shore but during a few weeks after the first of August the pack melts and breaks away from the land. This provides a channel-like route along the shallow waters of the shore. The width of the passage and the length of time which it remains open vary from year to year, with about 5 years in 20 completely ice free and 1 year in 20 completely iced.

Because of the ice conditions, shallow barges are used in all of these operations. While other vessels are more suitable to the rough seas sometimes encountered en route, barges with shallow draft are required for passage of the water between the shore and the ice which at times can be only 15 to 20 feet deep. Each year the fleet is composed of several mainline barges, several smaller barges, aircraft landing vessels and the necessary tugs and support vessels. While ice conditions are certainly a limiting factor in vessel selection, a close-in ice pack does provide some protection from high seas. Therefore, while ice-free years tend to provide easier routing, severe weather conditions tend to offset navigation benefits.

At the present time, most of the shipping to the North Slope both to the pipeline and the DEW line system is handled by a Seattle-based barge company, Crawley Maritime Inc. A large portion of the cargo headed for the pipeline areas consists of prefabricated buildings and equipment. While this type of cargo tends to be bulky and difficult to transport, the poor climatic conditions and resultant reduced worker efficiency at the destination make shipping the prefabricated goods more economical than transporting materials and building on site. Because of the nature of the cargo and destination point, alternate methods of transport such as truck or air shipping are not feasible.

Table 4.5 shows the amount of cargo shipped and the number of barges required from 1969 to 1976 with projections for 1977 and 1978 in support of the pipeline sites. In addition to these, about five barges are necessary for DEW System resupply per year.

Table 4.5 Shipments to North Slope Oil Operations 1969-1978

Year	Cargo (1000 Tons)	Number of Barges
1969	75	32
1970	187	36
1971	16	6
1972	3	2
1973	21	8
1974	67	16
1975	153	48
1976	70	22
Projected 1977	30	
Projected 1978	150	

Source: Crawley Maritime, Seattle, Washington.

As mentioned earlier, these barges travel along the shore with all vessels traveling together. This tends to reduce the informational needs of the group as a whole as well as providing additional rescue and safety precautions. In the past, the fleet has delivered its cargo to the assigned destination on every voyage. In only one year (1975) the barges were unable to return to Seattle and were forced to spend the winter frozen in the ice off the North Slope. In many years hull damage has been sustained, at times reaching severe levels.

#### Present Information System

Ice information is gathered through daily reconnaissance flights out of Point Barrow to the areas north and west of the fleet's course. These are controlled by those involved in the operations to the North Slope. In addition to ground landing sites, the fleet includes two landing craft vessels which are used for reconnaissance flights as well as emergency transportation. This type of information collection is necessarily hampered by poor weather conditions. Therefore, the system tends to fail when hazards to transport are the highest.

In addition to using the reconnaissance flights, barge operators also work very closely with members of the National Weather Service. The NWS surveys conditions and collects data from their forecast offices in Anchorage and from data collection centers along the Alaskan coast to the west of the barge operations. These reports as well as the information gained from the daily reconnaissance flights which cover the area to the north and west of Point Barrow for weather conditions are used in their forecasting efforts.

Ice modeling information is also available from the Arctic Institute of North America. This information is considered by the barge operations but is not thought to be accurate enough on which to base decisions. Emergency assistance is available from the U.S. Coast Guard.

In general, the operators of the barge fleet feel that their present information system is relatively accurate and dependable. They are not overly concerned with the weather limitations of the reconnaissance flights. For instance, last year (1975) there were only four days out of the season for shipping along the North Slope during which weather conditions precluded flying. It is not felt that this is particularly damaging to the progress of the fleet because under such circumstances, even if the course were known to be ice free, it would be too risky to move the vessels within close proximity of each other. However, this appreciation for the existing system does not indicate that the operators are not interested in new information. Personal communications with Crawley Maritime have indicated a need for any improvement in informational systems that is possible. It is also felt that increased efforts in the ice modeling field would be beneficial.

The transport operations expressed an interest in obtaining SEASAT data. And while no immediate effects of the information are foreseen, it is felt that eventually, with practice in using the information and acceptance of its timeliness and reliability, these data would be able to affect decisions and possibly replace or supplement portions of the existing system.

#### Experiment Description

The purpose of the North Slope transport experiment would be to determine the value of SEASAT-A data to barge operations north of Alaska. SEASAT's

microwave radiometer and synthetic aperture radar sensors can provide additional sea ice and iceberg information for this area. It is expected that this information would lead to improvements in barge movement scheduling and, to a certain extent, routing. Improvements would be measured by comparison of the costs of the actions which are taken without SEASAT data and actions that would be taken with SEASAT data. This would require modeling operations and expert evaluations of the value of the new information.

The experiment would be conducted during late July, August and September with the barge season. Information from SEASAT would be processed in Fairbanks and transmitted to the command ship or the aircraft landing vessel of the fleet by radio facsimile. From this point it would be made available to the barge operators and the NWS. Benefits would be measured in terms of 1) transit time savings, 2) fuel savings, and 3) reduced crew injury and hull damage.

Since all the vessels travel together and are controlled by a single decision maker there would be no opportunity for comparison of simultaneous behavior with and without SEASAT. This imposes several limitations. Weather and ice conditions may vary so drastically from year to year that comparison of two different years may not be significant. In order to do such a comparison, a normalization of all the variables would have to take place. With differences in ice conditions from ice free to impassable for the entire season possible, it may not be realistic to consider such a technique. The measurement then must take a more subjective approach. The experiment would require the cooperation of an expert observer to follow the decision process closely.

Another problem would be encountered in that SEASAT data will be new and not completely trusted. It is very unlikely that the barge operators would commit their entire operation to a course of action based on information from a source which has not been proven over time. The expert observer(s) would be able to give opinions on the benefit SEASAT-A would have been to the operation if it had been relied upon.

Analysis would be made to estimate the dollar benefits of SEASAT had the course of action suggested by its input been followed and historical data as it exists. This analysis would be performed with the necessary inputs from the barge operators and the NWS.

#### Limitations of the Experiment

The experiment as described earlier is limited in several aspects. The most important of these is that no direct measurement of benefits would be possible. Because of the variations in weather and ice conditions a comparison of two different years does not seem possible. In addition, since the information system in existence is already quite accurate and heavily relied upon, it is unlikely that the possible benefits from the addition of SEASAT would be exemplified in a short number of seasons. Operators would be particularly unlikely to base a decision on SEASAT information when it is in opposition to weather or ice predictions from the current system. Therefore, measurements and analysis must be made on the opinion of an expert(s) who is (are) working with the operations and such information that is available historically. It is unlikely that statistical significance can be gained from this type of approach.

Another limitation of the experiment is that the season for operation is so short. The five- to six-week length would not allow much time for consideration or problem resolution if problems should be encountered.

Finally, the area does not prove to be a large benefit area because of the limited number of users, the method and route of operations, and again, since the present system is so complete, it is likely that SEASAT-A would provide only slight incremental improvement. Therefore, in light of the type of experiment possible and its limitations, it is not recommended that this experiment be carried out. This is not intended to imply that there are no expected benefits from SEASAT in this area, because it is expected that in the long run, especially in a multi-satellite system, the benefits are expected to be great. Rather, it is believed that this is not a good area for an economic verification experiment at this time.

#### 4.1.5 Coastal Zone Applications

##### 4.1.5.1 Southeast and East Coast Hurricane Wind and Landfall Forecasts

SEASAT data are expected to contribute to improvements in the prediction of parameters which quantitatively describe sea and weather phenomena destructive to the coastal zones of the United States. Economic benefits accorded to these data result from the reduction of losses as a consequence of improved prediction for coastal zone destructive phenomena. The benefits thus derive from what are referred to as avoidable losses.

Studied benefits were derived from three distinct sources:

1. Direct action of sea incursion on property
2. Reduced expense for hurricane emergency procedures
3. Direct modification (seeding) of hurricane power.

Obtaining benefits in the area of the effects of sea incursion on property requires preventive actions to be taken, either to control the transient, predicted sea phenomena or to safeguard the property.

Improved prediction relating to sea incursion phenomena requires an integration of many individual computer models to be successful, a condition judged unlikely to occur before 1985. Reduced expenditures associated with hurricane emergency procedures are a result of improved prediction of hurricane landfall, most specifically that of predicted landfall with a confidence accepted by the affected general public. An improvement in hurricane prediction will result not only from improved or more extensive data but, also, from improved physical and analytical hurricane modeling in concert with an increase in available computer power. As such this capability is likely to be accumulated slowly over possibly the next 25 years. The last source of economic benefit will result from theoretical and experimental advances in the techniques for seeding hurricanes. It has been conjectured that SEASAT data could contribute to the establishment of an operational technique for hurricane seeding control. At present this potential benefit area is being developed under Project Stormfury, currently in a constrained manner because of guarantees sought by the Japanese government against intensified precipitation as a result of typhoon seeding.

Defining and constructing meaningful Economic Verification Experiments to determine potential SEASAT benefits to the U.S. coastal zones is clearly difficult. Of the three benefit areas investigated, the one relating to improved landfall prediction seems most promising and an experiment is proposed for this phenomenon.

#### Economic Verification Experiments

SEASAT-A data should improve the accuracy of predicted coastal zone damage phenomena parameters such as the time of occurrence, duration of

occurrence, extent or location of occurrence of various magnitudes of the phenomena which could result in damage to various classes of property. Coastal zone damage results from the interaction of excessive or unexpected sea conditions, weather activity and property in the land-water interface areas of the coastal zones. The phenomena of concern can all be currently forecasted or predicted by some existing techniques. The data supplied by SEASAT should improve the current forecasting capability and it is this improved capability that is the focus of the proposed economic verification experiments. Because of the statistical nature of forecasts of the parameters of interest, landfall location and time, however, it may take several years of observation to accurately assess the improvement actually obtained by SEASAT. It may be possible to obviate this problem, in part, by two procedures. First, continuous forecasts of the movement of hurricanes should provide a better forecast performance measure than merely landfall forecasts. This would require forecasting hurricane movement simultaneously by conventional techniques and with the addition of SEASAT data and comparison of these results to actual hurricane movement. Second, it may be possible to use simulations of SEASAT data to estimate forecast improvements that would have been obtained for previous hurricanes.

Economic losses resulting from coastal zone sea state, wind and precipitation phenomena can be divided into two categories, avoidable and unavoidable. Avoidable losses result from the cost of taking unnecessary protective actions and from damage that could have been prevented had sufficient protective action been taken. It should be observed that the cost of a protective action can be greater than the cost of the damage resulting if no protective action were taken. In this case, it is rational not to take protective

actions and the losses due to damage can be classified as unavoidable. In the cases where the cost of protective action is less than the cost of damage given no protective action, it is the net loss reduction, that is, the cost savings due to damage less the cost of protective action, that is of interest. Now suppose uncertainty exists in the estimate of the damage that will occur due to a forecast event. If protective action is taken, the cost of such action must be borne. However, it is not a certainty that the cost of the damage prevented will exceed the cost of the preventive action. Thus, given inaccurate forecasts, it is not always rational to take preventive actions that would be rationally taken given perfect forecasts. Consequently, one should expect that improved forecasts will result in reduced damage as well as reduced costs of unnecessary preventive actions.

Much of the preventive actions taken in the face of a forecast phenomena are taken by private individuals to protect their property. The decision process which leads them to take or not take preventive actions is not well understood and, at best, would be difficult to quantify. A further complication arises in that a finite, and sometimes lengthy, learning process is required before individuals change their behavior. This learning process includes a period during which individuals gain awareness of a new capability and confidence in the accuracy of the new forecasts. Also, during a learning period, new social pressures may be developed to alter the decision-making process. These might include insurance regulations requiring certain preventive measures in the face of a forecast phenomena. It is thus unlikely that the learning process could be well quantified without a very substantial effort.

Finally, there is a problem of comparison of losses with and without improved forecasts. In many experiments, it is desirable to establish both a test group and a control group. However, because of the dynamic nature of forecasting technology and because of the nature of the warning system, it is probably not possible to establish both groups and to measure differences between them with statistical significance.

The above discussion identifies some of the difficulties involved in determining experimentally benefits from improved prediction and forecasting of tropical cyclones, extratropical storms, tsunamis and surf.

Hurricane seeding benefits, at this time, have to be viewed as being unobtainable. The basic seeding objective is to reduce the available latent heat in a hurricane and, as a consequence, to reduce the attained wind velocities. However, some experts conjecture that a result of seeding may be that, while the winds are reduced, the precipitation is increased. But such an exchange has not been experimentally observed. If precipitation should increase, a concern should be expressed for those for whom the incremental disbenefit from precipitation exceeds the benefit from wind reduction. This concern depends on the particulars of the hurricane or typhoon. As a consequence, it has been decided to consider an experiment in which landfall prediction or hurricane movement forecasting may be improved. From any improvement in hurricane movement forecast, an economic benefit should be derived.

Because Project Stormfury seemed to be concentrating its efforts on the eleven or so typhoons expected to arise in the Pacific each year, and to track them with and without seeding in a northwesterly direction from Guam, it seemed reasonable to consider introducing SEASAT-A data into this program.

However, it now appears that Project Stormfury will be considerably curtailed and it is thus proposed to consider an experiment on hurricanes in cooperation with the National Weather Service.

#### A Coastal Zone Experiment

The National Weather Service currently has a technique for predicting hurricane phenomena including landfall. Between now and the period 1978-1981, when SEASAT-A data are expected to be available, hurricane forecasting techniques will be in a period of development and testing which is likely to result in significant changes, both in terms of the models used and the resulting forecast accuracies. Although this will be an added complication, it is proposed to conduct the following non-real-time experiment, in cooperation with and coordinated by Dr. John A. Brown, Jr.,\* to determine the improvement in hurricane landfall prediction obtainable using SEASAT-A data:

1. During the time period that data will be available from SEASAT-A, relevant data will be made available to Dr. John A. Brown, Jr.
2. He or his subordinates will examine the data supplied to assure its appropriateness for use in the operational hurricane prediction models.
3. If the data supplied are judged to be inappropriate, NASA will be informed including a statement of the reasons for its inappropriateness.
4. Otherwise, the SEASAT-A data will be used in the NWS hurricane models to produce hurricane landfall predictions. This will not be done in real-time.
5. Landfall prediction results will be obtained using both the current techniques (without SEASAT) and the same techniques with SEASAT data appropriately incorporated.

---

\* Chief, Development Division, National Meteorological Center, N.W.S., NOAA, World Weather Building, Washington, D.C. 20232 (301-763-8005).

6. The landfall prediction results with and without SEASAT data will then be compared to historical "truth".
7. Whenever possible, for hurricanes that do not landfall, movement forecasts will be made and separate results will be provided to infer landfall prediction accuracies with and without SEASAT data.
8. If possible, NWS will estimate or determine the sensitivity of landfall prediction accuracy to SEASAT-A data quality.

#### Calculation of Economic Benefits

Avoidable economic losses are assumed to exist because the hurricane interaction area is too large as a result of inadequate prediction of the hurricane landfall position. The area warned must then include an area, the overwarned area, because of this landfall position prediction error. Reducing this prediction error will then reduce the overwarned area, reducing the associated avoidable economic loss which produces a benefit.

The costs  $C$  of warning an area  $A$  are assumed to be dependent on the population density  $P$  in that area. Thus

$$C = APc$$

where  $c$  is the warning cost per unit of population. If within the area  $A$  is another area,  $a$ , which is the overwarned area then the avoidable cost  $D$  of overwarning is similarly

$$D = aPc$$

If further, as a consequence of improved prediction, there is a fractional reduction in the overwarned area by an amount  $f$ , while at the same time the population density changes by a ratio  $p$ , then the avoidable cost that is avoided or the benefit  $B$  is given by

$$B = fapPc = fpD$$

The value of  $f$  will be provided by the experiment as a consequence of SEASAT-A data. This value will be assumed appropriate to all hurricane landfall predictions.

The value of  $p$  will be determined using projections based on population trends as defined by the U.S. Department of Commerce, to the time period of interest. The parameter,  $D$ , will be taken from a theoretical paper by Sugg,<sup>\*</sup> since no practical measures have been found to exist.  $D$  is estimated as a range of values and will be adjusted for inflationary trends to the time period of interest. Sugg's 1966 values for the average number, 1.5, of hurricane landfalls in the United States ranged from \$10.4 million to \$34.9 million. Using an inflation factor of 50 percent until 1975, the current range of overwarning costs is \$13 million to \$43.6 million in 1975 dollars.

The benefit formula in millions of 1975 dollars is then given as a range, attributable to SEASAT-A data as

$$13fp \leq B \leq 43.6 fp$$

where the average number of landfall hurricanes is assumed to be constant up to the time period of interest.

It is expected that population density projections will provide a range of values also. Furthermore, it is expected that the values of  $f$  supplied by the experiment will have a range of statistical confidence values.

The benefits to SEASAT-A are therefore expected to be presented as a range of values with associated confidence levels.

---

<sup>\*</sup>Sugg, Arnold L., "Economic Aspects of Hurricanes," Monthly Weather Review, Vol. 95, No. 3, March 1967, pp. 143-146.

#### 4.1.6 Other Experiments

##### 4.1.6.1 Surveillance of the 200-Mile Limit

National ocean policy is moving toward the establishment of a 200-mile economic offshore zone either by treaty or by statute. It is expected that this will result in a U.S. marine resources management program at the federal level, treating the acquired "property" as a common public trust and attracting investment for commercial and industrial opportunity which is too speculative within the common property outlook of today.

Federally required functional activities within this 200-mile zone will consist of data collection, monitoring, management, research, implementation, regulation and enforcement, control and protection. These activities will be essential to the formulation of effective policy and its efficient and effective implementation, for both energy development and production, marine resources management and other operations that might evolve.

Within this economic zone foreign exploitation may be permitted under bilateral or other agreements but the general purpose of this offshore extension is to secure national exclusive rights within it. Clearly this implies many forms of surveillance of the extended economic zone, for which the synoptic observation and remote sensing capabilities of satellites could be uniquely cost effective, as a supplement to the current U.S. Coast Guard air and sea operations, in the three-mile territorial sea and the nine-mile Contiguous Fisheries Zone.

At this time the full range of satellite functions that will be most useful in the extended economic zone cannot be defined, yet data clearly need to be collected from all active satellites to provide inputs to

surveillance planning, which may eventually result in a satellite system specialized to the surveillance of the extended economic zone.

Thus, there is an opportunity, for example, to determine the effectiveness of SEASAT-A instrumentation in detecting and classifying surface shipping and its activity which, however, is more related to planning than to user economic verification experiments. If a commitment is made to monitor activities in the 200-mile zone, it is likely that cost savings could accrue through the use of satellites as opposed to surface vessels or aircraft. However, at the present time there does not appear to be a clear-cut economic experiment to perform in this area. Therefore, it is suggested that evaluation of SEASAT-A surveillance capabilities be undertaken by NASA for future planning in cooperation with NMFS and the USCG. The results of this experiment could be evaluated at a later date for their economic significance.

#### 4.1.6.2 Marine Mammal Management

Various marine mammals such as whales, the common seal, sea lions and porpoises are both significant to commerce and on the threshold of becoming endangered species. As a consequence there is considerable governmental and scientific interest in increasing familiarity with the habits of breeding, migration and distribution of the mammals in question so that they can be protected while still serving as a basis for commerce.

Schools of the mammals can be detected and tracked by being tagged with appropriate transmitters whose signals are collected via satellite receivers. Programs are in effect or are proposed to perform these activities and will establish "ground" truth with respect to certain species. The tagged species during migration and feeding, because of the number that co-exist, modulate the surface of the water and offer the possibility of

their detection and tracking through remotely sensed characteristic sea surface modulation signatures.

The U.S. tuna and skipjack fishing industry has the largest world fleet of specialized purse seiners (about 147) and is capital intensive. Currently, tuna fishing is confined to a small ocean area between Ecuador, Peru and the Galapagos Islands and the U.S. annual catch is continually decreasing, generally as a result of an overly successful tuna fishing technology. The tuna, it is known, are attracted to the surface in warm water in regions where water temperatures, upwellings and currents concentrate the micronekton on which they feed. Their exact seasonal movements within the general region of location are not known. During certain times of the year "spotter" porpoises carry with them substantial schools of tuna and these are used to locate the tuna. Frequently, during the catch, the porpoises themselves are destroyed. The porpoise are not an unequivocal indicator of tuna presence, however. Porpoise accompanied by birds are a more certain indicator. In the future, the search for tuna beyond the overfished eastern Pacific belt will probably be extended in the western reaches of the Pacific where studies of migration and forage indicate that tuna may be found. Tentatively, to some unknown degree, passive signatures of migration and feeding of schools of porpoises could be significant as aids to revitalizing the U.S. tuna fishing industry and to controlling the fishing of tuna. At the same time, porpoise preservation will be of increasing concern.

A marine mammal management experiment might provide benefits to scientific research and eventually also produce economic benefits to the tuna fishing industry or other commercial activities. The management process itself, at this time, cannot provide, however, the framework for a user economic verification experiment and further study is not recommended.

#### 4.1.6.3 Monitoring North American Goose Nesting Habitats

##### Introduction

Knowledge of the status of breeding populations of North American geese, their actual or probable annual production and migrating patterns, are all prerequisites for the setting of annual U.S. hunting regulations. The U.S. harvesting regulations are of great importance because a large portion of the North American goose harvesting occurs in the United States.

The annual production success of the Arctic nesting geese depends largely on the ice cover conditions of the nesting habitat areas during a two-week nesting period in May. If the nesting habitats are ice covered, nesting does not occur; therefore, no young are produced for that breeding year.

An experiment is proposed to utilize the SAR imagery system of the SEASAT-A to provide ice-mapping images of the Yukon-Kuskokwin Delta nesting habitat during the May 1978 nesting period. It is believed that such information will aid the management and harvesting of the North American goose populations. Economic verification would be carried out by measuring and evaluating the losses that would result from failure to accurately predict a reduced annual goose population, which would affect harvesting regulations for following years.

The experiment would provide SAR imagery of the Yukon-Kuskokwin Delta nesting habitat during the nesting period of mid-May 1978. The images will then be processed and interpretations and results compared with ground-truth observations of the same area.

##### Background

The North American Arctic breeding grounds provide most of the geese available to U.S., Canadian and Mexican sportspeople. Most North American

geese, with the exception of some Canadian geese (*Branta canadensis*) and white-fronted geese (*Anser albifrons*), utilize the Arctic for their nesting and brood nesting periods. Some four species of Arctic nesters include:\*

- Brant (*Branta bernicla*)
- Black Brant (*B. nigricans*)
- Emperor geese (*Phalacrocorax canadensis*)
- Snow geese (*C. rossii*).

See Figures 4.15 and 4.16 for the locations of breeding areas and migration corridors, and Table 4.6 for estimates of population by species.

Goose reproduction success is affected by many factors; however, the most significant single variable is the timeliness of the disappearance of the snow and ice coverings over the nesting habitats. The birds arrive in the Arctic approximately mid-May and within two weeks must locate suitable nesting areas. If these nesting areas are covered by ice during this two-week period, the birds will not nest, thus affecting the following year's population. The possibility of renesting in the same year seldom occurs.

Adverse weather conditions may be more extensive in the mid to high latitudes than in the southern nesting habitats. Goose reproductive success directly follows the patterns of adverse weather conditions over nesting areas during this two-week period in May. Several studies have been conducted in North America and U.S.S.R. providing more definitive data on the effects of late seasons or adverse weather conditions on the nesting success of various species.\*\*

---

\* "USFW Activities in Application of Satellite Imagery to Goose Management," H. Reeves, R. Munro, A. Marmelstein, From Workshop in Remote Sensing of Wildlife, November 18, 1975, Quebec.

\*\* "Monitoring Arctic Habitat and Goose Production by Satellite Imagery," H. Reeves, F. Cooch, R. Munro, Journal of Wildlife Management, July 1976.

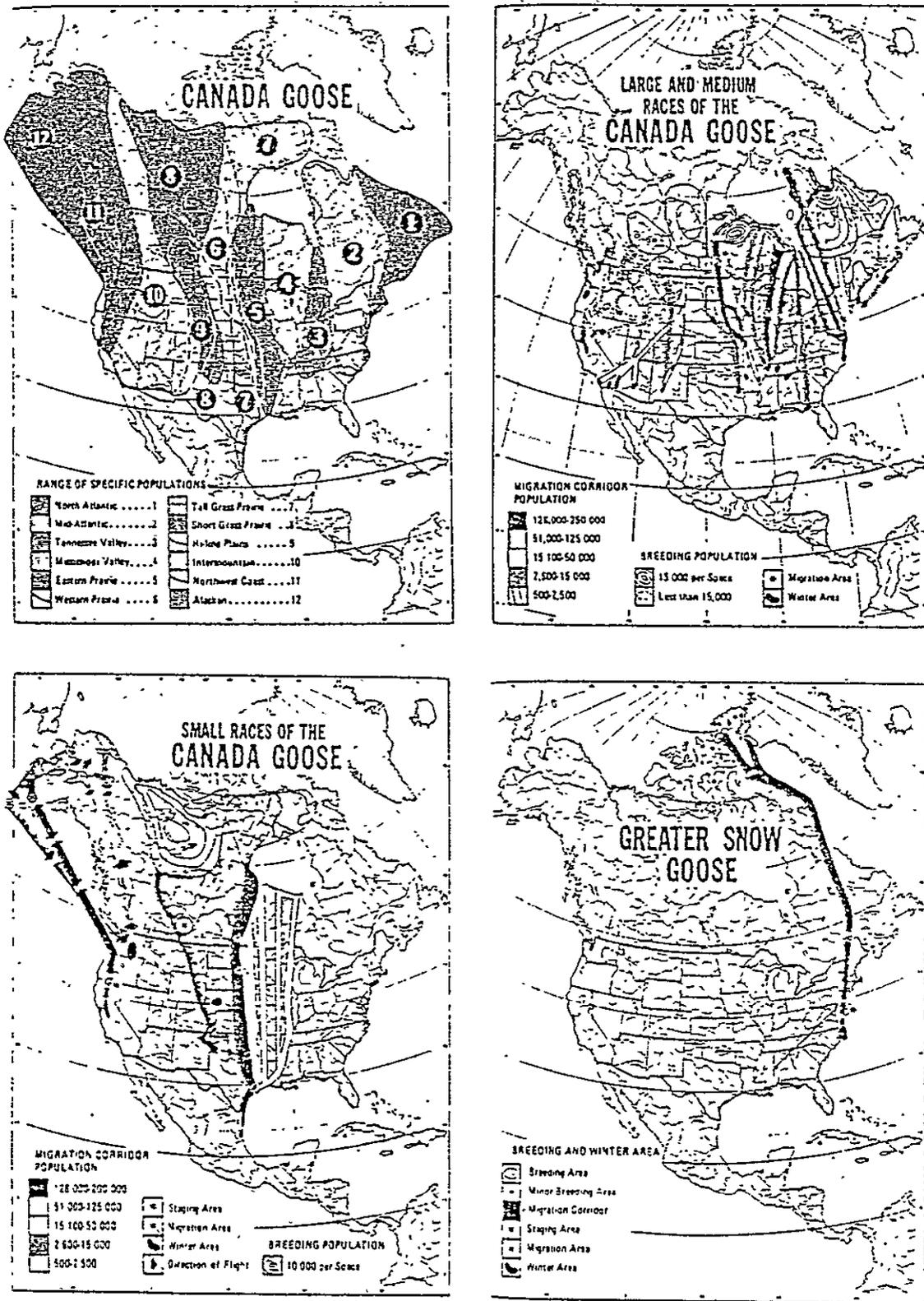


Figure 4.15 Breeding Areas and Migration Corridors (Source: Ducks, Geese & Swans of North America, Frank Bellrose.)

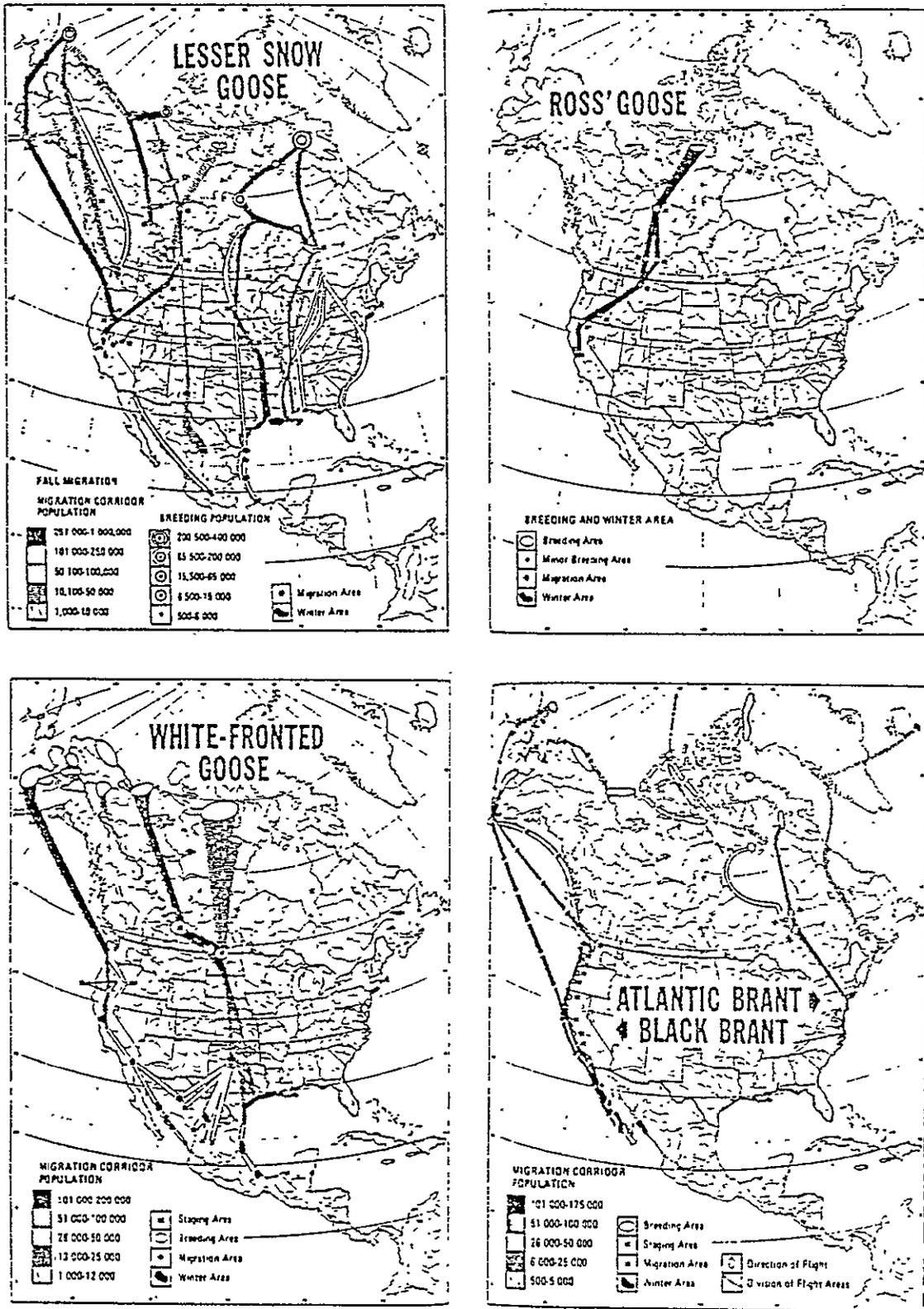


Figure 4.16 Breeding Areas and Migration Corridors  
 (Source: Ducks, Geese & Swans of North America, Frank Bellrose.)

Table 4.6 Goose Populations Based on Fall and Winter Surveys, 1955-1974 (in thousands)\*

Year	Species						
	Canada	Cackling	White-fronted	Snow	Ross'	Black Brant	Brant
1955	1,056	222	239	1,052	**	134	184
1956	1,144	175	225	1,370	**	**	164
1957	996	112	111	1,035	**	131	162
1958	1,021	194	159	1,083	**	126	211
1959	1,068	136	162	953	**	68	217
1960	981	156	195	1,212	**	137	238
1961	1,328	166	204	1,326	**	175	266
1962	1,169	191	226	1,167	28	170	125
1963	1,352	238	190	1,347	25	140	167
1964	1,416	109	221	1,270	32	190	183
1965	1,308	103	141	1,356	32	167	182
1966	1,367	66	126	1,051	30	160	165
1967	1,532	124	245	1,449	31	180	219
1968	1,507	64	107	1,183	39	154	214
1969	1,639	104	152	1,206	20	143	131
1970	1,828	97	280	1,276	22	142	107
1971	1,808	113	166	1,644	28	149	151
1972	1,963	102	178	1,845	31	125	73
1973	1,935	54	125	1,438	19	125	42
1974	2,056	86	147	1,744	27	130	88
Average 1955-73	1,390	133	182	1,277	28	145	168
Percent Change in 1974 from							
1973	6.3+	59.3+	17.6+	21.9+	42.1+	4.0+	109.5+
1955-74 average	47.9+	35.3-	19.2-	36.6+	3.6+	10.4-	47.6-
* Emperor goose population not included in winter survey.							
** Incomplete data.							
Source: Files, Office of Migratory Bird Management, Laurel, Maryland							

Arctic goose production may therefore range from very good to poor during any given year. Generally good production can be anticipated during years when the snow and ice coverings over the nesting habitats have disappeared before the nesting period begins.

The estimation of reproductive success is important in the establishment of hunting regulations. The inability to accurately detect the goose production for a year has led to overharvesting of geese during years of low production and short-term population declines. In the past, several years of closed hunting seasons were required to restore the goose populations to harvestable levels.

#### Management Objectives

Until recently the estimates of Arctic nesting successes have been basically guesses. The nesting habitats are too inhospitable and cover areas too large for effective ground surveys. The Fish and Wildlife Service does require monitorings of habitat conditions for predictions of probable annual goose production so that appropriate annual harvesting regulations can be effected.\*

#### Experiment Purpose

The purpose of the proposed experiment would be to present SEASAT-A information on ice and snow cover conditions obtained with the synthetic aperture radar (SAR) to the U.S. Fish and Wildlife Service. The instrument package and the SAR have great potential as data sources concerning ice conditions on the North American Arctic breeding grounds. Other methods of

---

\*"Monitoring Arctic Habitat & Goose Production by Satellite Imagery," H. Reeves, F. Cooch, R. Munro, Journal of Wildlife Management, Vol. 40, No. 3, July 1976.

imagery, VHRR and MSS, have been used for this purpose; however, these sensors cannot image through cloud cover. The image quality of these two imagery techniques is affected by cloud coverings and can provide resolutions of between 91.4 to 0.8 kilometers. SAR, however, is not susceptible to cloud covering interference and can therefore provide more definitive information about the nesting habitat ice conditions on any given day. Further, the ground resolution for SAR is about 25 meters, enabling biologists to make reasonable annual forecasts of goose production.

The benefits of more accurate ice cover information could result in more accurate predictions of the following harvesting season's goose population. More appropriate regulations could then be enacted to manage and protect the population of Arctic North American geese for the long-term benefit of hunting and sportspeople.

#### Experiment Description

The North American Arctic goose experiment would consist of a series of SAR images of the nesting habitat at Clarence Rhode National Wildlife Refuge at the Yukon-Kuskokwin Delta in Alaska during the mid-May nesting period.

Field personnel will be available at the site to provide ground truth for the SAR processed data. The combined SAR imagery and ground data will then be analyzed by the Migratory Bird Research Lab at Laurel, Maryland. This analysis will then be used by the U.S. Fish & Wildlife Service to establish the 1979 season hunting regulations for North American geese, or used as a hindsight prediction verification of the 1978 migratory populations.

The SEASAT-A orbit will be nearly polar, thus providing SAR imagery of the areas of interest during all weather conditions, except the most severe rain storms. The ground resolution would be about 25 meters.

### Participants and Data Flow

Selected images from the SEASAT-A SAR would be processed and received at the Patuxent Wildlife Research Center. The images will then be interpreted to identify snow and ice cover over nesting habitat areas.

A considerable wealth of information currently available on goose distribution and breeding seasons and habitats will facilitate the interpretation of the satellite imagery.

### Economic Benefits

Economic benefits can be achieved as a result of the improved knowledge of the North American goose nesting habitat. It is anticipated that the improved knowledge of annual ice cover over nesting habitats can lead to improved harvesting and management decisions by the U.S. Fish and Wildlife Service.

This experiment is not designed to measure the benefits which may result from improved harvesting and regulatory decisions. That task would require establishing a data base over several years, including many more of the nesting habitat sites. It is anticipated that a general economic impact evaluation can be conducted to estimate the impact that improved hunting regulations and wildlife management policies could have.

It is estimated that in 1970 over \$710 million were spent by migratory bird hunters. Water fowl hunters alone spent approximately \$237 million in the same year. Expenditures by hunters go toward a variety of goods and services, often significantly affecting local hunting community businesses such as hotels, restaurants and sports shops, as shown in Table 4.7.\*

---

\* Environmental Statement for the Issuance of Annual Regulations Permitting the Sport Hunting of Migrating Birds, Fish and Wildlife Service, 1975.

Table 4.7 Expenditures of Waterflow Hunters,  
United States, 1970 (in thousands)

Expenditure Item	Number of Spenders	Total Spent
United States total	2,053	\$237,931
Food and lodging:		
Food	821	25,348
Lodging	103	1,649
Transportation:		
Automobile	1,609	27,074
Bus, rail, air, water	12	1,372
Auxiliary equipment:		
Special hunting clothing	238	3,744
Tents	14	330
Boats	15	6,420
Motors	11	5,246
Other equipment	367	13,361
Hunting equipment:		
Shotguns	162	26,089
Shells	1,006	22,351
Decoys	182	9,012
Other hunting equipment	502	6,399
Permits:	778	4,753
Privilege fees and other:		
Annual lease and privilege	44	4,287
Daily entrance fees for commercial preserves	111	4,095
Daily entrance fees for hunting other private	85	9,935
Special government fees	8	101
Guide fees and other expenses:		
Pack trip fees	12	2,618
Alcoholic beverages	282	9,383
Rental Equipment	50	514
Other trip expense	383	14,248
Magazines	137	1,207
General club dues	54	787
Special club dues	44	3,555
Boat launching fees	12	565
Dogs	147	32,252
Other	66	1,337

Source: Adapted from U.S.D.I., 1972.

Hunting stamp revenues and other expenditures by the hunting population have provided the financial support for the study and preservation of wildlife habitats across the country, as shown in Table 4.8. Revenues from hunting stamps alone have totaled approximately \$153 million from 1934 to 1973.

The improved knowledge of migratory bird populations could help to provide estimates of the harvestable populations of birds each year. As with other wildlife species, it is possible that sustained overharvesting could result in diminution of the species. Hunting quotas during the following hunting season may be seriously limited, or hunting would be prohibited completely for one to two years to permit the bird population to increase to a harvestable size. The ability to accurately predict annual bird populations would help to ensure an annual hunting season for migratory birds, thus maintaining a steady multimillion dollar hunting and sports industry.

Table 4.8 Duck Stamp Sales, 1934-1973*					
Years	Number Years	Total Stamps Sold	Average Per Year	Cost	Total
1934-48	15	18,917,556	1,261,170	\$1.00	\$ 18,917,556
1949-58	10	22,009,338	2,200,934	2.00	44,018,676
1959-71	13	22,933,933	1,764,148	3.00	68,801,799
1972-73	2	4,238,233	2,073,287	5.00	21,191,165
Total	40	68,099,060	1,702,476		152,929,196

Source: Files, Office of Migratory Bird Management, Laurel, Md.

\*The Migratory Bird Hunting Stamp Act of 1934 requires that anyone 16 years or older must possess a valid duck stamp to hunt water fowl.

#### 4.2 International Cooperative Experiments

Insofar as SEASAT will provide a capability for both active and passive remote sensing on a worldwide basis, a number of foreign nations have expressed interest in the program. Notable among these is Canada. The climate and remote sensing requirements of Canada favor the use of active microwave sensors. The areas of Canada which are of greatest interest in the SEASAT program include the Gulf of St. Lawrence, the Labrador Sea, the Northwest Passage and the Beaufort Sea. These areas are cloud covered or fogbound much of the year and the sea state and ice conditions are of considerable interest. The application of SEASAT in these areas is of interest to the Canadians because ice is easy to detect or interpret in open water areas and because the active, microwave sensors should obtain useful imagery despite cloud cover. A variety of Arctic operations could benefit from SEASAT activities. These involve mainly transportation and gas and oil exploration.

Although Canada has expressed considerable interest in the SEASAT program and has participated in many SEASAT meetings, there is as yet no formal commitment by the Canadian government to participate in the SEASAT program. Thus, the experiments which are proposed below should be viewed as areas of potential interest by the Canadian government. Implicit in this interest are assumptions regarding SEASAT data reception and processing. It is assumed that, for the experiments taking place in eastern Canada, SEASAT data would be read out at the proposed Canadian ground station, Shoe Cove, Newfoundland. These experiments would require the installation by Canada of an SAR processor. The experiments to be conducted in western Canada would make use of the Fairbanks, Alaska receiving station and U.S. data processing

facilities. Thus, the experiments that might be conducted in eastern Canada would require a greater economic commitment by Canada than those to be conducted in western Canada. However, the experiments conducted in western Canada would require a greater degree of cooperation between the United States and Canada. In light of the SAR processing limitations, this latter consideration could be quite significant.

The proposed international cooperative experiments are detailed below.

#### 4.2.1 Applications to the Offshore Oil and Gas Industries

At the present time, Canada is actively exploring for gas and oil deposits in the Beaufort Sea, the Labrador Sea and the Queen Elizabeth Islands areas. These activities involve mainly exploratory drilling through about the year 1982. After that it is expected that developmental drilling would begin.

Three major companies are involved. Exploration in the Beaufort Sea is being conducted by Canmar (Canadian Marine Research), a wholly owned subsidiary of Dome Petroleum. Pan Arctic is drilling at Cameron Island near Melville Island and has found some gas and oil in that area. In the east, Petrocan (Petroleum Canada) has been granted \$1.5 billion initial funding for drilling on the Nova Scotia shelf and now has six wells in the Sable Island area.

In all Canadian offshore oil and gas operations sea state, ice of all sorts and wind are important. The motion of icebergs and sea ice can interfere with and damage drilling operations, and heavy seas can prevent drilling operations. In areas further north where the sea is continuously ice covered seismic work must be done on the ice. For these operations, it is important to know the ice conditions and surface roughness as an aid to guiding the movement of men and vehicles.

#### 4.2.1.1 Oil Exploration in the Beaufort Sea

Oil and gas exploration in the Beaufort Sea is presently being conducted in areas where the water depth is 60 to 120 feet. These areas are particularly prone to the actions of sea ice which can move in on extremely short notice disrupting drilling operations. To alleviate potential environmental hazards, Canmar has proposed and uses an ice warning system. In this system two supply ships, equipped for ice breaking and reconnaissance, are assigned to each drill ship. Each supply ship is equipped with two aircraft, one fixed wing and one helicopter, which patrol an area twelve miles out from the drill ship in the direction from which ice is likely to come. The aircraft may be used to patrol an area as far as fifty miles from the drill ship. However, their operations are affected by the weather which is very often foggy and windy. During the average August in the Beaufort Sea region, there are fifteen days with fog. To aid in environmental protection efforts, the Atmospheric Environment Service of Canada's Department of Environment is spending about \$250,000 in 1976 on the development of a real-time environment prediction system, but larger expenditures have been proposed and are necessary to develop the operational system fully. The system includes satellite data and imagery. In addition, the operators are presently using both LANDSAT and NOAA data when available.

The objectives of the Beaufort Sea experiment would be to determine the ability of SEASAT-A to monitor ice and winds in the Beaufort Sea for the purpose of improving environmental safety in drilling operations and increasing the efficiency of oil and gas exploration. It is expected that this experiment would have the support of Canmar through the Atmospheric Environment Service of the Department of Environment and that it would, in

addition, involve the Floating Ice Division of the Ocean and Aquatic Sciences Branch of the Department of Environment.

Experiments involving oil and gas exploration in general are also discussed in Section 4.1.1.

#### Beaufort Sea Test Area

The Beaufort Sea Test Area involves the Arctic Petroleum Operators Association (APOA) which consists of 36 oil and gas companies. The test area would cover the offshore area out to latitude 72° North between longitudes 126° to 140° West in the southern Beaufort Sea as shown in Figure 4.17. The geographical landmarks would be Cape Bathurst at the mouth of the Amundsen Gulf and the Alaskan-Yukon boundary as the western extremity. This area encompasses the continental shelf with water depths increasing to 6000 feet at the northern limits.

#### Summary of Physical Environment

1. The ice regime can be divided into three zones:
  - a. The landfast ice which extends out to the 60 foot water depth
  - b. The shear zone which extends out to between 60 to 100 miles from shore
  - c. The polar pack.
2. Breakup of the fast ice occurs every summer producing ice-free conditions in coastal waters. This ice-free zone in coastal waters is very variable in extent from year to year. In good years, the edge of the polar pack may recede 300 miles while in bad ice years a clearance of 20 miles is the maximum.
3. The differences in fetch from year to year affect significant wave heights during the summer months.
4. The area seems to be sheltered from the effects of the Beaufort Gyre. Dynamics of ice movement are complex and are probably influenced by local winds and currents.

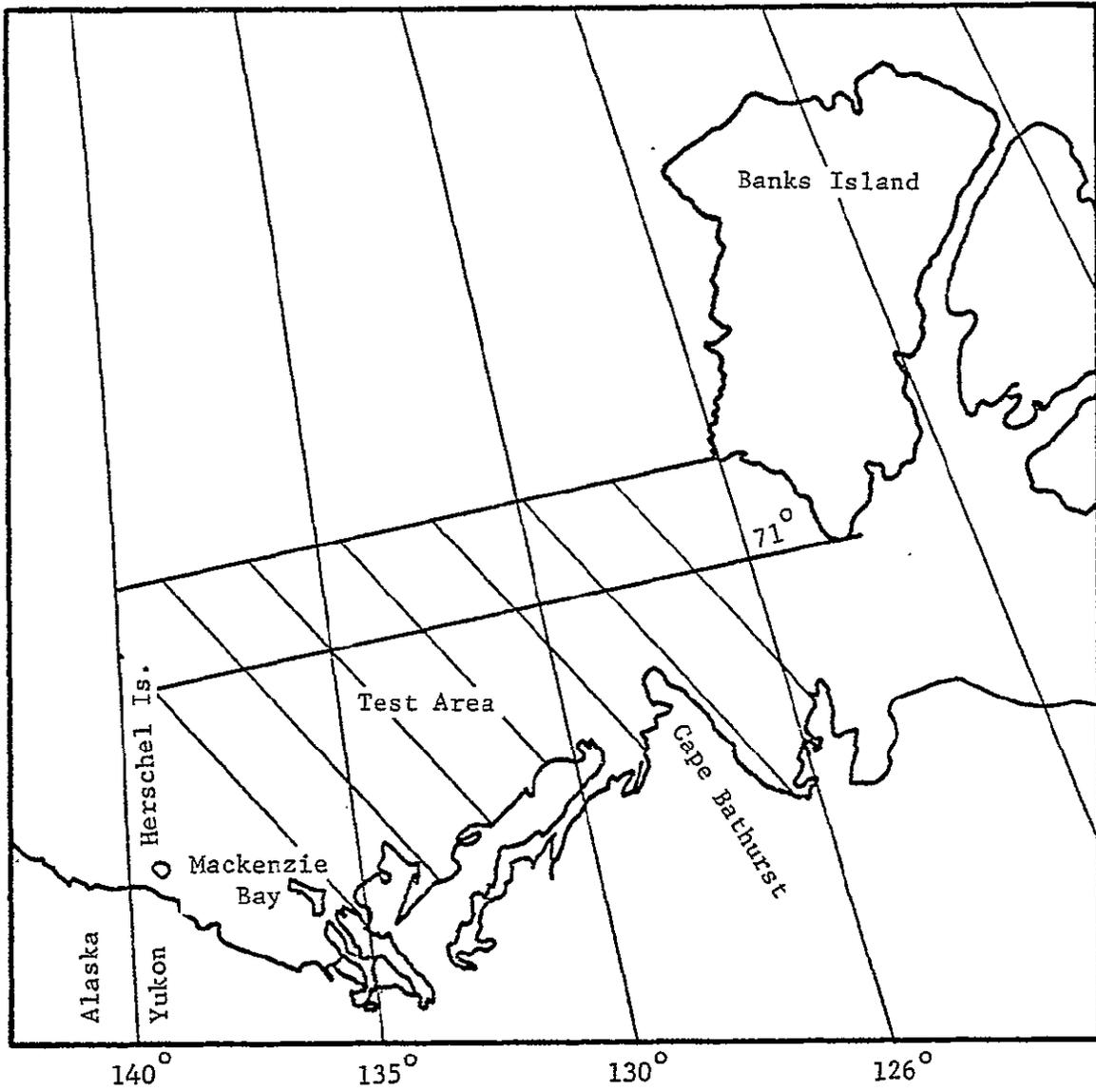


Figure 4.17 Proposed Offshore Test Area For SEASAT-A Experiment

5. The discharge of fresh water from the Mackenzie River is an important factor in affecting ice growth. Ice growth commences first in coastal waters and progresses seaward in a series of steps. The rate of progression and number of steps depend on yearly meteorological conditions.

#### Economic Incentive

Petroleum and natural gas exploration permits covering approximately 42 million acres of the southern Beaufort Sea have been issued. In view of the large acreage and the high per well costs in these areas, large expenditures will be involved.

Ice reconnaissance in the past has been devoted primarily to the yearly resupply program to Arctic communities. The increasing industry presence in the Beaufort Sea imposes increased and new demands on ice reconnaissance. Apart from the increase in shipping for summer supply operations, exploration and production activities are conducted on a year-round basis.

Under consideration for the Arctic region is the extension of the shipping season with suitable ice strengthened vessels for the removal of oil and minerals, the increased use of drillships and the building of offshore structures. Exploration from artificial islands is already underway in the Mackenzie Delta region of the Beaufort Sea. In the Arctic Islands, wells have been drilled from rigs situated on artificially thickened floes. Drillships are operating in the southern Beaufort Sea in the summer of 1976.

Presently, artificial island building costs are around \$245,000 per day. It is estimated that wells drilled by the drillships in the deeper water will cost around \$40 million.

The shortness of the summer open water season in the Arctic makes the most efficient use of equipment essential. In drillship operation and in the deployment of equipment for island building, accurate prediction of pack ice

movement is essential if unnecessary moves from location are to be avoided. Apart from the cost involved due to unnecessary moves in drillship operation, pack ice movement could delay the completion of a well until another year.

#### Objective

The objective is to evaluate SEASAT-A data as an aid to improving oil and gas exploration operations in the ice infested waters of the southern Beaufort Sea. The time frame of this study would be to encompass the summer and the winter, from the commencement of new ice formation in the fall to the completion of breakup in the spring.

Results of this study would help to bring improvements in the following areas:

1. Better meteorological forecasts. Meteorological forecasts are extremely unreliable for the area at this time. Meteorological data are presently only obtained from Dew Line stations along the coast. No permanent offshore stations exist.
2. While the Canadian Department of Environment has implemented a Beaufort Sea meteorological program aimed at improving forecasts for the summer months, more offshore data are required. Improved wave forecasting depends partly on better weather forecasts, but distance from shore to edge of polar pack creates significant variations in the wind fetch from year to year.
3. More data on the yearly extremes would help predictive models. This includes monitoring the dynamics of summer ice invasion into coastal waters that could cause a potential disruption of drilling operations.
4. Forecasting of date of new ice formation during the fall enables maximum utilization of season and important shipping seasons to be extended.
5. Monitoring of ice dynamics during freeze-up includes the growth and progression of the fast ice and the southerly migration of the polar pack. This is important in assessing the pile-up that may be generated around fixed platforms. In the fast ice zone, prediction of the degree of pressure ridges is a possibility. This is important in the study of over-the-ice transportation systems. Identification of ice type is also important.

6. Ice dynamics during the winter in the shear zone is important in estimating how far oil may be transported due to a potential well blowout.
7. Monitoring of the breakup pattern of the ice in the spring is important in helping to predict summer conditions.

#### Verification Procedures

Ground truth information would be gathered within the framework of industry operations at the time of the experiment. During the summer season three drillships, which would serve as platforms for meteorological observations, should be operational. Further meteorological observations would be obtained from artificial island sites and remote recording stations.

Wave rider buoys would be deployed. Reconnaissance flights to monitor ice conditions would be undertaken around the drillships and artificial island sites. Ships radar would be used to monitor the dynamics of floes in the vicinity of drillships.

During the winter, LANDSAT imagery, aerial photographic flights and visual reconnaissance flights would be undertaken to monitor ice conditions in the near-shore area. Historical data gathering on conditions in the near-shore area has been undertaken for the past five years and could provide a base for comparison.

It is hoped to involve the Canada Centre for Remote Sensing and possibly other Canadian government agencies in the program to assist in surface truth.

All SEASAT instruments are applicable to this test area. Samples of the coverage of the various instruments over the test area are shown in Figures 4.18 through 4.21.

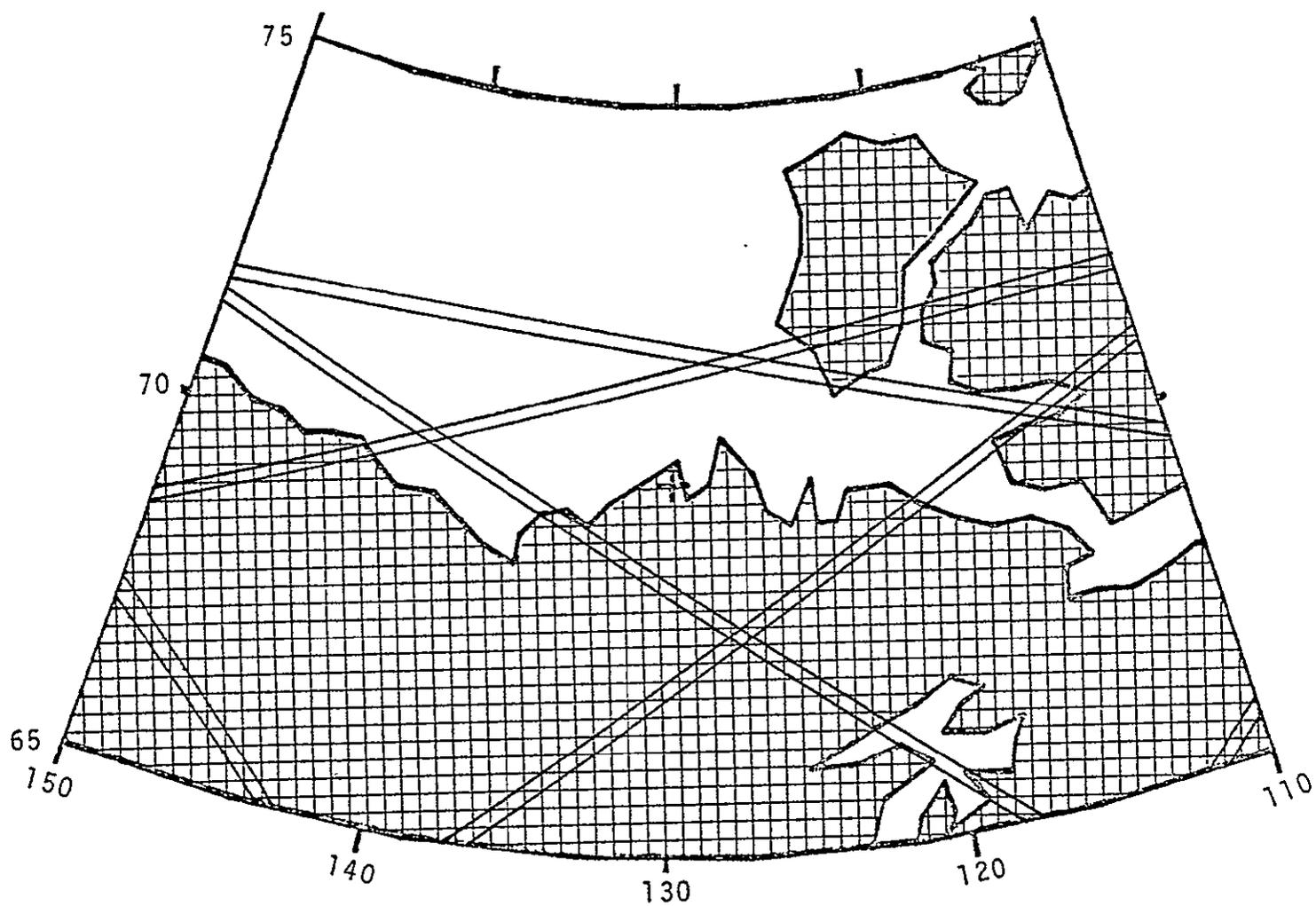


Figure 4.18 One-Day Altimeter Coverage Over the Beaufort Sea Test Area

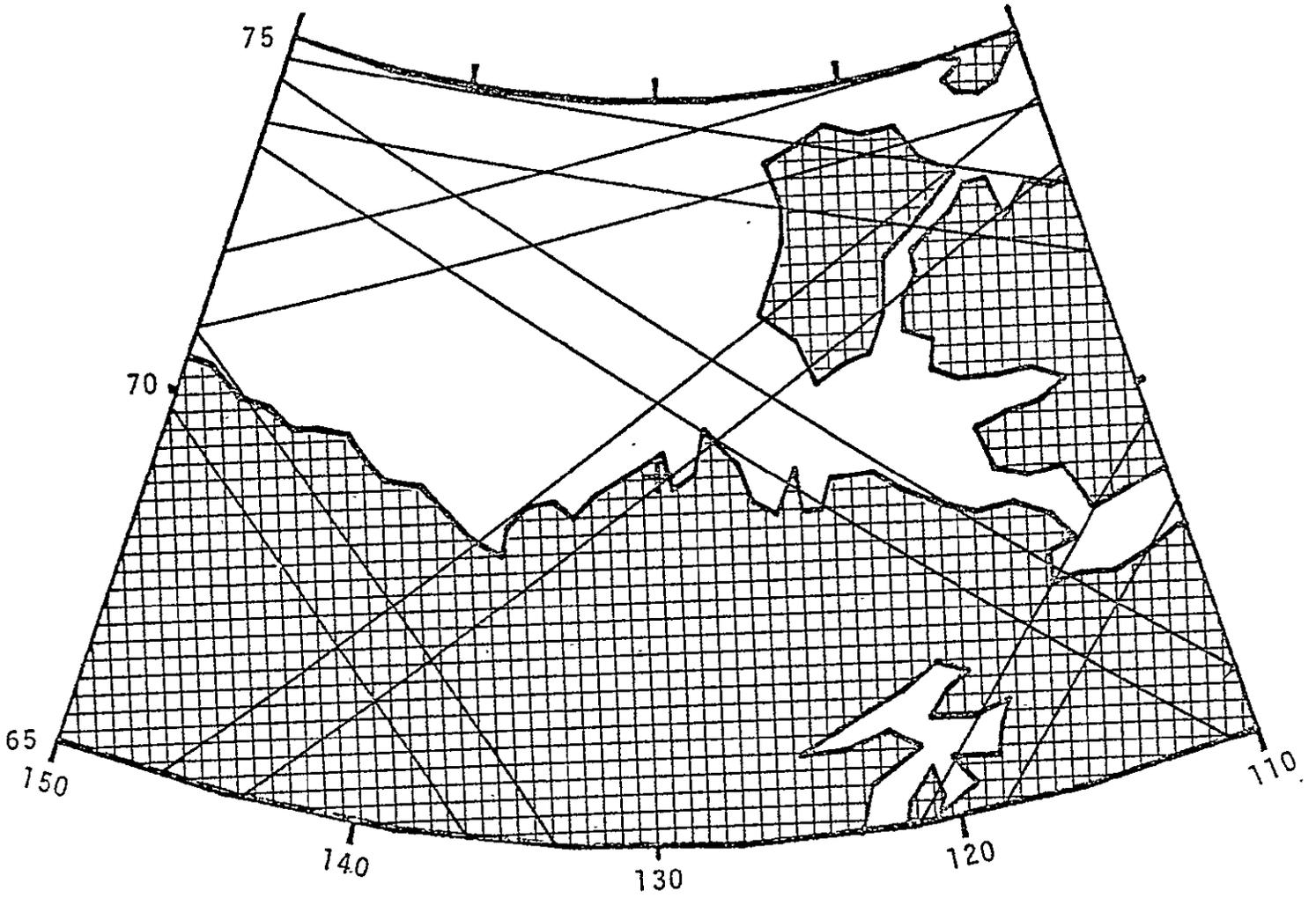


Figure 4.19 One-Day SAR Coverage Over the Beaufort Sea Test Area

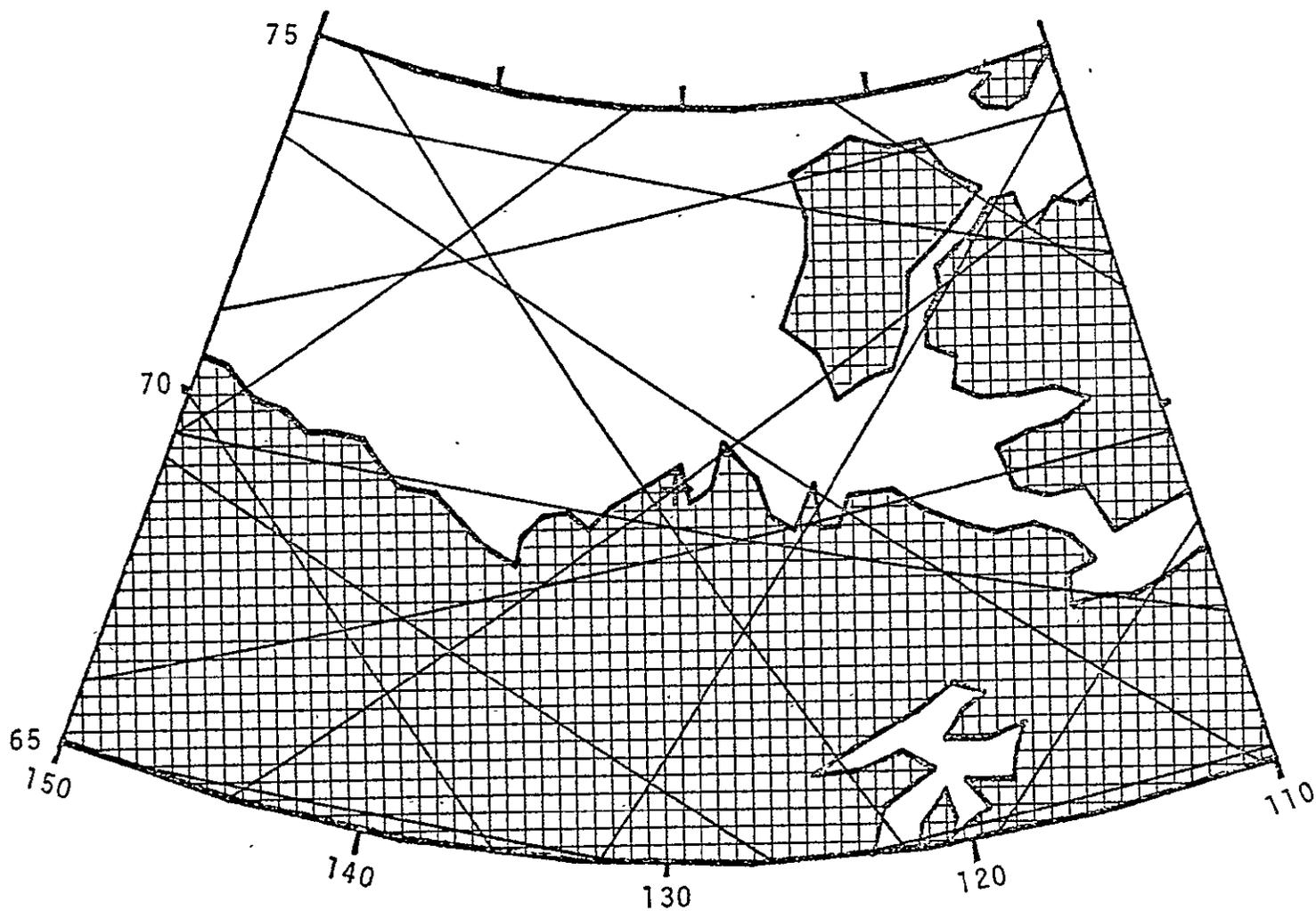


Figure 4.20 One-Day Scatterometer Coverage Over the Beaufort Sea Test Area

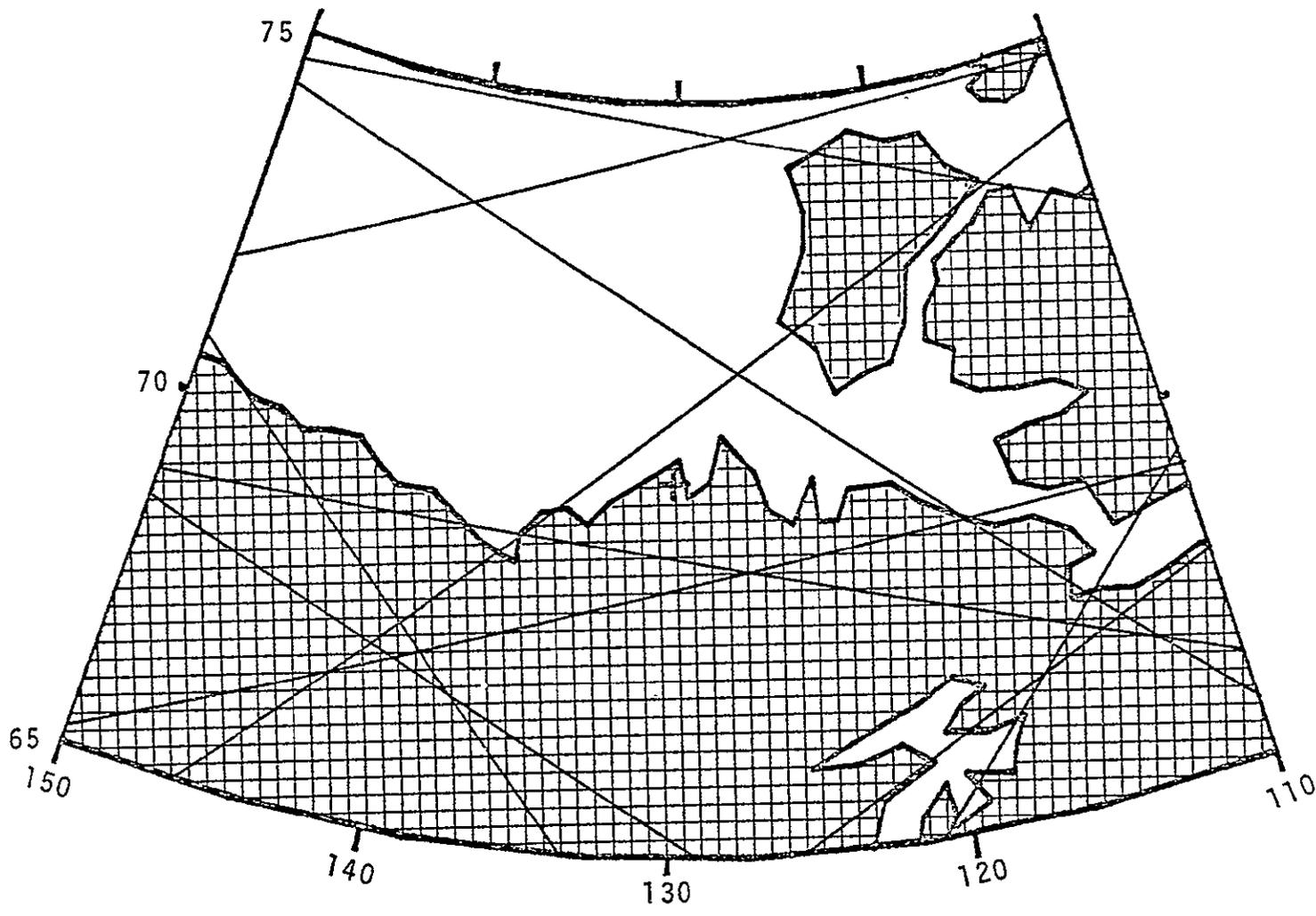


Figure 4.21 One-Day SMMR Coverage Over the Beaufort Sea Test Area

#### 4.2.1.2 Oil Exploration in the Labrador Sea

Private industry has been active in oil exploration in the Labrador Sea and the Nova Scotia Shelf. Petrocan has indicated promising gas showings off the Labrador Coast, with dynamically positioned drillships continuing to operate. Scotian Shelf drilling has not yet been as promising in terms of actual gas showings. This experiment would involve both the Atmospheric Environment Service and the Aquatic Sciences Programme of Canada's Department of Environment. Through these agencies, the Canadian government is presently examining the feasibility of developing a meso-scale forecast model for the east coast region. The key problems in the Labrador Sea include ice fields, icebergs and sea state. Sea state becomes increasingly important after early October when extremely heavy seas become frequent. Much of the drilling in this area is done in the Labrador current which carries icebergs southward from the Davis Strait. In the event that an iceberg poses a potential hazard to a drill ship, there are two alternatives. The first is to tow the iceberg out of the area in which it could interfere with the drilling operation. The second is to disconnect the drill ship and move it out of the way of the iceberg. Environmental safety requires a one- to four-hour warning upon hazardous ice and sea state conditions, but up to two days warning can be economically beneficial. There are three critical periods in the drilling operation that need ice-free and calm sea conditions. These include the initial drilling phase, the casing phase to protect the well, and the testing phase. The operators would like to extend the drilling season into October and perhaps November, and during these periods, especially, improved information would be beneficial.

The objective of the Labrador Sea experiment would be to determine the capability of a SEASAT-A to measure sea state, winds and ice in the Labrador Sea to provide improved decision-making information for oil exploration efforts in this region.

Experiments involving oil and gas exploration in general are also discussed in Section 4.1.1.

#### Labrador Sea Test Area

The Labrador Sea Test area involves the Eastcoast Petroleum Operators Association (EPOA) which consists of 20 oil and gas companies. The test area is shown in Figure 4.22. It is bounded by 53° and 63° North and extends up to 150 miles offshore.

#### Summary of Physical Environment

Sea Ice	- Freezeup in about December Breakup in about July Pack ice continuously moving Presence of multiyear ice (pressure ridges) Mainly first-year ice Numerous first-year pressure ridges
Icebergs	- Presence of icebergs all year round Maximum frequency - February to August Minimum frequency - November and December Average size - about one million tons
Sea State	- The sea conditions are generally good from breakup until September 15 and then they progressively deteriorate to become very bad in November and December
Currents	- Main current is the Labrador current parallel to the coast going south.

At this time, the environmental data recorded in this area are not sufficient and probably will not be sufficient within the next few years.

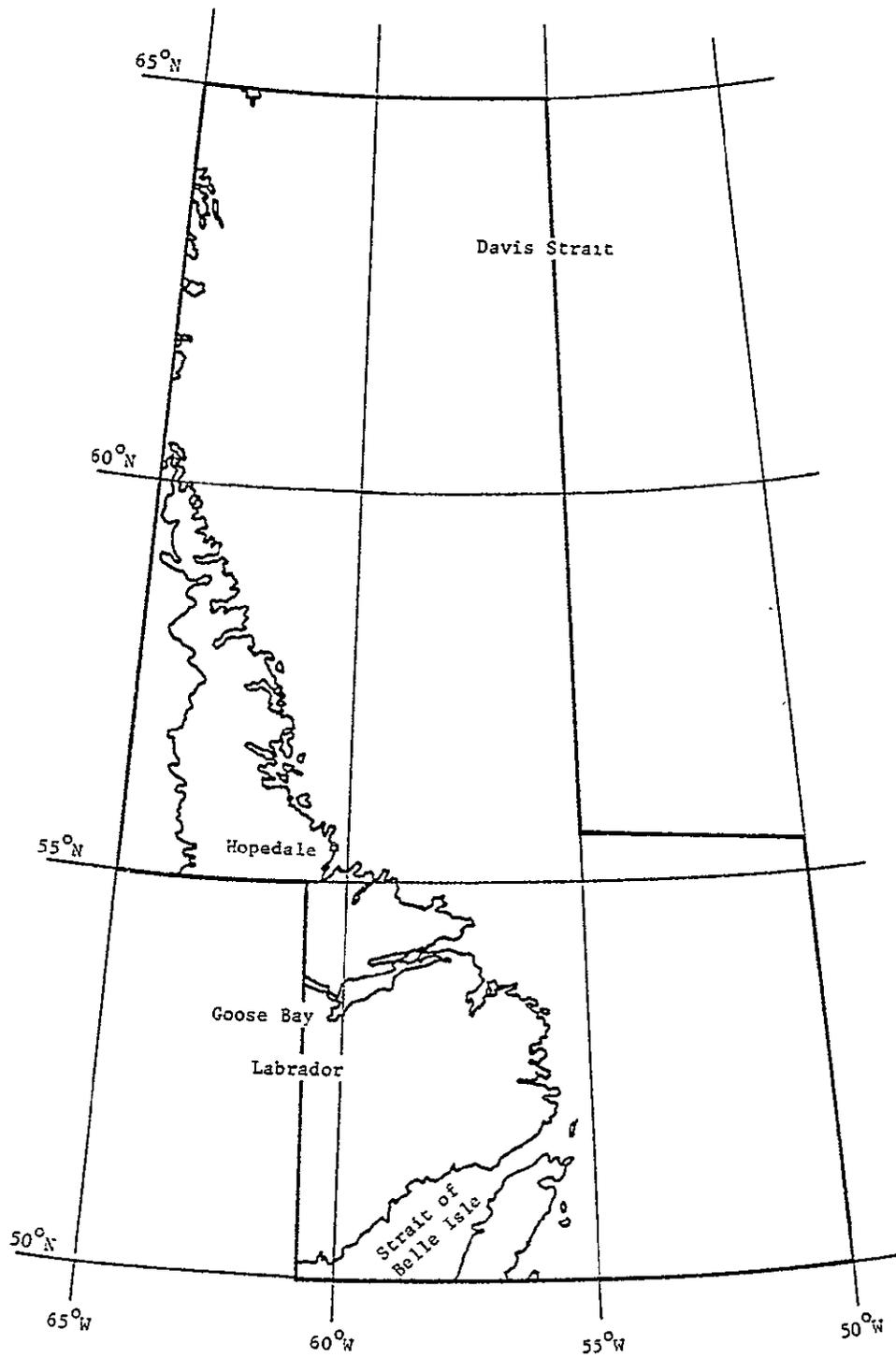


Figure 4.22 Labrador Sea Test Area

### Economic Incentive

Petroleum and natural gas exploration permits already cover most of the offshore waters on the Canadian east coast. In 1976, four rigs will drill in the iceberg alley and it can be anticipated that the number will increase in the next years because the area seems to have a good petroleum potential.

The shortness of the summer open water season makes the most efficient use of equipment essential:

- Start operations as early as possible (breakup)
- End operations as late as possible (freeze-up)
- Avoid down time due to weather or icebergs.

At this time, only exploration is being performed and it costs between \$100,000 and \$150,000 per day to operate a drilling rig in this area. However, in the future it is highly probable, should oil reservoirs be discovered, that oil production will start during the open water season, in which case each day lost will result in considerable financial loss.

### Potential of SEASAT

- To improve wind and wave forecasting
- To improve the forecast of freeze-up and breakup dates
- To give iceberg positions over large areas
- To provide historical data for wind, waves, icebergs, freeze-up and breakup dates
- To provide near real-time information for wind, waves, icebergs and sea ice.

### Verification Procedures

Ground truth information will be gathered within the framework of industry operations at the time of the experiment.

- In the summertime the drillships will serve as platforms for meteorological information. The following information can be recorded:
  1. Waves--height, period, direction
  2. Wind--speed, direction
  3. Currents--speed and direction at various depths
  4. Icebergs--size, position and route of all icebergs located within about 12 miles of the rig.
- In the wintertime it is probable that a few ice surveys will be conducted, in 1978, and could serve as ground truth for:
  1. Sea ice--type, leads, roughness, pressure ridges
  2. Icebergs (in pack ice).

The SEASAT instruments applicable to this test area are: SAR, SMMR, altimeter, scatterometer and VIR. The coverage of the various instruments over the Labrador Sea test area are shown in Figures 4.23 through 4.27.

#### 4.2.1.3 On-Ice Seismic Work

In the more northern areas of Canada, where there is no open water, the smoothness of the ice surface is an important parameter for the movement of vehicles and men. In the areas that are continuously icebound, seismic work is done from on top of the ice. Tracked vehicles are used to transport men across the ice to areas where they perform seismic exploration. This activity involves drilling holes through the ice and detonating explosives beneath the water to gather seismic data. In addition, however, there is the movement of heavy equipment for laying pipeline collector systems through ice.

The objective of this experiment would be to determine the ability of SEASAT-A to monitor ice topography for the purpose of improving on-ice operations, including on-ice seismic surveys, laying pipeline collector systems through ice and general on-ice transportation.

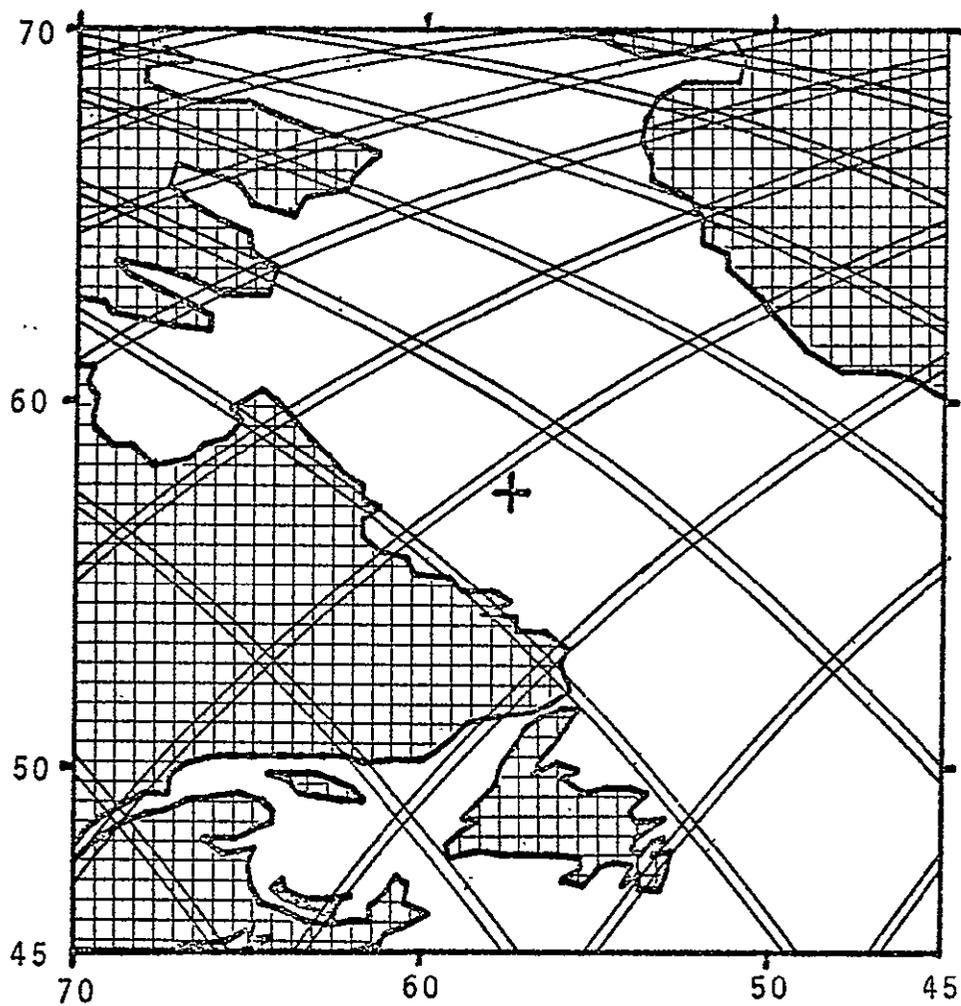


Figure 4.23 Altimeter 3-Day Coverage Over the Labrador Sea Test Area

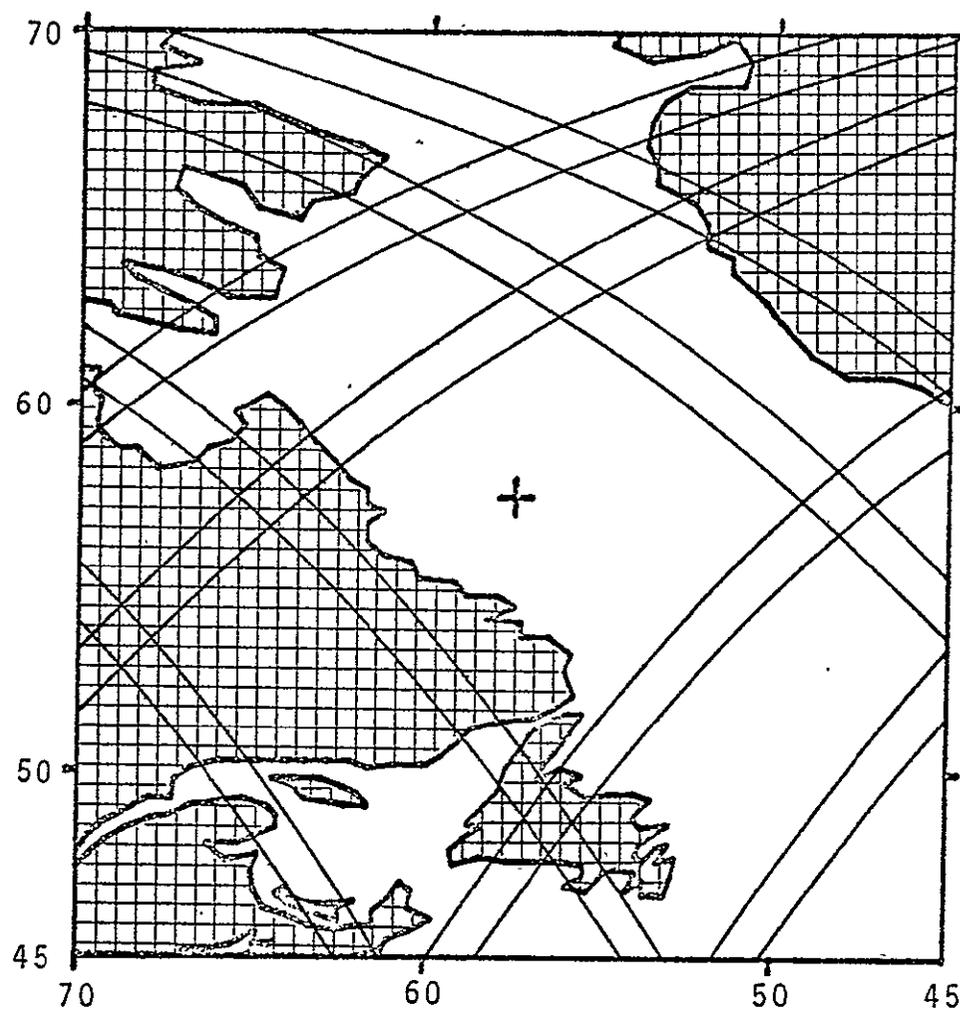


Figure 4.24 SAR 2-Day Coverage Over the Labrador Sea Test Area

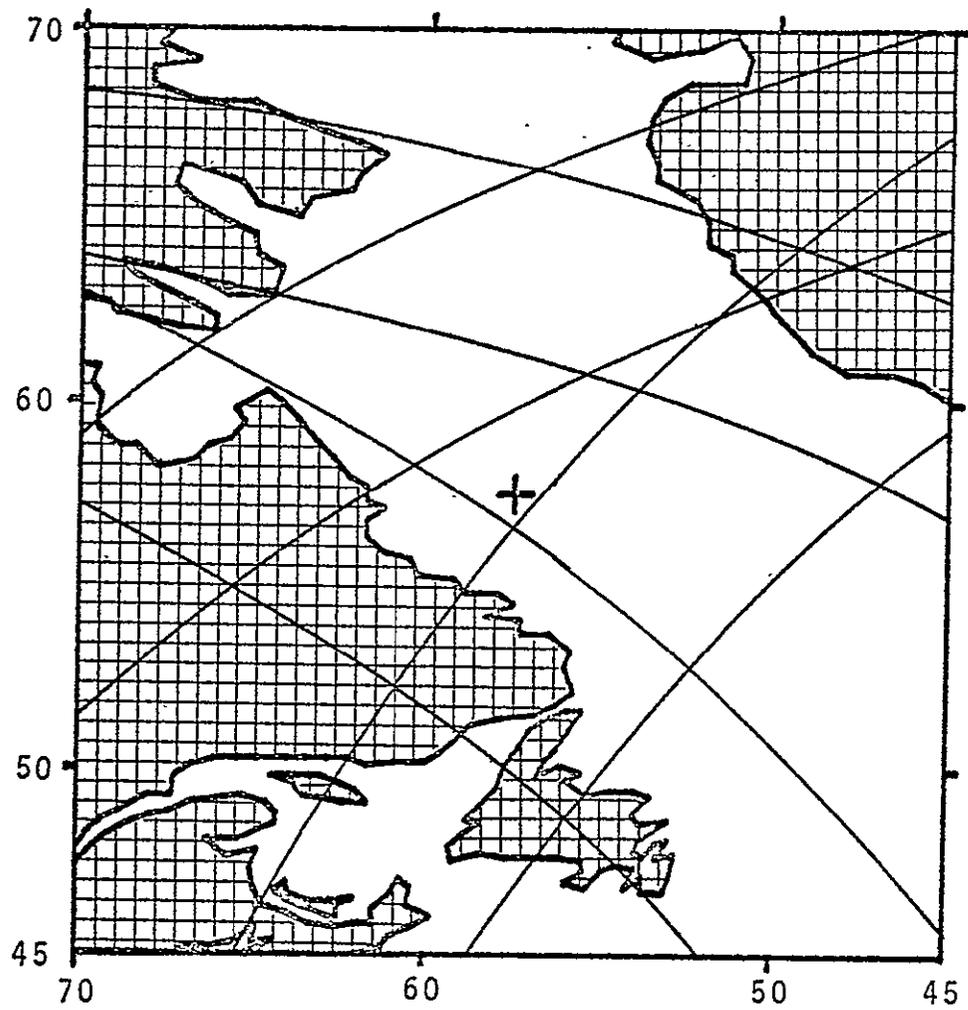


Figure 4.25 Scatterometer One-Day Coverage  
Over the Labrador Sea Test Area

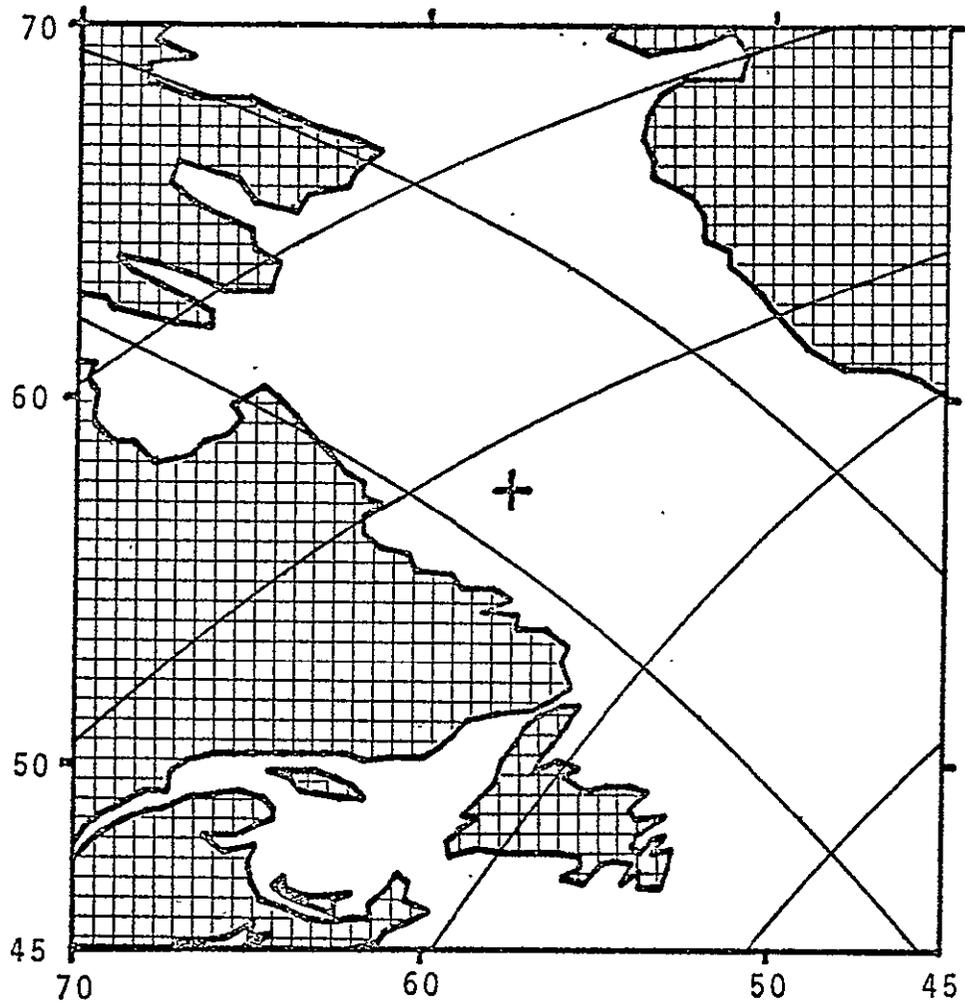


Figure 4.26 SMMR One-Day Coverage Over the Labrador Sea Test Area

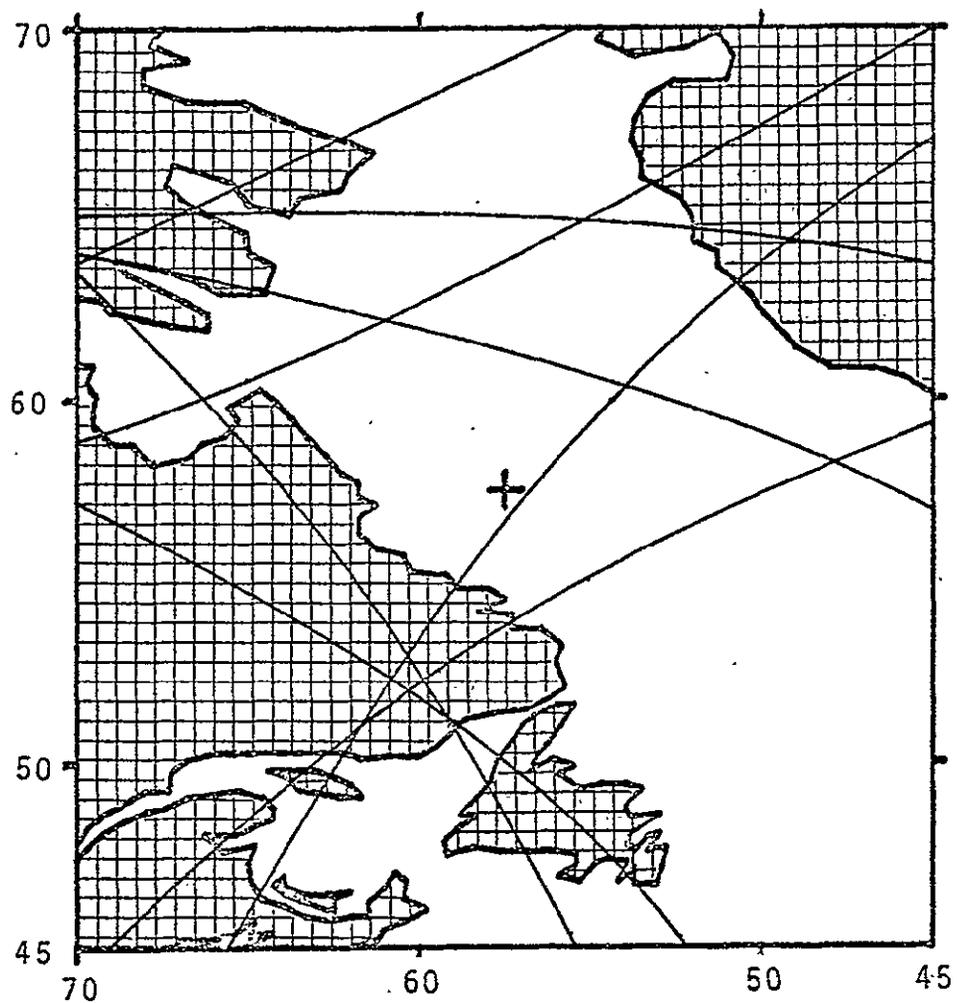


Figure 4.27 V/IR One-Day Coverage Over the Labrador Sea Test Area

#### 4.2.2 Applications to the Marine Transportation Industry

##### 4.2.2.1 Polar Gas Transportation Routing

Drilling operations in the Arctic Islands of Canada have resulted in the discovery of significant gas deposits. Continued exploration in these areas is desirable and commercialization will probably take place in the period after 1985. However, to derive capital for continued exploration activities it is believed to be desirable at the present time to recover some of the gas deposits at an earlier date. This would be accomplished by transporting gas, possibly from the wellhead to the south shore of Devon Island, for example, by pipeline and then from there by LNG tanker through Lancaster Sound, the Davis Strait and the Labrador Sea to markets on the east coast (such as Montreal, Boston, Baltimore or New York City).

At the present time there are about 200 ship operations per year in the area of interest, mainly devoted to resupply operations. To aid in the control of these ships, the Canadian government is installing a vessel traffic management station at Frobisher Bay. This station would maintain communications with all ships in the Queen Elizabeth Islands area.

The objective of this experiment would be to determine the ability of SEASAT-A to improve the economic efficiency of transportation in the areas of this experiment. Efficiency improvements would consist of reducing both lost time en route and at ports through an improved knowledge of ice conditions. SEASAT-A would be used in the identification and tracking of icebergs, ice islands and ice flows.

##### 4.2.2.2 A Ship Routing Experiment in the Belle Isle Straits

Ship traffic entering or departing the St. Lawrence River can choose to pass through either the Belle Isle Strait or Cabot Strait. For European

traffic, choice of the Belle Isle Strait results in transit time savings of about 24 hours as shown in Figure 4.28. Unfortunately, the ice-free season at Belle Isle Strait is a very brief one, usually lasting from August 1 through mid to late November. In addition, fog and other adverse weather conditions make ice and iceberg reconnaissance difficult. Routing decisions are, therefore, currently made with incomplete information.

A "Belle Isle Strait" experiment is proposed to validate economic benefits of the sea ice and iceberg data provided by SEASAT in the region of the Belle Isle Strait. Ship routing benefits would manifest themselves as changes in routing patterns for European shipping through the two straits and would be measured in shipping days saved, improved safety and reduced fuel consumption. The experiment may also provide an indication of further increases in shipping efficiency to be expected from the fully operational SEASAT system.

#### The Problem

Vessel traffic on the trade routes between the Gulf of St. Lawrence and northern Europe is subject to marked deviations from the shortest distance tracks, due to the ice fields. Most steamship operators give their vessel masters standing orders to circumnavigate all known ice by at least 60 to 100 nautical miles. To and from the Gulf of St. Lawrence, the minimum distance track uses the Belle Island Strait, north of Newfoundland. However, the ice-free season at Belle Isle Strait is a very brief one, usually stretching from August 1 through mid or late November. The alternative for this trade route traffic is to utilize the Cabot Strait, west of Newfoundland, which adds significant distance to the voyage. This means additional costs and possible further delays due to encountering additional weather en route.

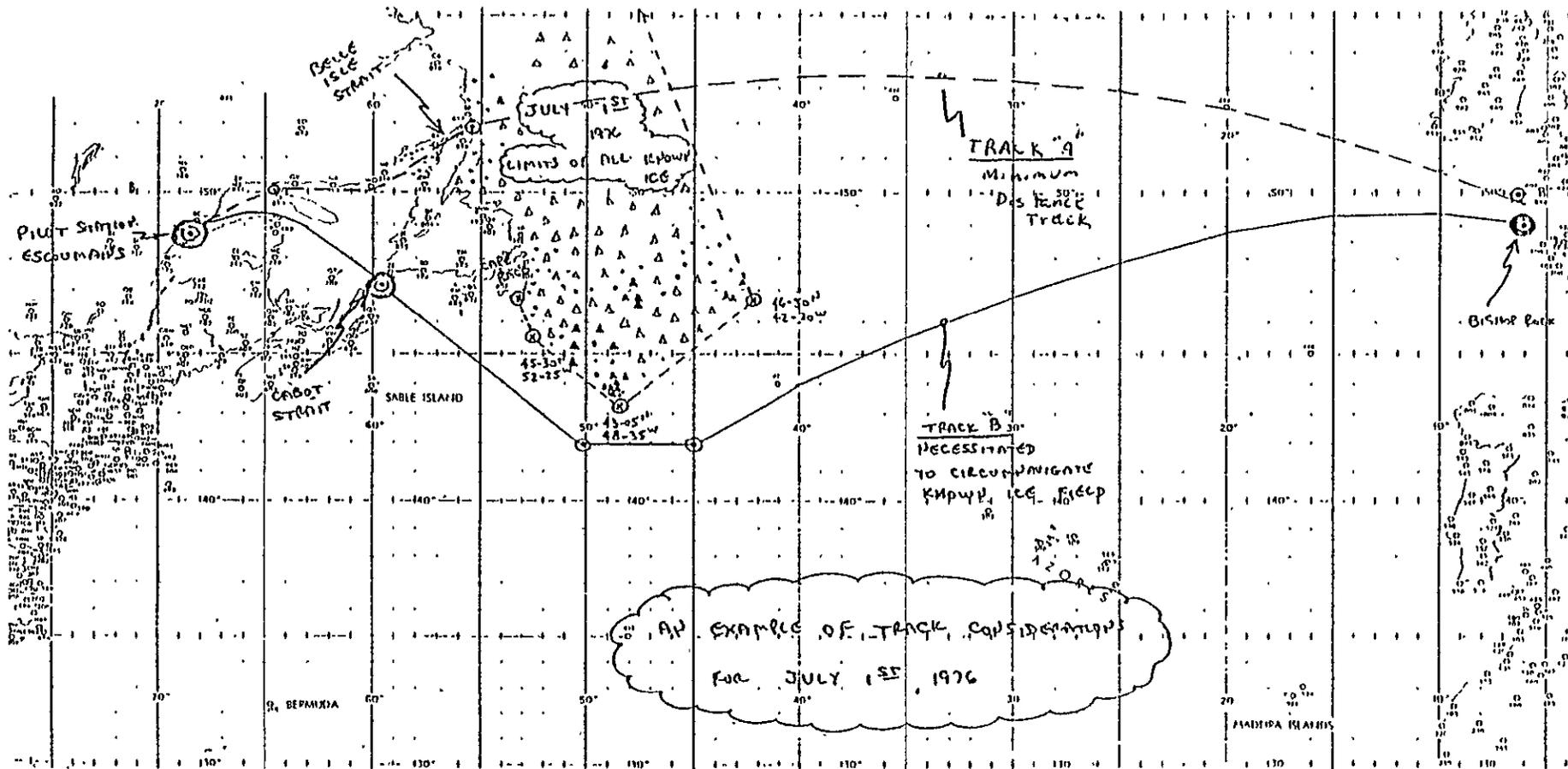


Figure 4.28 Alternate Routes for St. Lawrence - European Traffic  
 (Source: Bendix Field Corporation)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

A typical example of the distance difference between the Belle Isle Strait and Cabot Strait is:

Track A (Via Belle Isle Strait)  
2459 nautical miles Escoumains to English Channel

Track B (Via Cabot Strait)  
2859 nautical miles Escoumains to English Channel.

These routes are illustrated in Figure 4.28. Note that Track B is 400 nautical miles longer than Track A. A 15-knot vessel could therefore lose 26.7 hours of transit time if committed to transit Track B when the Belle Isle Strait and its approaches were "ice-free". Based on operating costs of \$3,000 per day,\* this amounts to \$3,340 per diverted ship.

#### Background

Belle Isle Strait is closed by sea ice from January through June, with slight variations in these times from year to year. Very little traffic uses the strait during this time. The shipping traffic through Belle Isle increases after June, though there are many icebergs in the area until August. A few icebergs may still be present in September. Sea ice begins to return to the Strait area in late November, and the sea traffic correspondingly decreases.

European shipping traffic through the St. Lawrence consists largely of exports of grains and scrap metals, and imports of fuels, finished metals and metal products. Approximately 1,300 ships travel through the Cabot and Belle Isle Straits during the months of May, June, July and August. During this transition period, the Belle Isle Strait becomes navigable. Approximately 30 percent (400) of this number represents European traffic and, at most,

---

\*Bendix Field Corporation.

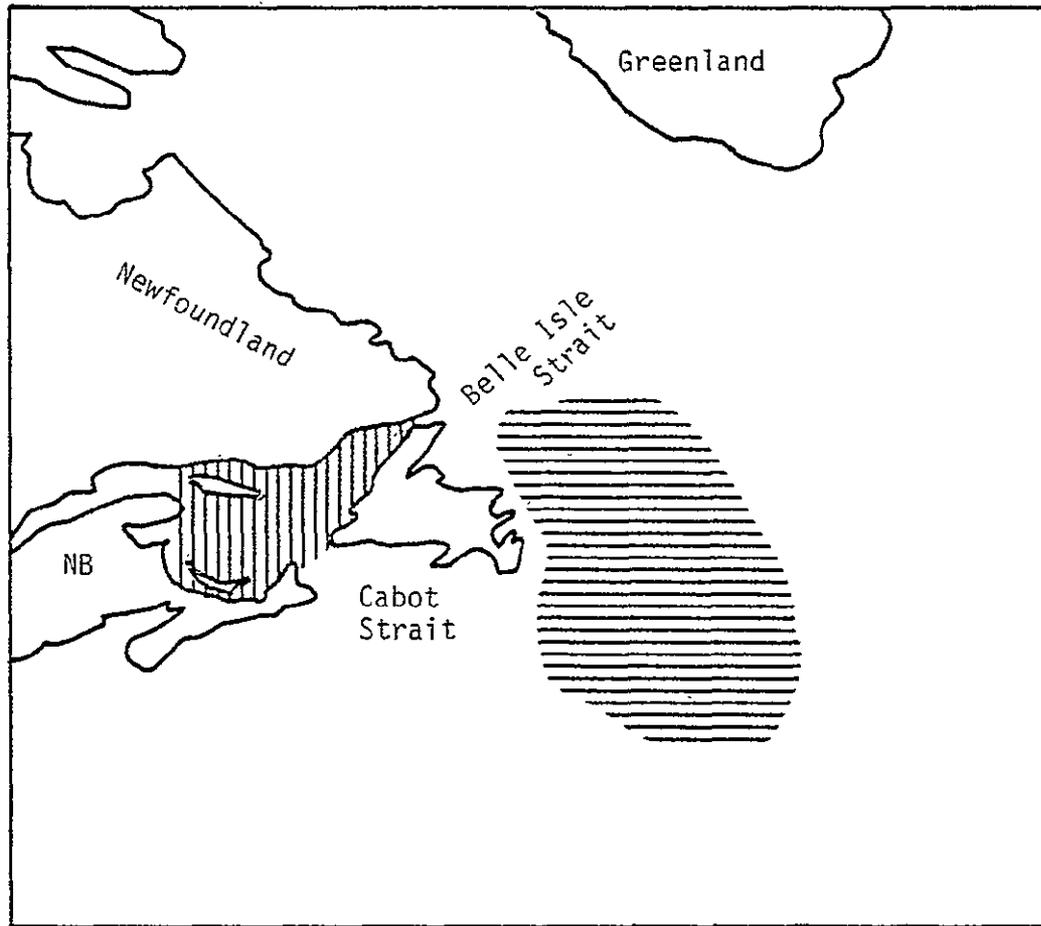
130 of these voyages passed through the Strait of Belle Isle. One can assume that the bulk of the 270 European voyages not using the Belle Isle Strait were deterred by perceived ice conditions in the Strait, resulting in operating losses on the order of \$900,000.\* The efficiency of European shipping traffic routing during this transition period is particularly sensitive to the quality of ice information that is available to the shippers.

Ice information for the mouth of the St. Lawrence is collected and distributed in a variety of ways. The area of interest is roughly split into two jurisdictions: the Cabot Strait--Grand Banks area is monitored by the U.S. Coast Guard's International Ice Patrol, while the Gulf of St. Lawrence, Belle Isle Strait and the northern areas of Newfoundland are monitored by the Canadian Atmospheric Environment Service's Ice Forecasting Central. The above jurisdiction division, illustrated in Figure 4.29, is an informal one. In fact, the regions of interest for each group overlap. The two groups cooperate in ice information collection for the area.

The International Ice Patrol (IIP) is active during the months of January through July. Its primary task is the location of sea ice and icebergs in the Grand Banks region southeast of Newfoundland. The IIP surveys ice conditions during this period through ship reports and aerial (visual and radar) ice reconnaissance. During the 1973 season there were 77 flights, 11 of which were in June and 9 of which were in July. Figure 4.30 illustrates a typical set of flight reconnaissance patterns, flown over a period of three days. Ice conditions are updated through these data daily. In

---

\*Communication with Robert Raguso, Bendix Field Corporation, August 1976 and communication with Lucien Misson, Canadian Department of Transport, August 1976.



-  Canadian Ice Central
-  USCG International Ice Patrol

Figure 4.29 Principal Ice Surveillance Areas

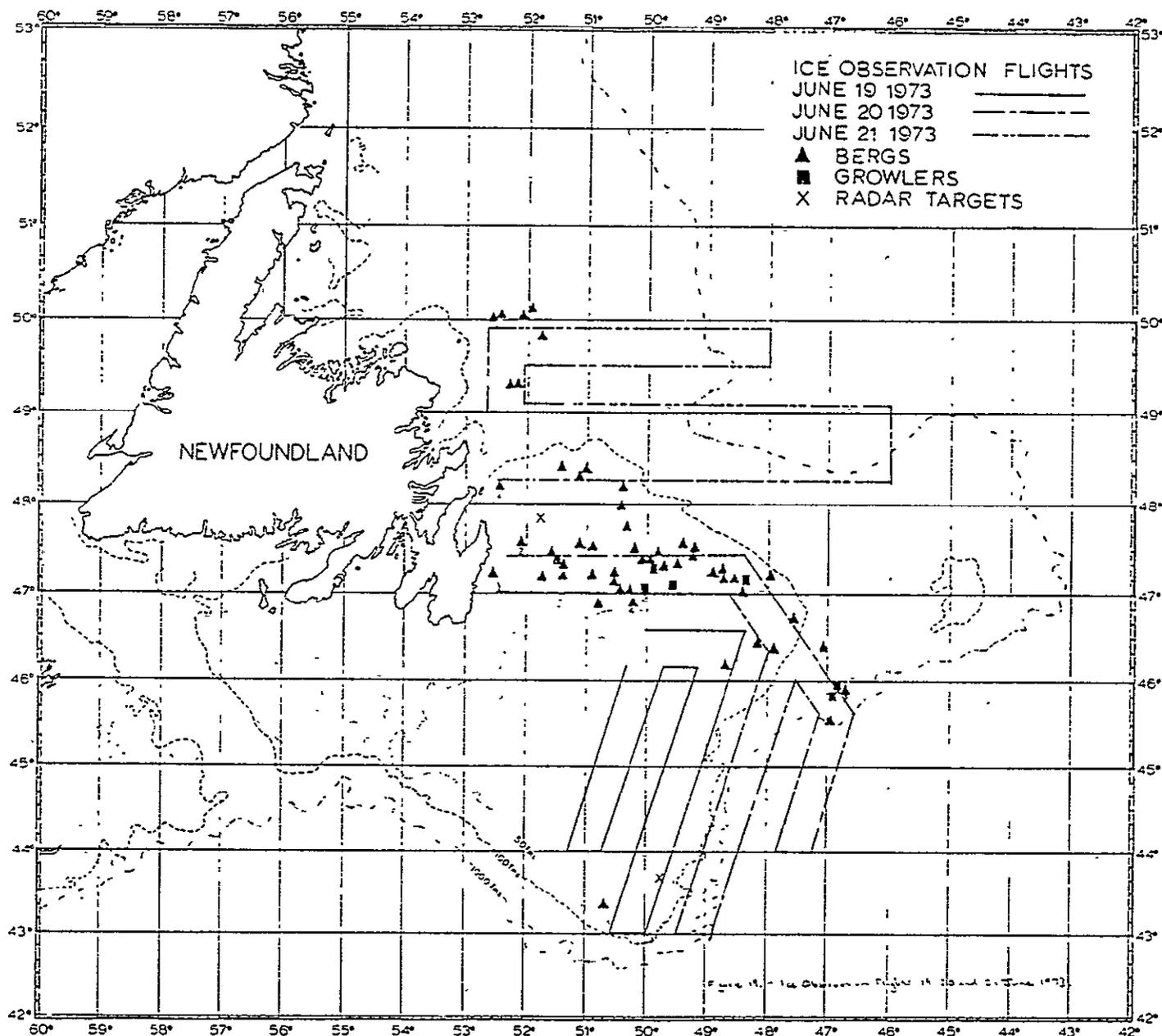


Figure 4.30 Typical IIP Surveillance Flight Patterns  
 (Source: USCG: Report of the International  
 Ice Patrol Service in the North  
 Atlantic Ocean, 1973. Bulletin  
 No. 59.)

addition, the IIP updates ice positions by using a computer model of ice movement and deterioration. Ice reports specifying the limits of all known ice are broadcast twice daily from radio stations in the United States, Canada and Europe. Facsimile broadcasts of sea ice and icebergs are made once a day from the Boston Station.\*

Canada's Ice Central is active throughout the year, but its efforts shift to the arctic regions in summer and early fall. From December through June, Ice Central surveys the Gulf of St. Lawrence--Belle Isle area with an average of three visual reconnaissance flights per week. This information, combined with ship sightings and IIP information, is incorporated in a daily update of ice conditions. Facsimile broadcasts and ice reports specifying the limit of ice are issued twice daily nationwide via four radio stations. Ships in the St. Lawrence area receive information from the Halifax station. Halifax radio's facsimile broadcasts are hampered by a low quality fax broadcaster.\*\*

Broadcasts of ice conditions in the Gulf of St. Lawrence and Cabot and Belle Isle Straits influence the choice of route for ships entering and leaving the St. Lawrence River. The ship's captain must decide during the voyage which strait his ship will use, or the shipowners may give him specific route orders. In either case, these decisions are affected by the quality of ice information received. A lack of adequate ice information can result in route selections that are indirect and/or dangerous. Decision makers choosing an exiting or entering strait during the transition months

---

\* Communication with Cmdr. Albert Super, USCG, July 1976.

\*\* Communication with Bill Markham, AES Ice Central, July 1976.

(May, June, July, August) face a lack of adequate ice information. The Belle Isle Strait is under intensive visual surveillance (three flights/week) only during May and June. (After June the Canadians divert the aircraft to arctic operations.)

Aerial reconnaissance efforts are hampered by fog and bad weather. Even aircraft with "all weather" sensors are ineffective when weather conditions prohibit takeoff. These conditions cause 50 percent down time for Canadian surveillance efforts. Yet periods of bad weather are most critical to the shipping decision makers, since winds are strongest and ice is most mobile during storm conditions.

The operational SEASAT system will alleviate these difficulties, providing all-year and all-weather ice detection capability for all areas within receiving range of the Shoe Cove Station. This area is illustrated in Figure 4.31. SEASAT information, at least in the short-run, will not supplant but rather will supplement current data collection efforts. SEASAT-A will not provide complete daily microwave radiometer and synthetic aperture radar coverage of the area of interest, but the information provided by the sensors will be significant. Typical microwave radiometer and synthetic aperture radar coverage for two consecutive days are illustrated in Figures 4.32 and 4.33 respectively.

#### Experiment Purpose

SEASAT's microwave radiometer and synthetic aperture radar sensors can provide additional sea ice and iceberg information for the St. Lawrence--Belle Isle area. The purpose of a Belle Isle Strait experiment would be to determine the worth of this added information in making better choice-of-strait decisions. Improvements in routing efficiency would be verified through an

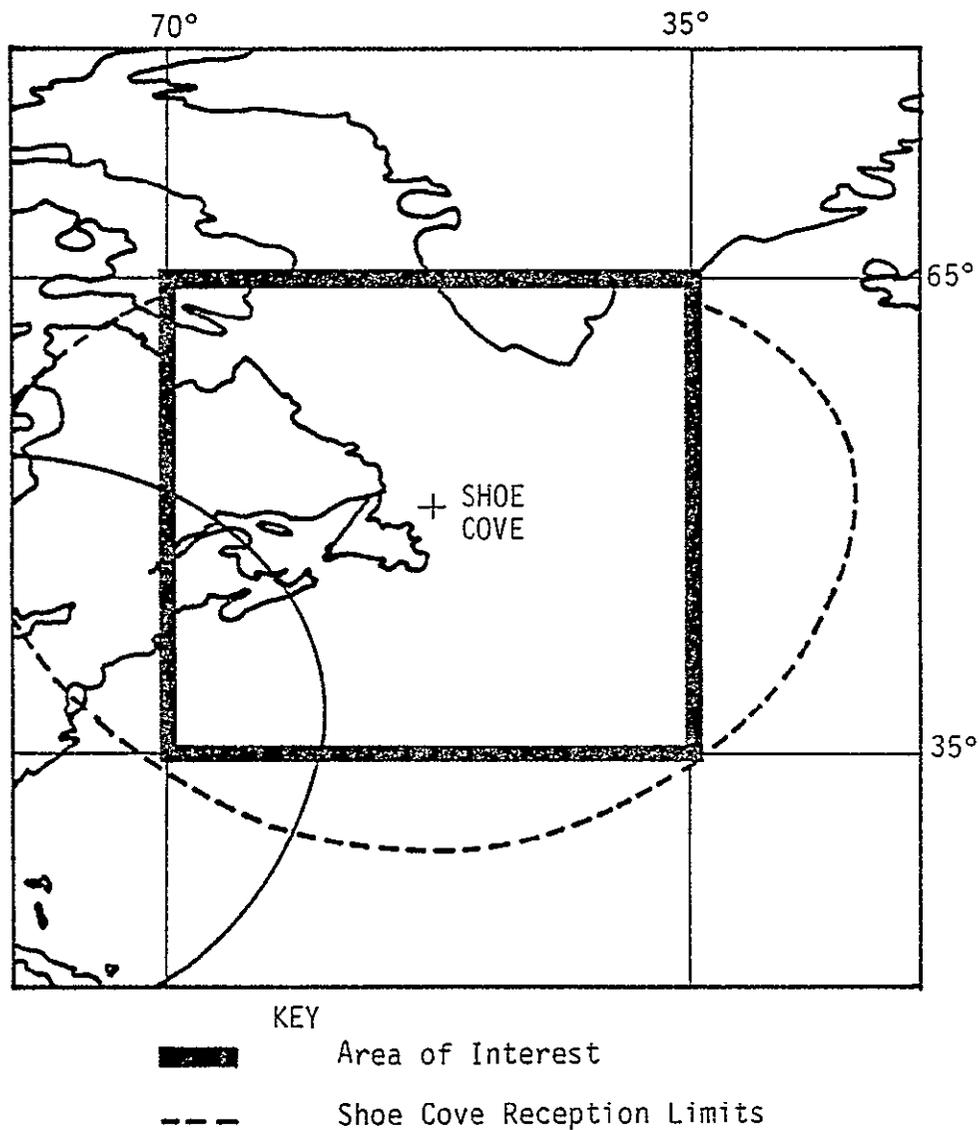


Figure 4.31 Shoe Cove Reception for St. Lawrence Area  
 (Source: Interactive Graphics Orbit Selection (IGOS), Battelle Laboratories, Columbus, Ohio.)

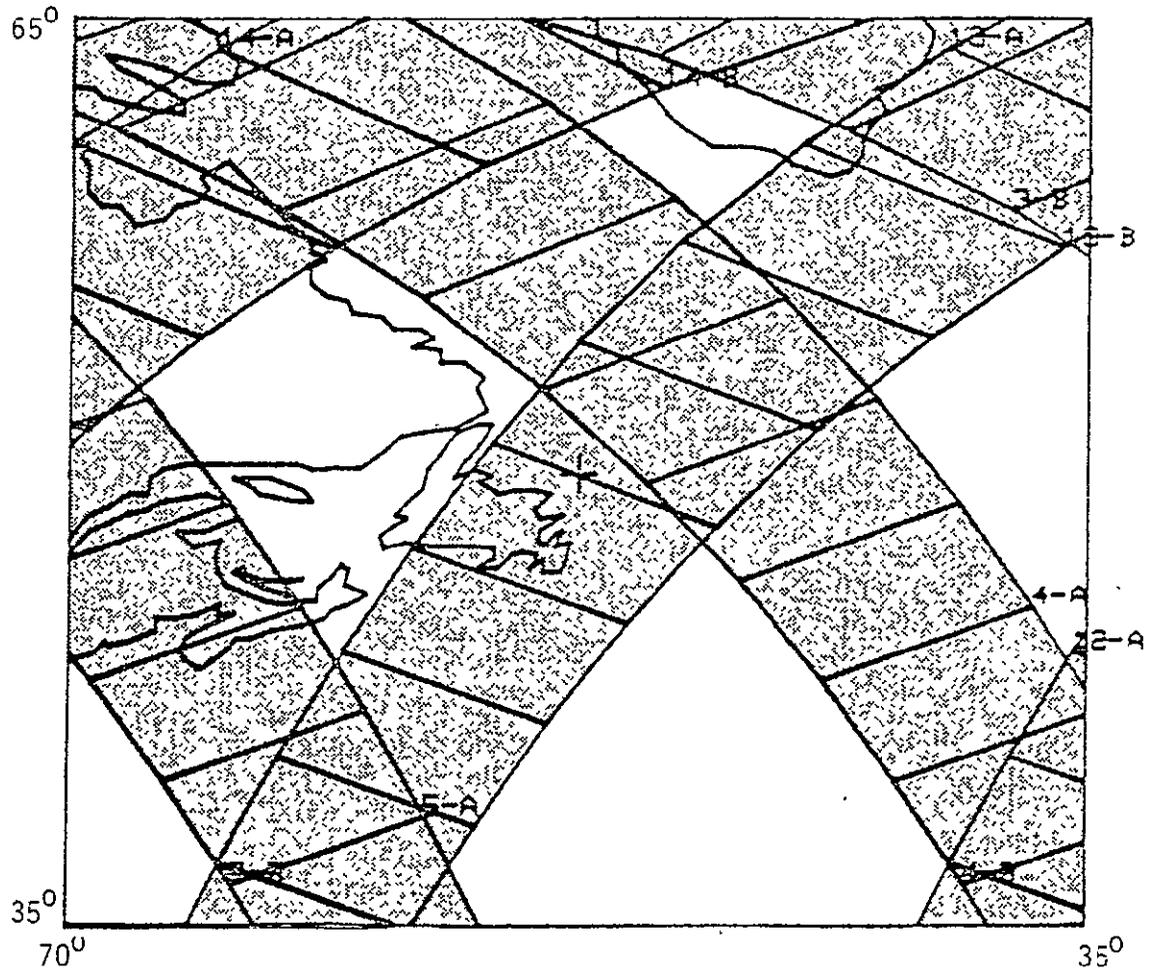


Figure 4.32 Typical One Day Coverage for SEASAT-A Microwave Radiometer Sensor (Source: IGOS, Battelle Laboratories, Columbus, Ohio)

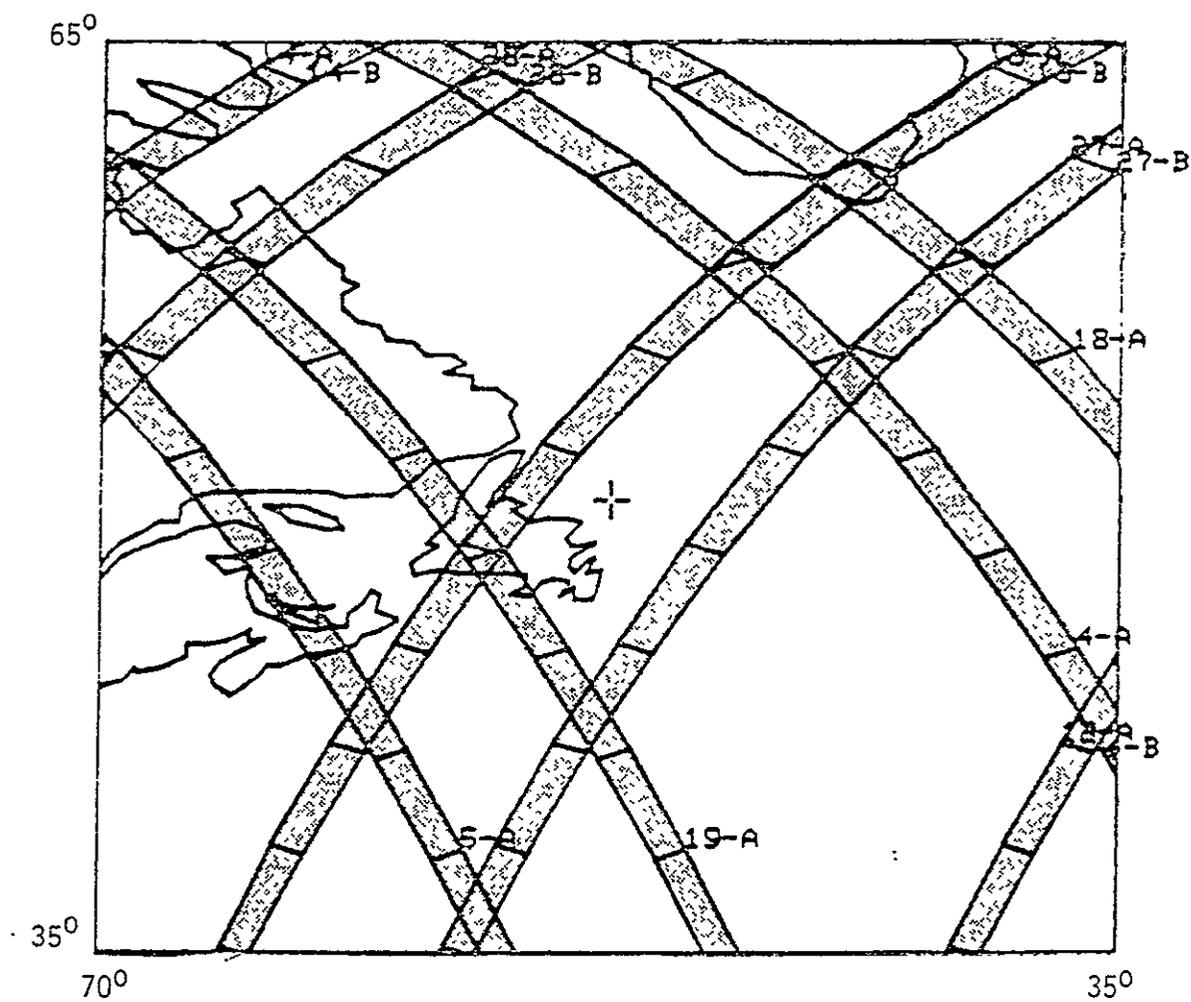


Figure 4.33 Typical Two Day Coverage for SEASAT-A Synthetic Aperture Radar Sensor (Source: IGOS, Battelle Laboratories, Columbus, Ohio)

operational model involving real satellite information, ships and decisions. The operational model should also verify that the new information provided by SEASAT can be analyzed, distributed and used effectively.

#### Experiment Description

The experiment would be conducted during May, June, July and August of 1978. During this period, Belle Isle Strait becomes navigable and gradually ice free. The number and tonnage of European traffic using both straits would be monitored through reports to the Vessel Traffic Management Center in Halifax and through the records of ship routing companies. Routing behavior for experimental and control groups would be compared to determine the improvements in routing due to the added information. Benefits under conditions of added information may accrue in three ways:\*

- Transit time savings,
- Fuel savings, and
- Reduced loss of life and/or reduced vessel damage.

Dollar estimates of the benefits to the experimental sample would then be generalized to cover all European traffic for the period of interest. Belle Isle Strait routing benefits that might accrue to European shipping traffic during the remainder of the year are expected to be small relative to the benefits of added information during the transition period described earlier.

#### Experiment Sample Description

The population under consideration consists of all vessel crossings between northern Europe and the St. Lawrence Seaway for the months of May

---

\* These benefits will be observed directly for a subset of the experimental group, and inferred by route choice for the remainder of the experimental group. See Sample Description.

through August of 1978. Since the new SEASAT-A information would be made available to all traffic, there will be no active control group. The experimental group would consist of all vessels that report their choice of strait to Vessel Traffic Management in Halifax. It is expected that this group would make up a majority of the ships using the St. Lawrence Seaway.

Since no active control group would exist, a historical control group must be constructed. This proxy would consist of historical data for a representative subgroup of ships whose trips fall in the experimental sample. The control group data would be constructed from historical choices made under ice and weather conditions similar to those of the test period. This subgroup will also be used to form a proxy for a second experimental sample, since it may be the case that a short-run lack of user confidence in new SEASAT-A data will cause an underestimate of the long-run routing benefits of SEASAT-A. Shippers may well be reluctant to rely on new, untested data sources. Therefore, a panel of routing experts will examine the ice and weather situations faced in 1978 by the subgroup mentioned above, and determine any changes in routing that would be made if the SEASAT-A data were assumed to be fully reliable.

A visual representation of the control, experimental and second experimental samples is given in Figure 4.34. The design uses direct observations, expert opinion and statistical inference to determine vessel routing decisions. The control, experimental and second experimental samples are used to hypothesize the makeup of the total population of Control, Experimental 1 and Experimental 2 groups.

#### Experiment Analysis

In order to describe the calculation of economic benefits, it is necessary to index the three cases of interest:

Key: — Direct Observation  
 ~~~~~ Expert Opinion  
 - - - - Inference

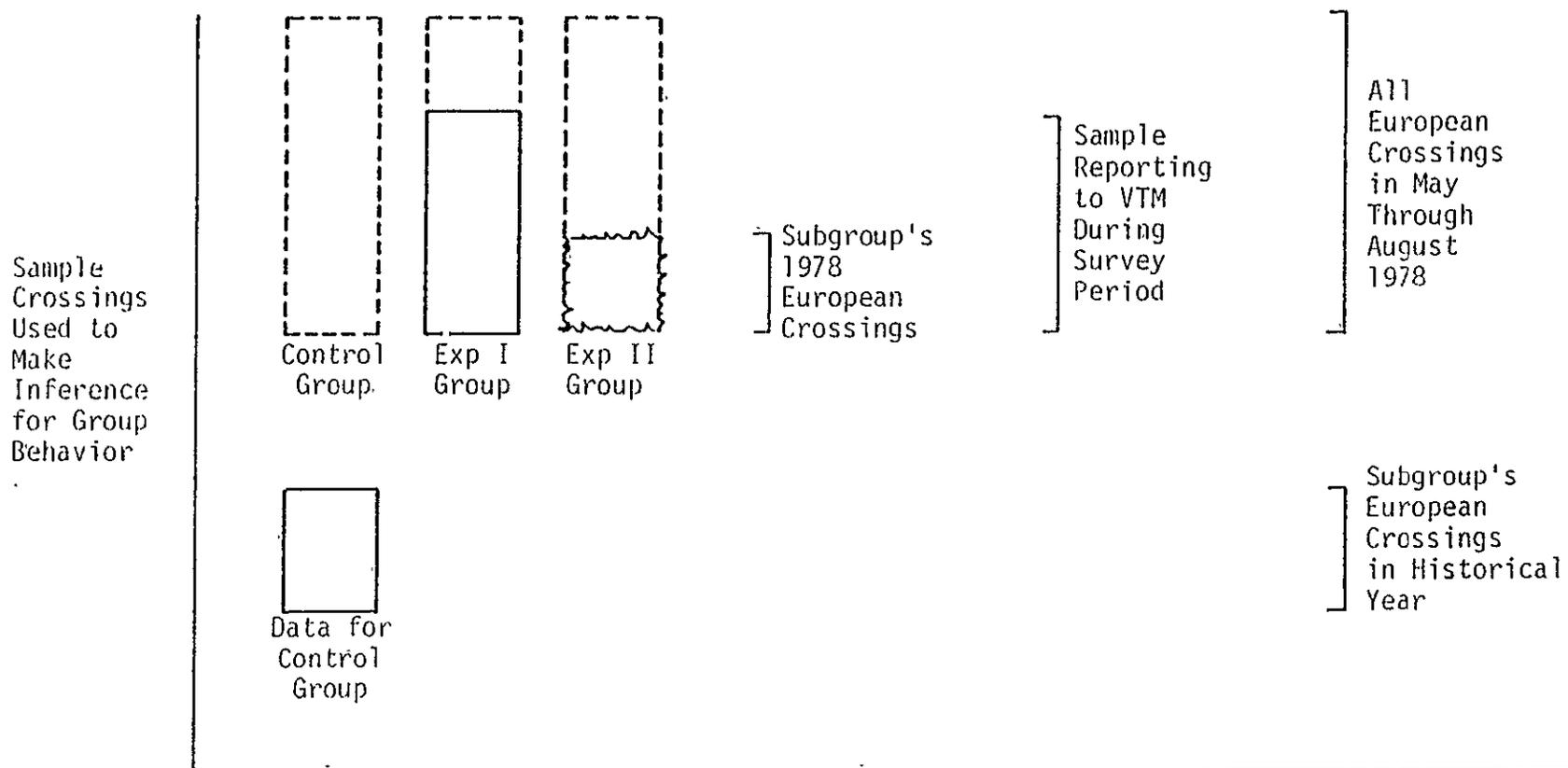


Figure 4.34 Characteristics of Control and Experimental Groups

0 = No SEASAT Data (Control Group)

1 = SEASAT-A Data Provided (Experimental Group 1)

2 = SEASAT-A Data Fully Accepted (Experimental Group 2)

For each case, an estimate of the number of trips (by weight class) that would pass through the Belle Isle Strait is desired. Let  $n_{1j}$  be the number of trips in group 1 of weight class  $j$  that choose the Belle Isle Strait. The, for example,  $n_{1j} - n_{0j}$  estimates the additional number of ships using the Belle Isle Strait when SEASAT-A data is provided. It is then possible to examine the three types of benefits.

$T_j$ : dollar value of time saved per Belle Isle trip (weight class  $j$ )

$F_j$ : dollar value of fuel saved per Belle Isle trip (weight class  $j$ )

$H_j$ : dollar value of hazards reduced per Belle Isle trip (weight class  $j$ ).

Sources for these data are outlined as follows:

$T_j$ : estimated from historical data or expert opinion

$F_j$ : estimated from historical data or expert opinion

$H_j$ : estimated from historical data or expert opinion

$n_{0j}$ : statistical inference based on percentage of ships in weight class  $j$  using Belle Isle in the historical sample

$n_{1j}$ : statistical inference based on percentage of ships in weight class  $j$  using Belle Isle during the 1978 season

$n_{2j}$ : statistical inference based on percentage of ships in weight class  $j$  hypothesized to use Belle Isle in 1978 if the decision maker accepts SEASAT data as reliable.

By multiplying dollar savings per additional Belle Isle route times the total number of additional Belle Isle routes, the total dollar benefits in each of the three categories are found. For example, for fuel



$$\begin{array}{l} \text{Dollar benefits for 1978} \\ \text{for fuel savings based on} \\ \text{actual SEASAT information} \\ \text{use (Experimental Group 1)} \end{array} = \sum_{\substack{\text{weight} \\ \text{class } j}} F_j (n_{1j} - n_{0j})$$

and

$$\begin{array}{l} \text{Dollar benefits for 1978} \\ \text{for fuel savings based on} \\ \text{complete SEASAT information} \\ \text{use (Experimental Group 2)} \end{array} = \sum_{\substack{\text{weight} \\ \text{class } j}} F_j (n_{2j} - n_{0j})$$

This analysis then, would yield estimates of one-year benefits in time, fuel and hazard savings due to the added information provided by SEASAT-A. The analysis will also provide an estimate of the degree of confidence placed in the new data source by ship routing decision makers. Furthermore, it may be possible to estimate the magnitude of the heretofore unknown (but positive) correlation between SEASAT-A benefits and the benefits to be expected under a fully operational system. The three-satellite operational system would provide complete SAR and SMMR coverage at least twice a day, and would allow reliable 48 hour forecasts of ice and weather conditions.\* The panel of routing experts consulted in the formation of the second experimental sample will also be asked to determine additional routing changes that would occur due to added information from a fully operational SEASAT system. The expected benefits would then be calculated as outlined above.

A breakdown of responsibilities associated with this experiment by participating organizations is shown in Table 4.9.

#### 4.2.2.3 The Agulhas Current and Associated Phenomena

The waters of the oceans have motions which occur in a variety of forms from surface ripples and waves to surface and subsurface currents

---

\* SEASAT Economic Assessment, Volume II, ECON, Inc., 1976.

Table 4.9 Responsibilities Associated With Experiments

| Group                                                  | Economic Verification Program Coordination | SEASAT-A Information Analysis and Distribution | Data Collection |         |         | Economic Analysis |
|--------------------------------------------------------|--------------------------------------------|------------------------------------------------|-----------------|---------|---------|-------------------|
|                                                        |                                            |                                                | Group 0         | Group 1 | Group 2 |                   |
| ECON                                                   | X                                          |                                                |                 |         |         | X                 |
| AES Ice Central (Canada)                               |                                            | X                                              |                 |         |         |                   |
| USCG International Ice Patrol                          |                                            | X                                              |                 |         |         |                   |
| Canada Centre for Remote Sensing                       |                                            | X                                              |                 |         |         |                   |
| Canadian Coast Guard Vessel Traffic Management Halifax |                                            | X                                              |                 | X       |         |                   |
| Marine Traffic Regulation Center, Quebec               |                                            |                                                |                 | X       |         |                   |
| Statistics Canada                                      |                                            |                                                | X               | X       |         |                   |
| Commercial Ship Routing Companies                      |                                            |                                                | X               | X       | X       |                   |

interconnecting the seas and oceans. The former topographic phenomena are a function of the wind and can impede the movement of shipping and be a cause of its damage. The currents are oceanographic phenomena of unidirectional water flow accounted for by water pressure and density variations defined by sea surface temperature and salinity as well as wind forces. Ships can advantageously use the currents to increase their rate of movement and thereby save both time and energy. Exact knowledge of current locations and directions of maximum flow are therefore significant to the maritime transportation industry. Ocean currents acquire increasing commercial significance as the amount of shipping moving in their location increases. The Agulhas is one such current, as a consequence of the closing of the Suez Canal and the employment of super tankers to transport oil from the Persian Gulf around the Cape of Good Hope. Waves and currents are both influenced by meteorological variations and it is always possible for them to interact in a manner that is dangerous to shipping. This condition, which occurs in the vicinity of the Agulhas Current as well as the Gulf Stream\* as a consequence of meteorologically induced instabilities, gives rise to abnormal or freak waves of great danger to shipping.

#### The Agulhas Current

The Agulhas Current has its origin in the tradewind region of the Central Indian Ocean, through the South Equatorial Current or surface drift, flowing westwards to Madagascar (Malagasy Republic) and the Mozambique coast. Two stream currents are formed, one moving southwards along the east coast

---

\* James, R. W. (U.S. Naval Oceanographic Office, Washington, D.C.), U.S. Department of Commerce, NOAA, EDS., "Dangerous Waves Along North Wall of the Gulf Stream," Mariners Weather Log, Volume 18, No. 6, November 1974, pp. 363-366.

of Madagascar and the other along the coast of Mozambique. The Madagascan component, when it reaches the south of Madagascar, veers westward across the Mozambique channel combining with the Mozambique component between Durnford Point and Durban in Natal, South Africa, as the Agulhas Current flowing in a southerly direction as shown in Figures 4.35 and 4.36.

Since the time of sailing ships, and as recently confirmed by measurements taken by the National Research Institute for Oceanology, Durban vessel MEIRING NAUDE, the current's maximum flow of 3 to 5 knots (1.5 to 2.6 m/s) has been known to fall on the 100-fathom line approximately south of Durnford Point, Natal (see Figures 4.37 and 4.38). This speed is particularly attained during the southern summer and autumn when the northeast monsoon is blowing in the Arabian Sea, giving rise to a maximum flow through the Mozambique channel. The width of the current is from 50 to 90 miles. The 100-fathom line marks the boundary of the continental shelf which, along this coast, is relatively narrow, varying from about 20 miles in the north and south to only 5 miles between Durban and Port St. Johns (see Figure 4.38). Under certain meteorological conditions, the southern flow extends across the continental shelf to the coast, the current generally tending to broaden out, the further south it is. The depth of the current is over 1,000 feet.

When a cold front passes along the southern and eastern seaboard a counter current of 1 to 2 knots flows to the east and northeast within 3 to 4 miles of the coast, inside the Agulhas Current. Prior to the passage of a cold front an upwelling occurs close inshore and there is also a tendency to increase the velocity of the Agulhas Current. Some 90 miles offshore, there is a hint of a northerly current and northerly speeds of about 1 knot (0.5 m/s) were found to exist some 180 miles offshore by a satellite-tracked

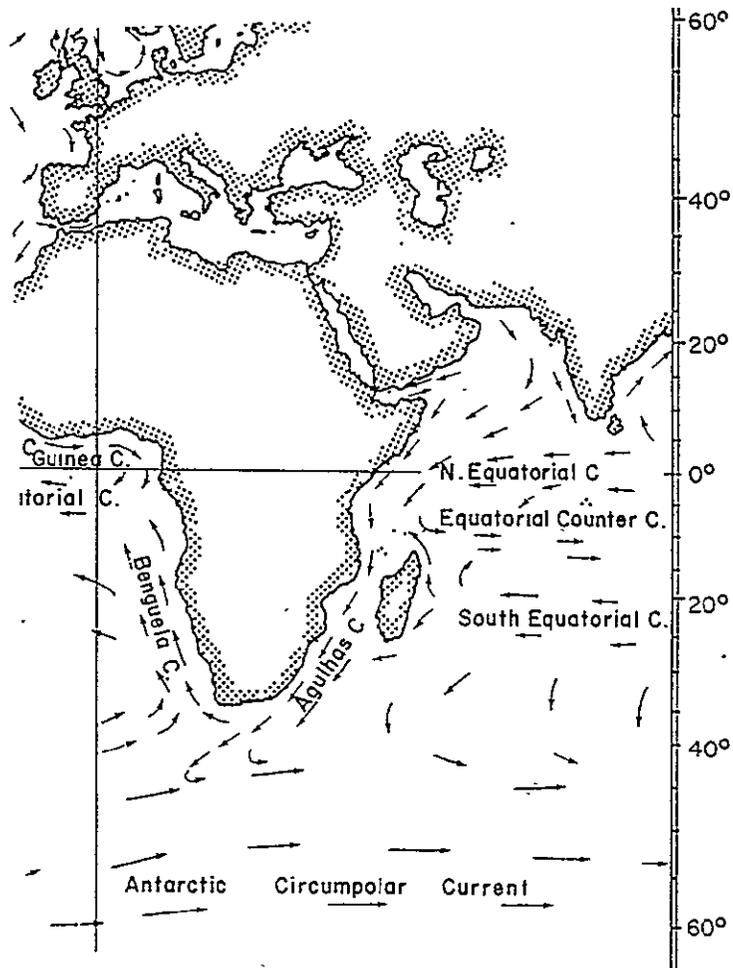


Figure 4.35 Ocean Currents Around Africa



Figure 4.36 The Agulhas Current

buoy in 1974. But the source of this current does not seem to be known although it is still described as the Agulhas Current.

It is generally observed that the Agulhas Current is well known as to its disposition and characteristics. Its principal southerly speed can be very reasonably located by shipping from soundings that locate the 100-fathom line. It seems reasonable to assume that shipping could locate and take advantage of, or avoid, currents in making passage through the Mozambique channel going south and north to the Persian Gulf, thus saving some 300 miles of additional transit distance that would result from passage east of Madagascar. Nevertheless, the best route to be followed in rough weather by a vessel traveling to the southwest off the coasts of Africa is not necessarily that which will gain 2 m/sec from the Agulhas Current. If, over some lengthy period of time, swells have been generated by southwesterly winds,

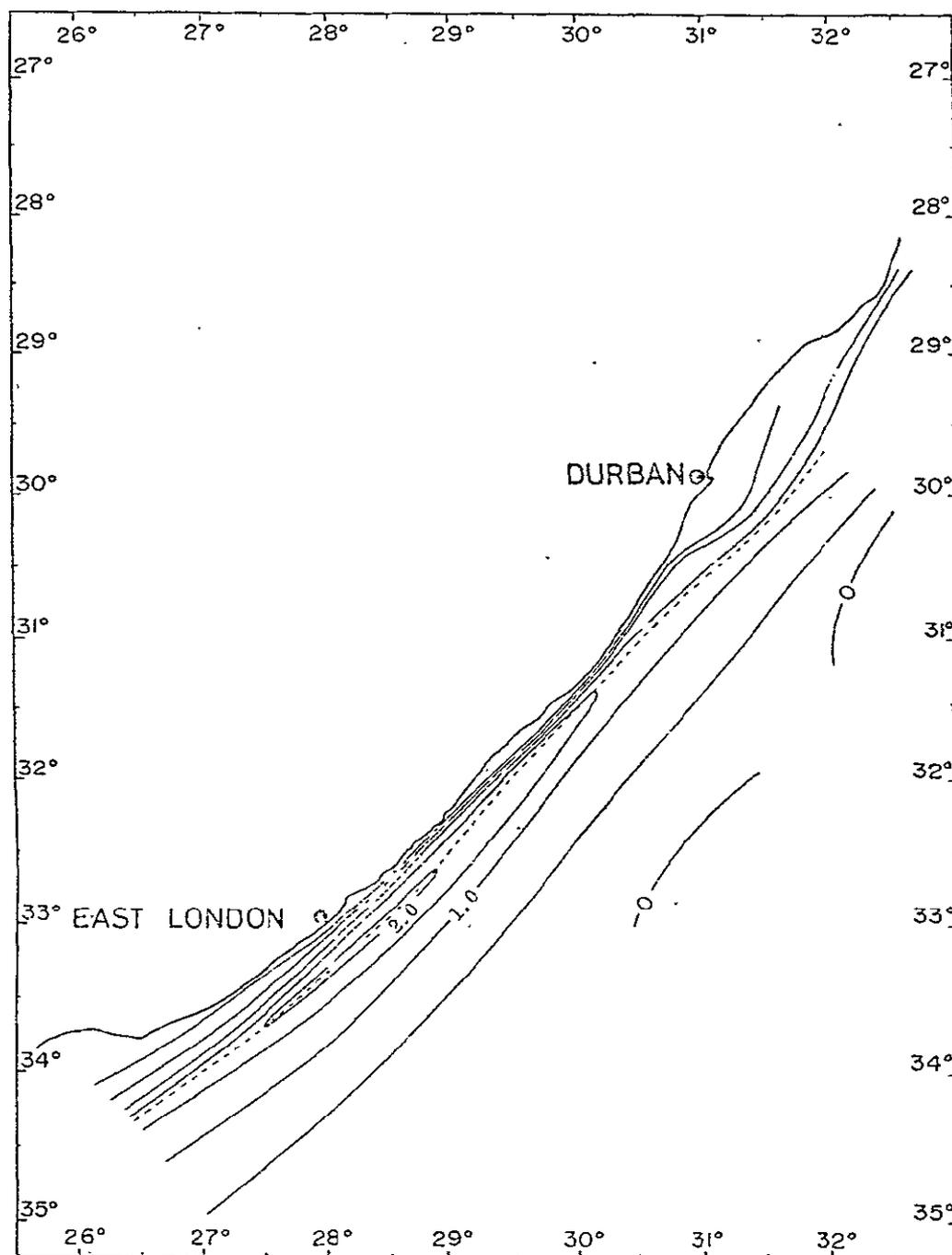


Figure 4.37 Mean Southerly Current Speed Parallel to the Coast in m/s (Source: Schumann, E. H. (National Research Institute for Oceanology, Durban, R.S.A.), U.S. Department of Commerce, NOAA, EDS., "High Waves in the Agulhas Current," Mariners Weather Log, Volume 20, No. 1, January 1976, pp. 1-5.

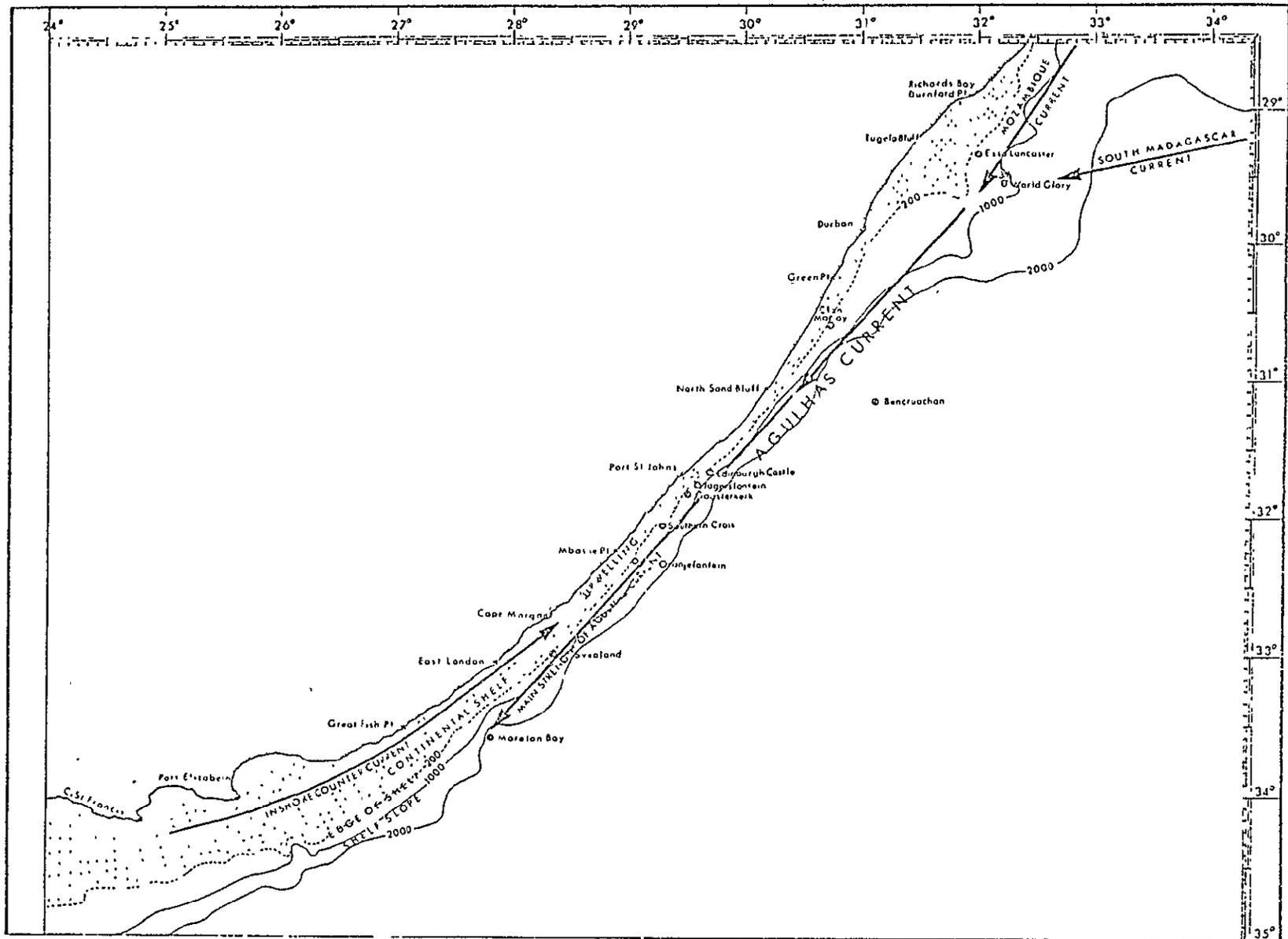


Figure 4.38 Chart of South East Coast of South Africa Showing Continental Shelf, Shelf Edge and Continental Slope, Agulhas Current, Inshore Counter Current and Coastal Upwelling, Positions of Ships Which Have Encountered an Abnormal Wave, Depths in Metres (Source: Schumann, E. H. (National Research Institute for Oceanology, Durban, R.S.A.), U.S. Department of Commerce, NOAA, EDS., "High Waves in the Agulhas Current," Mariners Weather Log, Volume 20, No. 1, January 1976, pp. 1-5.

abnormal or freak waves can be produced which can damage or sink ships in this region.

#### Abnormal or Freak Waves Off the Southeast Coast of South Africa

During the summer months, November to May, the local meteorology is such that prevailing winds are from the northeast or east and coincide with the current, adding to its speed. Occasionally, prevailing winds are west to southwest but are of a short duration with a short fetch. The depressions that move from west to east regularly around Antarctica are usually too far south to influence the coastal regions of interest. In the winter months, June to October, the southern depressions move northwards and strong south-westerly winds blow against the Agulhas Current parallel to the southeast Africa coastline. Further to the west, the winds are more southerly so that the parallelism of current and winds is less common.

Waves in the Agulhas Current are those produced by local winds and the swells originating in the Southern Ocean, a fetch of about 1,200 miles (depressions are centered in the vicinity of Marion Island about 47°S, 38°E). The swells are, therefore, fully developed by the time that they arrive in the vicinity of Port Elizabeth. Thus, even without local winds, ocean waves always exist. The locally produced waves have shorter wavelengths and are steeper than the ocean waves. Together, however, they are opposed by the Agulhas Current, the speed of which tends to both shorten the wavelength and raise the height of the sea. This effect is most pronounced where the current is maximum on or about the 100-fathom line. The range of wavelengths occurring in the current region can result in wavetrain interference so that wave superposition can occur for a few minutes creating a gigantic wave. The presence of the current when this occurs can give rise to non-sinusoidal

waves with a height in excess of 60 feet, with steep wavefronts about to break and with an excessively long trough preceding the wave. A ship steaming in this sea state may suddenly find its bow falling into a long sloping trough, most likely longer than the length of the ship. At the bottom of this trough there is a steep wave greater than 60 feet high moving at 30 knots, on the verge of breaking. As the forepart of the ship ploughs into this wave, the wave becomes unstable and tends to crash into the ship aft of its forward buoyant volume. The stresses then generated can severely damage the structural integrity of the ship and in some instances break the ship in two.

Since April 1952, 11 ships located on Figure 4.38 have encountered or been damaged by abnormal waves; all except one in the southern winter time, all except one proceeding in a southerwesterly direction. It has been suggested that many other encounters may have occurred but that the ship speed on these occasions was suitably reduced and no damage resulted. Analysis of the weather conditions encountered by the 11 ships, combined with the theory of wave superposition, has led to the formulation of a set of operating rules to minimize the possibility of encounter:

"Because these abnormal waves occur without any warning there seems to be no way in which a vessel could be maneuvered to avoid damage if it occurs in the direct track of the vessel. But there is one obvious criterion which does give a distinct guide as to how to avoid meeting an abnormal wave and that is to keep away from the vicinity of the outer edge of the continental shelf or 100 fathom (200 m) line between Richards Bay and Great Fish Point, when steaming to the southwest with a falling barometer, a fresh northeasterly wind blowing, and a change to fresh to strong southwesterly winds forecast in the next twelve hours, by standing in towards the coast, so that when the wind changes, the ship will be inshore of the 100 fathom (200 m) line, then to remain inside the 100 fathom (200 m) line until the wind and sea have moderated sufficiently to edge gradually out beyond the 100 fathom (200 m) line.

It is to be noted that shipping steaming in a northeasterly direction usually remains within 3 to 4 miles of this part of the South African coast in order to take advantage of the inshore counter current referred to above. Southbound traffic should therefore avoid closing the coast more than is necessary especially between Durban and Bashee river light.

It is also to be noted that certain vessels, which, by virtue of the nature of their cargo, are required to keep a specified distance clear of the coast should, under the above weather conditions, keep beyond the influence of the core of the Agulhas Current, i.e., not less than 20 miles seaward of the edge of the continental shelf where there is less risk of encountering an abnormal wave. When off Great Fish Point course can then be altered to keep within the winter loadline limits.\*

In addition, apart from the danger of encountering an abnormal wave by following the main course of the Agulhas Current, it is suggested that ships steaming to the southwest into southwesterly swells should avoid the current's mainstream because the swell wave height will be amplified by the current; for safety, the ship's speed should be reduced by more than the additional speed that could be gained from the current flow. This is particularly true for more southerly latitudes.

#### Extraordinary Swell Wave Heights Off the South African Coast

The Cape of Good Hope has relatively settled weather in terms of gales and rain but high waves are much more prevalent than might be expected.

A statistical study of observed wave heights has been made in Marsden Square 441 (30° - 40°S; 20° - 30°E), shown in Figure 4.39 as an area to the south of the southern coast of the Republic of South Africa. Significant swell heights of over 40 feet have been observed (significant wave heights are the average of highest one-third of observed wave heights, extreme wave

---

\*Mallory, J.K. (University of Cape Town), "Abnormal Waves on the South East Coast of South Africa," The International Hydrographic Review, Volume LI, No. 2, pp. 99-129. The International Hydrographic Bureau, Monaco, July 1974.

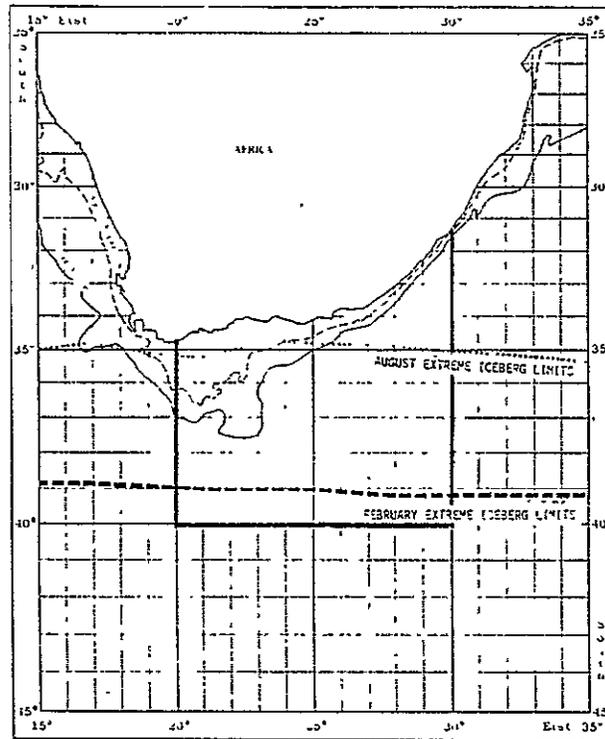


Figure 4.39 Coast of South Africa. The Sea Area Outlined is the Region for Which the Wave Observations Were Summarized (Source: Quayle, Robert G. (National Climatic Center, NOAA, Asheville, North Carolina), U.S. Department of Commerce, NOAA, EDS., "Cape Rollers--Unusually High Swells Off the South African Coast," Mariners Weather Log, Volume 18, No. 3, May 1974, pp. 145-148.)

heights may be equal to 1.8 times the significant wave height). The wave height monthly probabilities for this region are shown in Figures 4.40 and 4.41. The swells result from wind disturbances in the vicinity of Antarctica and are fully developed over the fetches involved, from 800 to 1,200 miles.

Swells impede shipping transits by requiring reductions in speed and changes in course, according to actual swell conditions (height and frequency) encountered, to minimize the potential for producing structural damage from wave pounding. This is particularly significant for fully loaded oil tankers although today, because of excess tankerage, the economic implications are

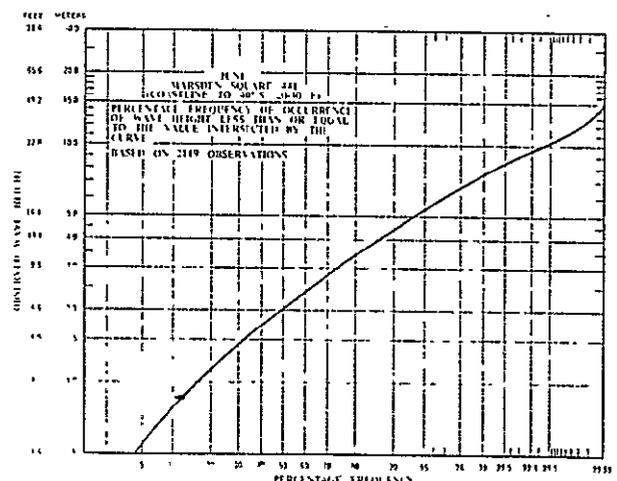
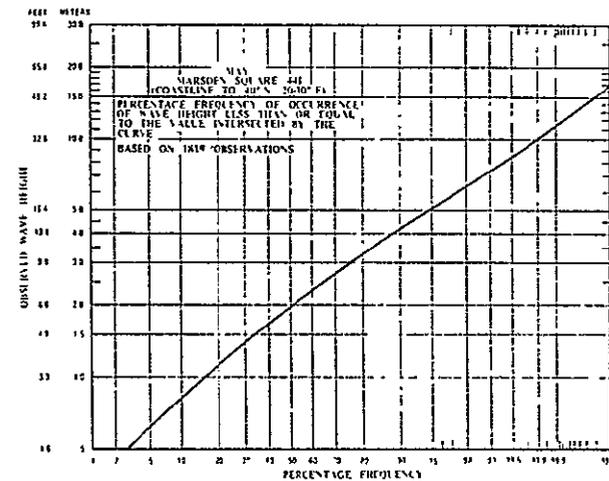
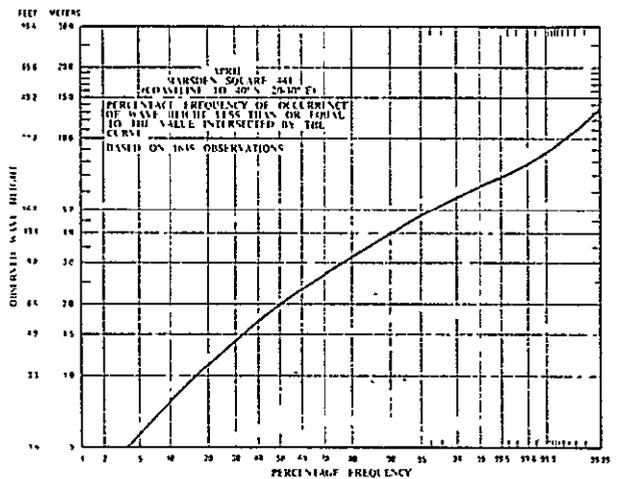
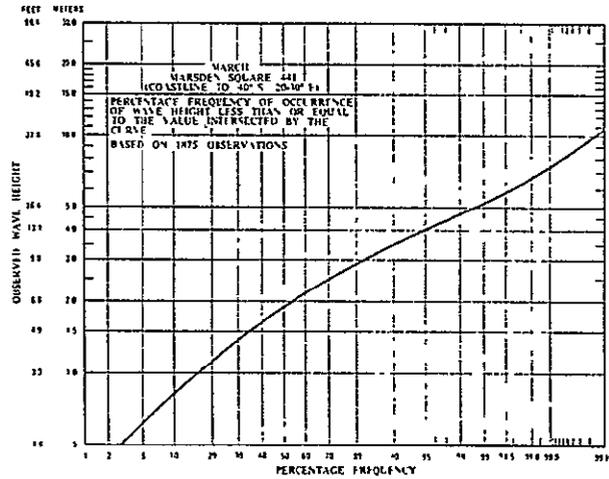
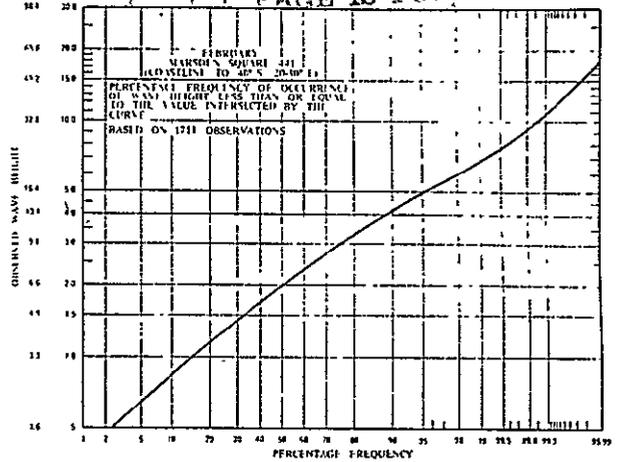
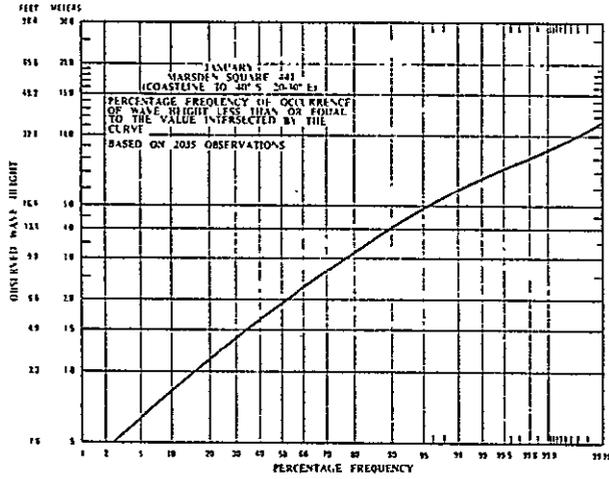


Figure 4.40 Wave Height Probabilities in Marsden Square 441 (January Through June) (Source: Quayle, Robert G. (National Climatic Center, NOAA, Asheville, North Carolina), U.S. Department of Commerce, NOAA, EDS., "Cape Rollers--Unusually High Swells of the South African Coast," Mariners Weather Log, Volume 18, No. 3, May 1974, pp. 145-148.)

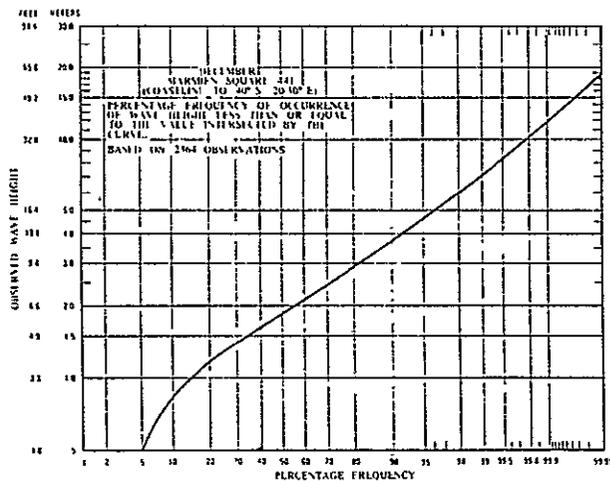
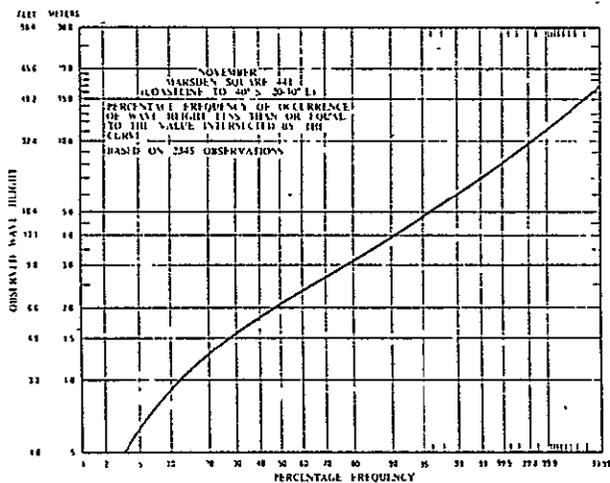
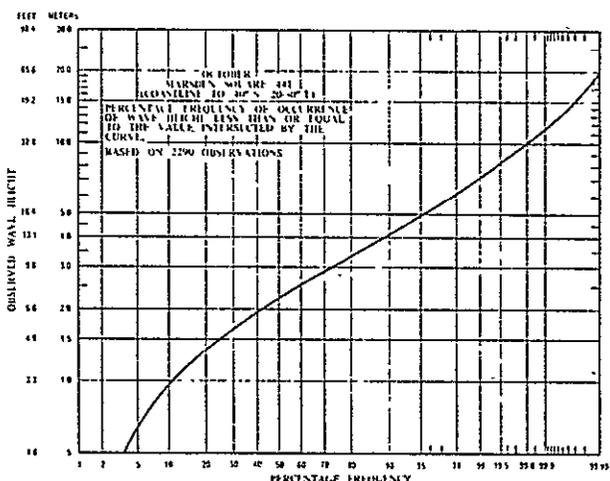
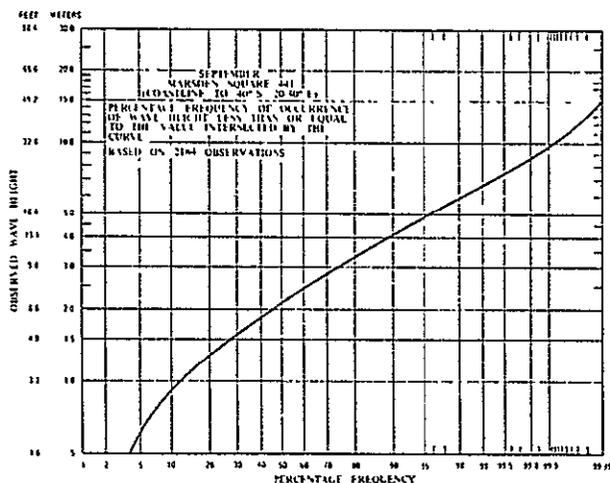
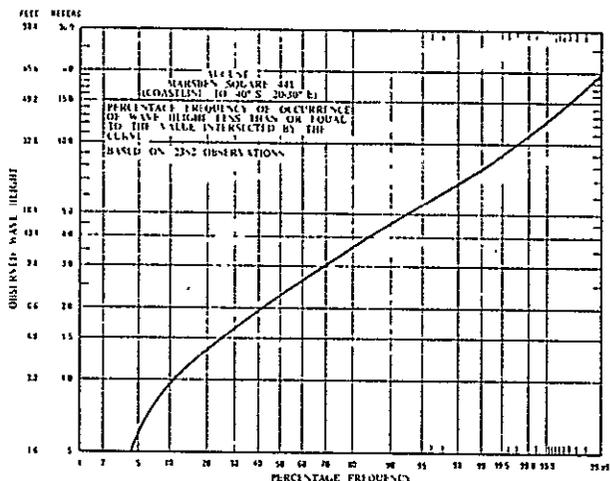
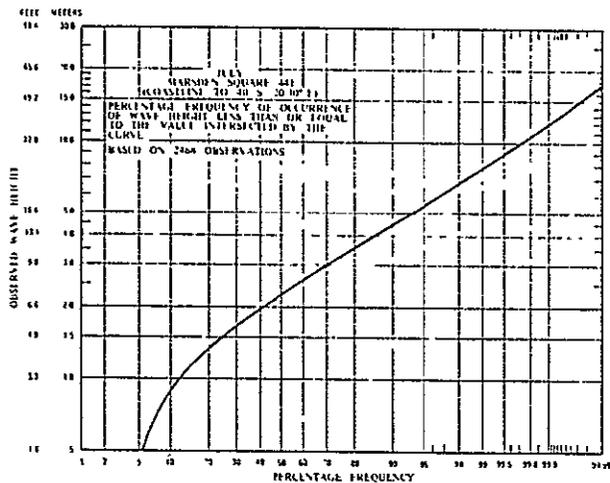


Figure 4.41 Wave Height Probabilities in Marsden Square 441 (July Through December) (Source: Quayle, Robert G. (National Climatic Center, NOAA, Asheville, North Carolina), U.S. Department of Commerce, NOAA, EDS., "Cape Rollers--Unusually High Swells of the South African Coast," *Mariners Weather Log*, Volume 18, No. 3, May 1974, pp. 145-148.)

considerably diminished. Future oil activity may reawaken interest in predicting sea swell conditions to minimize transit delays. It appears, however, that the depressions which give rise to the swells are seldom stationary for longer than 36 hours and that the observed swell heights result from wave interference patterns, so that prediction by SEASAT-A would be difficult.

In normal seas, returning empty tankers would be ballasted for most efficient steaming. The existence of weather seas requires extra ballast which again reduces transit speed and increases fuel consumption and transit time. In addition, dirty tanks must be cleaned to accept ballast and increased usage of the ballast tanks increases the salt water corrosion rate of the tank's steel plate. This can shorten the effective life of a tanker, or increase the amount of necessary tank washing, or require heavier ballast tank steel plate.

With the reopening of the Suez Canal, owners of tankers with ballasted draughts of about 50 feet, approximately up to 150,000 tons, can choose their route on the basis of predicted weather in the vicinity of South Africa. This choice requires a complex economic trade-off in terms of transit time savings, canal tariffs, the state of tankerage demand and the quality of prediction. Since the steaming time at the point of decision, Gibraltar, to the Cape of Good Hope is seven to eight days, this would be the necessary prediction interval. Again it seems unlikely that SEASAT-A data could contribute to the resolution of this particular tanker problem.

### Conclusion

The increase in shipping, particularly oil shipping, in the last few years in the vicinity of the Republic of South Africa has clearly been the inspiration for many studies and measurements of sea conditions in the

waters involved. The three sea phenomena addressed in this investigation, the Agulhas Current, abnormal waves and anomalous swell wave heights, have all been part of these studies and measurements. As a consequence, the Agulhas Current location and speed appears to be well determined; a theory and practice allowing mariners to maximize or avoid encounters with abnormal waves has been developed and statistical observation data on anomalous wave conditions have been collected and evaluated.

It is reasonably certain that the capabilities and operational limitations of SEASAT-A indicate that it is unlikely that a successful economic validation experiment can be performed in this region and further study for this purpose is not recommended. However, satellite observation of this region of a synoptic and continual character would seem useful to the scientific and economic community. It seems necessary to fully identify the extent and magnitude of the Agulhas Current, particularly the unmapped components that move north to northeast. It also seems necessary to confirm the theory of the generation of abnormal waves, to determine how frequently they occur and to confirm the regional extent of their occurrence. For this, it is necessary to determine an abnormal wave "signature" or "signatures." Yet the phenomenon appears, from theory and observation, to last only a few minutes and to be a quasi-random phenomenon. It seems reasonable to assume that the SEASAT-A radar resolution would be adequate to the detection task, but a combination of high resolution imaging radar and high resolution IR imagery may be more helpful.

The patterns of anomalous waves need to be observed to see if they have either a completely unpredictable structure or height and length distribution variations as a function of time, since their origin seems to be

in a reasonably regular meteorological activity. If there is a regularity to ocean wave characteristics, then this regularity could be applied to tanker scheduling. It would be necessary to know the frequency of occurrence and the duration of occurrence of low, medium and high swells and be able to suitably predict their occurrence and duration.

#### 4.2.3 Applications to the Ocean Fishing Industry

##### 4.2.3.1 Crab Fisheries Off the Labrador Coast

This experiment would be similar to the Alaskan king crab and tanner crab fishery experiments. However, it would take place on the east coast of Canada in Newfoundland, Prince Edward Island, and the Gulf of St. Lawrence. This area has very similar problems to those encountered in Alaska. Ice makes the season quite short. Thus, fishermen are anxious to make use of all apparently ice-free days that are available. In 1974, for example, wind kept the ice in near the northeast shore of Newfoundland. Then the wind changed and the ice appeared to be gone. Actually, it had moved out about 20 miles. The fishermen, who sought quickly to take advantage of the situation, suffered losses of about \$5 million in gear (traps, gill nets, lobster traps) when the wind changed again and the ice moved back in. In this year, the area from Cape Norman to Cape Race on the east coast, Cape Norman to Cape St. Gregory on the west, and Labrador north and south of Cape St. Charles was declared a disaster area. There was a recurrence of this problem again in 1975. There are several thousand fishermen that are affected by ice and storms in the area from the north shore of Quebec, down the coast of Labrador to Newfoundland. Storms affect fishing operations on a regular basis, but ice is a significant variable. It can present no problem one year and create a disaster the next.

also provide an indication of further increases in shipping efficiency to be expected from the fully operational SEASAT system, and may aid in the development and calibration of a predictive iceberg movement and deterioration model.\*

#### The Problem

During the months of December through July, shipping traffic between northern Europe and Canadian and northeast U.S. ports is routed based on, among other factors, sea ice and iceberg conditions in the Grand Banks region southeast of Newfoundland. Routes have been defined to the south of the iceberg region for maximum shipping safety but the iceberg field edge is frequently poorly defined so that all shipping requires precise information about iceberg location during the 240-mile transit, if transit time delay is to be minimized. Ships currently have two transit choices. They can proceed through the ice region at reduced speed or they can follow a course further south around the ice region at normal operating speeds. The former alternative usually requires a one-third speed reduction, the latter alternative an additional 100 miles of steaming. With an average cruising speed of 16 knots, the former alternative results in about 7.5 hours increase in transit time and the latter alternative about 6.25 hours.

Interview information from shippers operating in this area indicates that of the six to eight hours delay associated with the ice region passage, four hours could be saved through information contributed by SEASAT. Further, the frequency with which severe iceberg and sea state conditions occur leads to an estimate that about 50 percent of the transit traffic would

---

\*Communication with Capt. Kollmayer, USCG R&D Center, Connecticut, October 1976.

participate in this four-hour savings. Based on 1974 operating costs of \$9,700 per day and 6,700 voyages during the iceberg season, benefits are expected to be about \$5.4 million annually.\*

#### Background

The Grand Banks region is infested with icebergs that drift southward in the Labrador current from Greenland and Baffin Island. The bergs are protected within a field of sea ice that may extend south of Newfoundland in the months of January and February. As the sea ice recedes, the icebergs continue their drift southward, endangering shipping traffic in the Grand Banks region, in the vicinity of the 48th parallel.

The International Ice Patrol (IIP) was formed in 1914 following a conference on the safety of life at sea. Its charter is to coordinate, collect and disseminate sea ice and iceberg information for the Grand Banks region. Since its inception, the IIP has been the administrative and operational responsibility of the United States Coast Guard. Most countries pay for IIP service on the basis of gross tonnage benefiting, which is determined through port information collected by the Canadian Government and the U.S. Bureau of Census. Benefiting tonnage for recent years are shown in Table 4.10. The precise length of the operating season for the IIP depends on year-to-year ice conditions. The surveillance and ice report activities are performed while there are substantial numbers of icebergs below 48° N latitude.

Surveillance activities include aerial (visual and radar) reconnaissance, USCG cutter reports, and voluntary reports from ships in the area. Typical flight reconnaissance patterns are illustrated in Figure 4.30 in Section 4.2.2.2. During the 1973 season, there were 77 such flights.

---

\*SEASAT Economic Assessment, ECON, Inc., October 1974, pp. 7-73.

| Table 4.10 Maritime Shipping Expressed in Gross Tons Benefiting from International Ice Patrol |             |
|-----------------------------------------------------------------------------------------------|-------------|
| 1971                                                                                          | 83,148,000  |
| 1972                                                                                          | 93,877,000  |
| 1973                                                                                          | 107,805,000 |
| 1974                                                                                          | 96,448,000  |
| 1975                                                                                          | 102,326,000 |
| Source: Office of Maritime Affairs, U.S. Department of State.                                 |             |

In addition to the above, the IIP updates ice positions by using a computer model of iceberg movement and deterioration. The model uses latest positional data observations supplemented by current, wind and sea temperature observations. The assumed parameters for ocean currents are based on "first principles" and have not been validated. An effort is under way at the USCG Research and Development Center to perfect an eight-day predictive model of the Labrador Current<sup>\*</sup> based on actual current inputs. The existing iceberg movement model has not been formally tested for the accuracy of its predictions of iceberg drift and deterioration.<sup>\*\*</sup>

<sup>\*</sup> Communication with Dr. Welsh, USCG Research and Development Center, September 1976.

<sup>\*\*</sup> Communication with Commander Albert Super, IIP, July 1976.

Based on the above data the patrol prepares, twice daily, bulletins describing the positional limits of sea ice and icebergs. These reports are broadcast from four radio stations in the United States, Canada and Europe. Facsimile broadcasts of sea ice and icebergs are made daily from the Boston station, for ships equipped with facsimile receivers. An example of the type of data available is illustrated in Figure 4.42.

Aerial reconnaissance efforts are hampered by fog and bad weather. Even aircraft with "all weather" sensors are ineffective when weather conditions prohibit takeoff. The periods of bad weather are most critical to the shipping decision makers, since winds are strongest and ice is most mobile during storm conditions. In addition, given the available number of aircraft, it is impossible to cover the entire region on a daily basis, even under ideal weather conditions.

These services are used for route selection and scheduling for transit navigations but generally lack the precision, in both information and updating frequency, to allow schedules to be finely tuned with dependability. SEASAT's information input will supplement the IIP to allow this fine tuning of schedules if the SEASAT supplied data can be integrated into the operations of the IIP. The operational SEASAT system will provide all-year and all-weather ice detection capability for the area observed while the satellites are in range of the Shoe Cove Station. This area is illustrated in Figure 4.31 in Section 4.2.2.2. SEASAT's scanning microwave radiometer (SMMR) and synthetic aperture radar (SAR) will provide information on sea ice extent and larger (>15m) icebergs. Though it is not certain that the bergs will be distinguishable from small fishing vessels, both are hazards to be avoided by shipping traffic. SEASAT information, at least in the

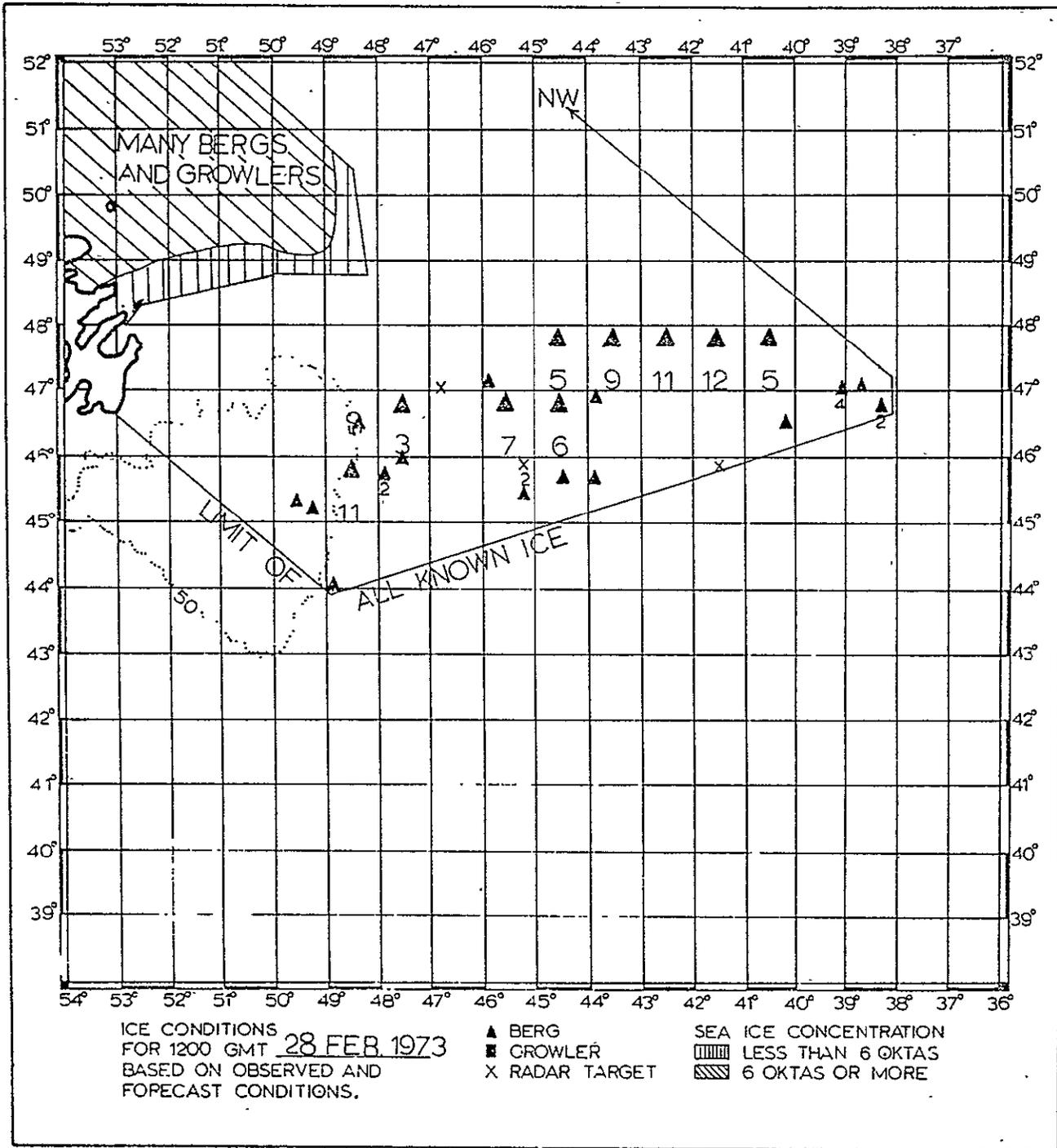


Figure 4.42 Ice Conditions on February 28, 1973  
 (Source: USCG: Report of the International Ice Patrol Service in the North Atlantic Ocean, 1973. Bulletin No. 59.)

short run, will not supplant but rather supplement current IIP data collection efforts. SEASAT-A will not provide daily SMMR and SAR coverage of the Grand Banks region, but the information provided by the sensors will be significant. Typical coverage patterns for SMMR and SAR are shown in Figures 4.32 and 4.33 in Section 4.2.2.2.

#### Experiment Purpose

SEASAT's microwave radiometer and synthetic aperture radar sensors can provide additional information on sea ice and icebergs in the Grand Banks region. The purpose of this experiment would be to estimate the value of this added information to shippers who use the services of the International Ice Patrol. The value of this information would be determined by examining logs of actual trips taken before and after the launch of SEASAT-A. The experiment would also examine the practical problems of SEASAT-A data analysis and distribution methods, and provide opportunities for development and calibration of more accurate iceberg drift and deterioration models.

#### Experiment Description

The experiment would compare two samples of ship crossings; those traversing the Grand Banks region with present IIP information, and those crossings having additional SEASAT information. Experimental and control crossings would be screened on the basis of weather and ship class to form representative samples. Sample ship owners would be asked to provide pre- and post-voyage information of route, transit time, fuel costs, and ice related delays.

Performance differences due to improved IIP sea ice and iceberg forecasting capabilities would then be examined. Benefits under conditions of added information may occur due to:

- Transit time savings
- Fuel savings
- Reduced loss of life and/or vessel damage.

Dollar estimates of benefits to the experimental sample should be representative of benefits incurred by all shipping traffic using the services of the International Ice Patrol.

#### Experiment Sample Description

The population consists of all vessels benefiting from the services of the IIP in a single year. The bulk of these vessel transits occurs during the months of January through July, and are between Europe and either the St. Lawrence Seaway or the northern Atlantic ports. If the Belle Isle Strait experiment is performed, then St. Lawrence traffic should be excluded from the present sample, or it will be difficult to combine the benefits estimated in these separate experiments. In addition, if the Ocean Routing Experiment is undertaken, its sample selection and benefit inference must exclude traffic that is considered in this experiment. This, again, is to avoid double counting the benefits that are experimentally verified during the operation of SEASAT-A.

Based on the above determination of eligibility, experimental group samples would be taken for the 1978 through 1980 ice seasons. The control group sample would be based on historical trip data from the most recent pre-SEASAT years with weather conditions similar to the 1978-1980 experimental period. Furthermore, due to the reluctance of users to rely on new untested data, a panel of shipping experts would examine the trip data for a subset of the experimental group. This panel would attempt to determine changes in routing (and resulting benefits) that would have occurred if the

SEASAT data were accepted as fully reliable. This panel may estimate the worth of the added information provided by the fully operational SEASAT system.

As outlined above, the experiment would attempt to examine performance differences among four groups.

- Group 1: Recent historical trips without SEASAT data
- Group 2: 1978-1980 actual crossings with SEASAT-A data available
- Group 3: 1978-1980 crossings with SEASAT-A data fully accepted
- Group 4: 1978-1980 crossings with fully operational SEASAT data accepted.

These groups must be similar in all respects excluding use of SEASAT data. Any lack of similarity will weaken the power of statistical measures of benefits due to SEASAT information use. Thus, it is important to select sample Groups 1 and 2 above from those whose important characteristics match each other closely, and who are fairly representative of the overall population. Important factors are identified in Section 4.1.2.1, An Ocean Routing Experiment, and a method for obtaining representative samples, given many such variable factors, is suggested there.

#### Results Analysis

Assuming such a selection is possible, several characteristics of performance will be measured for each group:

- Route
- Ice hazard encounters, and associated vessel damage and loss of life
- Trip delays due to unforeseen ice
- Transit time
- Fuel consumption.

Associated with each performance factor is a corresponding cost in dollars. This cost would, in general, depend on the vessel type assumed for the voyage. For example:

$T_{ijk}$   $\equiv$  trip delay (hours) for trip  $i$  in vessel class  $j$  of sample group  $k$

$C(T_{ijk})$   $\equiv$  associated (1978) dollar costs for the above delay.

The "C" function should be based on cost statistics for the shipping industry. One potential source is a survey conducted by H. P. Drewry (shipping consultants) through the April 1975 issue of "Shipping Statistics and Economics."

Cost savings per vessel class would be based on the average savings over the sample trips for vessels in that class. For example:

$$\frac{\text{Dollar benefits for vessel class "j" transit time savings based on actual SEASAT-A information use}}{=} N_j \left( \frac{\sum_{i=1}^P C(T_{ij2})}{P} - \frac{\sum_{i=1}^Q C(T_{ij1})}{Q} \right)$$

where

$N_j$  = number of trips of vessel class  $j$  benefiting annually from IIP services

$P$  = number of trips of vessel class  $j$  in experimental group (Group 2)

$Q$  = number of trips of vessel class  $j$  in control group (Group 1).

Similar analyses could yield estimates of benefits for each performance characteristic mentioned above. These estimates, made for several vessel types benefiting from IIP and for general IIP benefiting traffic, would be based on actual data collected for a representative sample. The results would indicate the value of SEASAT sea ice and iceberg information to the International Ice Patrol and its users.

### Experiment Implementation

While both the International Ice Patrol and its users are most interested in the capabilities of SEASAT, they will be cautious to rely on this data, as lives and property are at stake. The cooperation of the IIP in this experiment is based on the assumption that there will not be encouragement of risk taking for the experimental group. From a preliminary survey of Canadian and U.S. shippers, we find mixed reactions to the experimental monitorings of routes and transit time.\* Selection of sample groups appears possible though not easy, and requires, at the least, anonymity of the vessels involved.

#### 4.2.4.2 Application to Great Lakes Ice Monitoring

##### Introduction

Until the winter of 1972-73, shipping traffic in the Great Lakes was halted due to ice from late December through March. A \$6.5 million federal program to extend the season was begun, with benefits estimated at \$360 million per year. The shipping lanes from western Lake Superior to southern Lake Michigan were kept open all year for the first time in 1975. The average annual cost of this effort is expected to be roughly \$40 million.\*\* The possibility of a SEASAT economic verification experiment was considered for this region; however, at the present time it appears that the benefits of such an experiment would not be worth the effort for reasons outlined below.

##### The Problem

An area of increasing commercial shipping interest is that of the Great Lakes--St. Lawrence Seaway region (see Figure 4.43).

---

\* Communication with Bob Raguso, Bendix Corp., October 1976.

\*\* Communication with M. DiGiovanni, U.S. Army Corps of Engineers, October 1976.

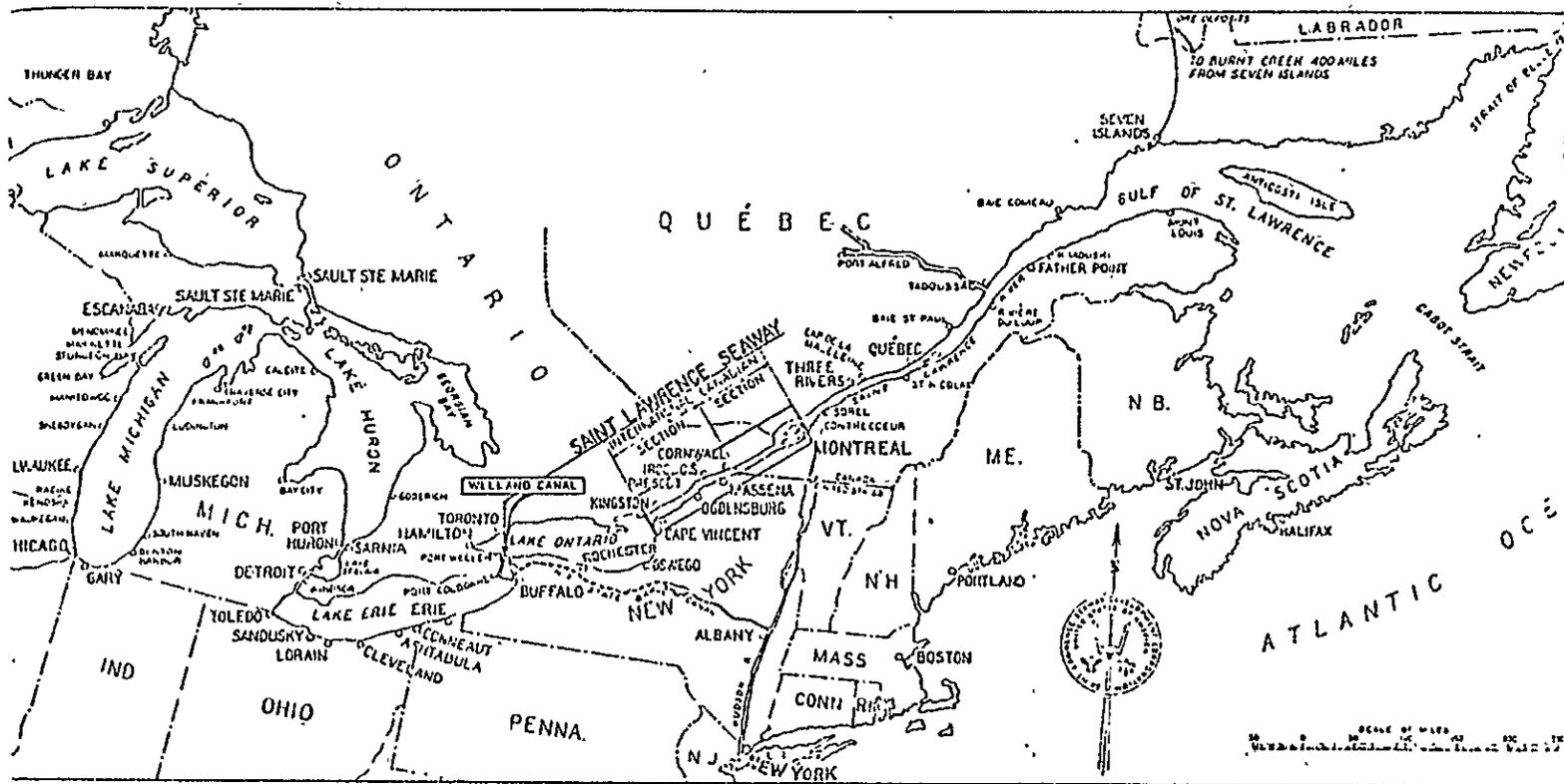


Figure 4.43 Great Lakes--St. Lawrence Seaway Under Navigation Season Extension Investigation. (Source: "The Great Lakes--St. Lawrence Seaway Winter Navigation Board," First Annual Report, Department of the Army, Corps of Engineers, Detroit, Michigan, 1972.)

Interlake transportation of bulk commodities such as wheat, limestone, coal and iron ore comprise the majority of Great Lakes shipping activity. In 1972, 217 million net tons of bulk cargoes were hauled on the lakes. For the same period, general cargo through the St. Lawrence was only 7 million tons.\* Unfortunately, in past years navigation on the Great Lakes has been suspended every winter for about four months because of ice conditions. This is a costly practice because it forces the end users of the shipping services to engage in expensive stockpiling and/or to pay expensive ground transportation rates to move cargo during the interim period. Also, seasonal loss of jobs and underutilization of costly equipment and facilities pose additional economic problems.\*\* There were many reasons for the difficulties, including inoperable locks, ice clogged interlake routes and problems in loading and unloading ores in subfreezing temperatures.

#### Background

Recognizing the above problems, Congress authorized a feasibility study in 1965 of the practicability, means and economic justification for extending the navigation season on the Great Lakes and the St. Lawrence Seaway. Based on the favorable findings and recommendations of this initial study, a more extensive three-year (\$6.5 million) program involving ten federal agencies was established in FY 1972 for investigating and demonstrating the practicability of year-round navigation.\*\*\*

---

\* Ransom, W. R., "New Economic Life for the Great Lakes," The Society of Naval Architects and Marine Engineering, May 1974.

\*\* "Ice Reconnaissance: SEASAT Application in the International Ice Patrol Program," Final Report to ECON, June 1974.

\*\*\* King, Seth S., "Icebreakers Keeping Frozen Great Lake Open During Winter," New York Times, March 16, 1975.

The upper lakes remain free of solid ice due to the action of strong winds. The major problems for ships were at the docks, in the locks and through narrow and shallow interlake connections such as the 120-mile route through Whitefish Bay and St. Mary's River between Lakes Superior, Michigan and Huron. The development of "pelletized" ore relieved some of the loading/unloading problems. The action of Coast Guard icebreakers in Whitefish Bay, St. Mary's River and the Straits of Mackinac; along with the deepening of channels, helped ships to navigate through the interlake connections. In addition, locks have been modified so that they operate year round.

An important aspect of the season extension effort is the monitoring of ice and weather conditions in the Great Lakes region. It is here that SEASAT information might be of benefit in providing more timely ice and weather reports than are currently available. This, to some degree, may help shippers in route selection.

#### Experiment Shortcomings

The three major difficulties in designing a SEASAT-A experiment relate to users need, SEASAT capabilities, and problems in measuring benefits. Unlike the Grand Banks region in the IIP experiment, the most important areas for ice surveillance, the interlake connections, are relatively small and effectively covered by aerial reconnaissance and ship reports. It would most likely be more cost effective to improve timeliness in the existing system rather than gear up for SEASAT data analysis and distribution.

In addition, the capabilities of SEASAT A, and most likely of an operational SEASAT system, are not sufficient to meet all informational needs and thereby supplant current aerial reconnaissance. For example, SEASAT's determination of ice thickness is based on determining the age (one year, two

years, etc.) of the ice, while all Great Lakes ice is "new" ice by these standards. In addition, daily coverage of the area will not be possible with SEASAT-A.

This lack of ability to supplant the current information system leads to the third area of difficulty: benefit measurement. In spite of the shippers' enthusiasm for its use,<sup>\*</sup> it is doubtful that SEASAT data would make much, if any, difference in transit times. In 1972-73 the average transit time between Lake Superior and Lake Michigan for AAA vessel class iron ore carriers was 5.9 days during the extended season. This is only .5 days more than during the regular season average.<sup>\*\*</sup> This does not leave much room for improvement, considering the fact that there will be inevitable delays in the locks and interlake connections that SEASAT cannot reduce. This problem was verified by the Chairman of the Working Group on the Great Lakes Season Extension, who felt that SEASAT benefits would mainly arise from reduced information collection costs.<sup>\*\*\*</sup> However, as stated above, SEASAT-A probably will not supplant surveillance efforts.

For these reasons, an economic verification experiment for the Great Lakes Region is not recommended at this time.

---

<sup>\*</sup> Communication with William Buhrman, U.S. Steel, October 1976.

<sup>\*\*</sup> Ransom, William R., "New Economic Life for the Great Lakes," The Society of Naval Architects and Marine Engineers, May 1974.

<sup>\*\*\*</sup> Communication with M. DiGiovanni, U.S. Army Corps of Engineers, October 1976.

#### 4.2.5 Other Experiments

A variety of other experiments have been considered to a limited extent by the Canadians. Brief descriptions of potential experiments are provided below.

##### 4.2.5.1 Caribou Migration Monitoring

Canada has great herds of caribou which roam across the Northwest Territories. At the present time very little is known about the habits of the caribou and their migration routes. Knowledge of these routes is important in planning gas and oil pipelines and other impediments to the movement of caribou. There appears a possibility that the SEASAT-A SAR will be able to identify caribou herds and areas over which they have migrated. The objective of this experiment would be to determine the capability of the SEASAT-A SAR to identify and monitor caribou herds with the purpose of determining their migration routes.

##### 4.2.5.2 Monitoring the Canadian 200-Mile Economic Zone

This experiment would be essentially the same as the experiment identified in Section 4.1.6.1, Marine Fisheries Surveillance of the 200-Mile Economic Zone, except that it would apply to Canadian territory. However, in addition to simply monitoring fishing activities in the 200-mile economic zone, Canada has a general interest in maintaining a log on the position of all ships operating in the northern areas. As shipping increases in the northern areas of Canada it would become increasingly important from the standpoint of safety to keep track of the position of ships operating in this area. The purpose of this experiment would be to determine the capability of SEASAT-A sensors to identify and track ships in the Canadian 200-mile economic zone and in the area of the Queen Elizabeth Islands.

#### 4.2.5.3 Circulation Patterns in the Beaufort and Labrador Seas

Two ocean currents are of importance to Canada in the offshore exploration for gas and oil. These are the Beaufort Sea Gyre and the Labrador Current. The Beaufort Sea Gyre is a clockwise movement of water in the Beaufort Sea area, and the Labrador Current is a current which flows from the Arctic Ocean down the east coast of Greenland, up the west coast to the Davis Strait and then down the Labrador coast of Canada. Knowledge of these currents is important both for prediction of ice and iceberg movements and to understand the potential damages that could be caused by oil spills. Historically, .031 to .113 percent of all oil handled has been spilled. It is projected that about 4 billion barrels per year of oil will be handled in the northern Canada areas. Thus, if historical records hold true, from 1.2 to 4.5 million barrels of oil per year might be spilled. On the one hand, due to strong environmental protection regulations and to use of high technology equipment, this spillage may be reduced. However, on the other hand, the extreme environment of this area may cause the spill to be closer to, or perhaps even exceed, the historical record. The effects of oil spills in the Arctic are poorly understood at present. For one thing, oil spills cause a change in the surface condition of the sea. Oil covered areas tend to be calmer than clean ocean areas. This has a severe affect on wild life, particularly birds which flock to the areas of calm sea. The mortality rate of birds landing in areas of oil spills is almost 100 percent. Another concern deals with the climatic effect of oil spills. Will such spills significantly affect the albedo, cause ice to melt or have an effect on the climate? The answer is not known at this time; however, it is expected that reasonable size spills will not have a big effect on the

climate. Sea ice can contain (i.e., confine) oil spills and therefore it is important to understand ice dynamics in the areas of oil exploration. Three projects are on-going at the present time. The most important is the AIDJEX project in the Beaufort Sea. The purpose of this project is to better understand Arctic ice dynamics. Two other projects, POLEX and BESEX, are being conducted to determine the effect of oil spills on the environment. The objective of an experiment in this area would be to make use of SEASAT-A data to help in the development of an understanding of ice dynamics in the Beaufort Sea Gyre and Labrador Current areas.

#### 4.2.5.4 Planning Data for the Design of Structures

Little is known about the environment in the far northern areas of Canada. This presents a problem in the design of structures to withstand environmental conditions in these areas. This experiment would make use of SEASAT-A sensors to gather data to improve the understanding of climatic conditions in the northern Canada areas as a basis for the improved design of structures. Areas of particular interest would include structures that are to be placed on the ice, and ships, particularly drill ships, to be used in the exploration for oil and gas. Observation of pressure ridges and ice structure would be key.

#### 4.2.5.5 Snow Water Equivalent Mapping

A knowledge of the water equivalent contained in snow cover is important for decision making in water impoundment management. This experiment would focus on the use of SEASAT-A sensors to measure snow water equivalent in the Columbia River basin as an aid to forecasting snowmelt runoff. This information would be useful in water impoundment management decisions for hydropower generation on the Columbia River. While this is an intriguing area and one.

of significant potential benefit, the likelihood of technical success may not be very good.

#### 4.3 Targets of Opportunity

There exists a variety of very interesting and potentially very beneficial applications of SEASAT data for which it is impossible or impractical to plan economic verification experiments. These applications relate to rare or fleeting phenomena, the observances of which by SEASAT-A cannot be planned in advance. Rather, these phenomena would be observed only as the result of the joint chance events that, a) the phenomena occur during the operational period of SEASAT-A and, b) that SEASAT-A happens to be in a position to observe the phenomena as they occur. Obviously, the chance that any specific phenomenon will be observed by SEASAT-A is remote. Nonetheless, many different types of phenomena can occur and it is likely that SEASAT-A will observe some of them. Such has been the case, for example, with LANDSAT-1 which provided data on the flooding of the Mississippi River, sandstorms in the Mojave Desert and other "unusual" phenomena which, taken as an independent data source, have proven immensely useful for a specific application. It should be anticipated that similar, economically important, opportunities will arise for SEASAT-A. It is reasonable, in planning economic verification experiments, to provide for the opportunity to obtain and analyze data relating to "unusual" phenomena on an ad hoc basis. Examples of what might be anticipated are provided below.

Water Incursion. Severe storms and unusually high tides can cause flooding of low-lying coastal areas. SEASAT might have the capability to monitor flood conditions during periods of darkness and cloud cover and

thus guide rescue and relief efforts to those areas most severely affected. There is a potential for saving lives as well as for monetary benefits.

Severe Storm Identification and Location. Storms of substantial vertical development are characterized by heavy precipitation, lightning and extreme atmospheric turbulence possibly including tornadoes. It would be of considerable interest to evaluate SEASAT sensors for the identification of such storms and to determine if it is possible to locate tornadoes or conditions likely to result in tornadoes. While there exists an extensive ground-based radar network in the United States for the observance of such storms, this network might be augmented in the future by a space-based system and coverage might be extended to areas not presently covered, for example, the Amazon Basin.

Mapping Flooded Areas. The Department of Housing and Urban Development is conducting a large scale flood plain mapping program in support of the Flood Insurance Program. As a supplement to this effort, it is always of considerable interest to know the extent of a flood at its crest. Unfortunately, many floods, especially flash floods, crest during a period of bad weather. It would be of considerable value if SEASAT could obtain an image of a flood at its crest.

Search and Rescue. In the event that a medium to large size aircraft were to be lost in a remote area, SEASAT might be useful in locating it. Search and rescue operations in ocean areas are particularly difficult. It might be desirable to test various size, collapsible corner reflectors for search and rescue efforts in the future. It is interesting to observe that SAR has been used in search and rescue operations in the past. For

example, an SR-71-based SAR was used--at considerable expense--in the search for Senator Hail Boggs a few years ago.

Tsunamis. It would be of interest to determine if SEASAT could detect tsunamis on the open ocean. The amplitude of these waves is relatively small but the wavelength is long, thus detection might be possible.

Oil Spills. It is likely that one or more major oil spills will occur during the operational period of SEASAT-A and SEASAT could prove to be a useful tool in directing efforts to contain the spill. If spill areas can be mapped and monitored by SEASAT, this could be an area of significant benefit.

Unusual Biological Phenomena. Occasionally, there are extensive ocean areas wherein unusual biological phenomena (for example, red tide) occur.

It would be of interest to determine which phenomena can be detected by SEASAT and to monitor various ocean parameters in known affected areas to provide additional data for scientific study.

No doubt, many additional potential opportunities exist. The above list is not meant to be exhaustive. Rather, it is meant to be illustrative and to stimulate the imagination such that opportunities to provide real and significant services are not missed.

## 5. EXPERIMENT EVALUATION AND RANKING

Because of resource limitations it may not be possible to perform all of the experiments that have been considered in this study. A rating of the candidate SEASAT-A experiments is provided to aid in selecting those that could be performed. Each of the experiments described in Section 4 has been rated according to eight attributes. These are identified as evaluation criteria and include the following:

- User interest
- Availability of SEASAT data
- Ability to demonstrate benefits
- Ability to generalize results
- Cost of implementing experiment
- User participation
- Expected economic significance
- Expected technical significance.

These attributes (defined below) might not be exhaustive and other attributes may need to be considered in the selection process. In addition, no attempt is made to assign importance to or to weight the attributes that are listed. The ratings are shown in Table 5.1.

The attribute-by-attribute ratings for each experiment are presented on a scale of one to ten with one indicating a low rating for that attribute and ten a high rating, except in the case of the expected cost of implementing the experiment where ten indicates a low expected cost and one indicates a high expected cost. It is important that the reader understand the nature of the ratings and use them accordingly. The ratings presented are subjective; derived by ECON through its knowledge of each experiment.

Table 5.1 Rating of Candidate SEASAT-A Economic Verification Experiments

| Experiment Title         | Attribute <sup>a</sup> |               |                             |                                 |                               |                                 |                    |                                |                            |                |
|--------------------------|------------------------|---------------|-----------------------------|---------------------------------|-------------------------------|---------------------------------|--------------------|--------------------------------|----------------------------|----------------|
|                          | Reference Section      | User Interest | Availability of SEASAT data | Ability to Demonstrate Benefits | Ability to Generalize Results | Cost of Implementing Experiment | User Participation | Expected Economic Significance | Expected Technical Success | Minimum Rating |
| Offshore Oil and Gas     | 4.1.1                  | 10            | 9 <sup>o</sup>              | 7                               | 9 <sup>o</sup>                | 7                               | 10                 | 10                             | 8 <sup>oo</sup>            | 7              |
| Ocean Routing            | 4.1.2.1                | 7             | 9                           | 5                               | 9                             | 7                               | 6                  | 9                              | 9                          | 5              |
| Valdez Tanker Routing    | 4.1.2.2                | 1             | 9                           | 4                               | -                             | 8                               | 2                  | 1                              | 9                          | 1              |
| Tuna Fisheries           | 4.1.3.1                | 6             | 8                           | 2                               | 7                             | 8                               | 9                  | 3                              | 6                          | 2              |
| Alaskan Crab             | 4.1.3.2                | 9             | 7                           | 7                               | 6                             | 5                               | 9                  | 5                              | 8                          | 5              |
| Fish Yield               | 4.1.3.3                | 8             | 10                          | 5                               | 8                             | 9                               | 3                  | 3                              | 6                          | 3              |
| Marine Upwelling         | 4.1.3.4                | 9             | 8                           | 8 <sup>++</sup>                 | 6                             | 8                               | 10                 | 6                              | 9                          | 6              |
| Alaskan Sea Ice          | 4.1.4.1                | 4             | 5                           | 2                               | 4                             | 8                               | 3                  | 3                              | 8                          | 2              |
| Hurricane Landfall       | 4.1.5.1                | 5             | 2                           | 7                               | 9                             | 10                              | 7                  | 4                              | 5                          | 2              |
| U.S. 200-Mile Limit      | 4.1.6.1                | 6             | 10                          | 7 <sup>**</sup>                 | 10                            | 10                              | X                  | 2                              | 9                          | 2              |
| Marine Mammal            | 4.1.6.2                | 3             | 3                           | 1                               | 2                             | 10                              | 8                  | 1                              | 5                          | 1              |
| Oil--Beaufort Sea        | 4.2.1.1                | 10            | 7                           | 8                               | 7                             | 5                               | 10                 | 9                              | 6                          | 5              |
| Oil--Labrador Sea        | 4.2.1.2                | 10            | 7 <sup>+</sup>              | 8                               | 7                             | F                               | 10                 | 9                              | 5                          | 5              |
| On-Ice Seismic           | 4.2.1.3                | 6             | 6                           | 6                               | 3                             | F                               | 9                  | 2                              | 3                          | 2              |
| Polar Gas Transport      | 4.2.2.1                | 7             | 6 <sup>+</sup>              | 8                               | -                             | F                               | 8                  | 7                              | 6                          | 6              |
| Selle Isle               | 4.2.2.2                | 7             | 4 <sup>+</sup>              | 8                               | -                             | F                               | 8                  | 4                              | 5                          | 4              |
| Agulhas Current          | 4.2.2.3                | 5             | 1                           | 1                               | -                             | 2                               | 3                  | 4                              | 2                          | 1              |
| Labrador Crab            | 4.2.3.1                | 5             | 6                           | 6                               | 6                             | F                               | 7                  | 4                              | 8                          | 4              |
| International Ice Patrol | 4.2.4.1                | 7             | 5 <sup>+</sup>              | 7                               | -                             | 5                               | 8                  | 3                              | 6                          | 3              |
| Great Lakes Ice          | 4.2.4.2                | 2             | 3                           | 4                               | -                             | 5                               | 1                  | 2                              | 3                          | 1              |
| Caribou Migration        | 4.2.5.1                | 3             | 2 <sup>+</sup>              | 2                               | -                             | 10                              | 4                  | 1                              | 1                          | 1              |
| Canada 200-Mile Limit    | 4.2.5.2                | 7             | 10                          | 7 <sup>**</sup>                 | 10                            | F                               | 7                  | 2                              | 9                          | 2              |
| Gyres                    | 4.2.5.3                | 7             | 3                           | 4                               | -                             | F                               | 8                  | 2                              | 3                          | 2              |
| Planning Data            | 4.2.5.4                | 6             | 6                           | 3                               | 6                             | F                               | Y                  | 4                              | 3                          | 3              |
| Snow Water Equivalent    | 4.2.5.5                | 6             | 8 <sup>*</sup>              | 4                               | 6                             | F                               | 3                  | 5                              | 2                          | 2              |

<sup>a</sup> Scale is 1 low to 10 high, except for Cost of Implementing Experiment where 1 is high cost and 10 is low cost.

<sup>+</sup> Assumes the installation of a SEASAT reception station at Shoe Cove (see Figure 4.29 for location).

<sup>\*</sup> Observations over land.

<sup>++</sup> Assumes large expenditure. The problem in demonstrating benefits in the Marine upwelling experiment will be statistical in nature. If a large sample is taken benefits could be demonstrated quite easily; this, however, will be quite costly.

<sup>\*\*</sup> Assumes that the 200-Mile Limit will be approved and patrolled.

<sup>o</sup> Experiment results which are not related to ice will be easily generalized.

<sup>-</sup> Generalized within itself, that is, the experiment covers the entire area or population to which it is applicable.

<sup>F</sup> Foreign government supported, assumes no cost to the United States government.

<sup>X</sup> Because the responsibility for and funds in support of the 200-Mile Limit have not been assigned to an agency or agencies, user participation is uncertain.

<sup>Y</sup> The Data Planning experiment would be a general data gathering process and user participation in the experiment itself will not be required.

<sup>oo</sup> Assumes wind and wave nowcasts and forecasts for a 24-hour period.

The experiment-to-experiment ratings for each attribute are believed to be consistent, that is, they provide a rank ordering of experiments attribute by attribute, but they do not provide a cardinal comparison of one experiment against another. Thus, the reader is cautioned against the use of the ratings shown in a weighted evaluation (utility) index. The numbers in Table 5.1 are ordinal numbers and should not be misconstrued to have additional meaning.

The attributes by which each candidate experiment is rated are defined below:

1. User interest--each experiment deals with a particular, potential SEASAT data user community. This attribute pertains to the interest expressed by the user community in the SEASAT program and the results which will be obtained from the SEASAT-A mission.
2. Availability of SEASAT data--each experiment will be supported in some way with SEASAT data. Both the collection and processing of these data are limited during the time frame of the SEASAT-A mission. This attribute pertains to the data requirements of each experiment and the extent to which the SEASAT-A system can meet those requirements. A high rating indicates that most or all requirements could be easily met. A low rating indicates that the SEASAT-A system capabilities may impose restrictions on the experiment.
3. Ability to demonstrate benefits--some experiments could produce results of a general scientific interest but which are difficult to relate to economic activities. Other experiments involve processes that can be directly related to economic activities. This attribute reflects the extent to which the SEASAT data gathered for the experiment can be related to economic activities and thence the extent to which a capability for obtaining economic benefits from an operational system can be demonstrated.
4. Ability to generalize results--due to system and resource limitations, any experiment performed during the SEASAT-A mission will probably be performed on something less than a global scale. Thus, the capability for economic benefits demonstrated by a SEASAT-A experiment would likely relate only to a fraction of the benefits attributable to an operational SEASAT system. This attribute relates to the extent to which the capability for benefits demonstrated in a SEASAT-A experiment can be generalized to obtain a measure of the potential benefits that will result from an operational SEASAT system.

5. Cost (to the U.S. government) of implementing experiment--while none of the experiments have been examined in sufficient depth to provide cost estimates for their performance, it is nonetheless clear that some will be more costly than others. This attribute reflects a preliminary rank ordering of experiments by cost. A low number reflects a high cost, a high number a low cost.
6. User participation--some experiments would involve actual SEASAT data user participation while others, for various reasons, might not. User participation is valuable from two points of view, first, it encourages technology transfer and, second, it can provide a nucleus of system proponents. This attribute pertains to the extent to which SEASAT data users would participate directly in an experiment.
7. Expected economic significance--benefits ultimately attributable to SEASAT have been quantified in the applications areas of some but not all of the proposed experiments. One goal of an economic verification experiment program is to demonstrate significant potential benefits attributable to an operational system. Thus, it is desirable, other factors aside, to concentrate on experiments that relate to large benefits on the global scale. This attribute relates to an approximate and preliminary rank ordering of experiments according to the likely or expected associated benefits attributable to an operational system.
8. Expected technical success--some experiments require measurements to be obtained from SEASAT data that there is a high expectation of obtaining. Others require untried or unproven uses of SEASAT data such that there is considerable technical uncertainty in the extent to which SEASAT data can serve a particular user. This attribute relates to the technical uncertainty associated with the application of SEASAT data. A high rating indicates a high degree of confidence that the technical capability of obtaining and using SEASAT data will be adequate to obtain the economic benefit expected.

In addition to the assumptions listed in the footnotes to Table 5.1 there are several other considerations associated with the rating by attribute.

#### User Interest

The Offshore Oil and Gas experiment is rated very highly because of U.S. offshore industry interest. It seems extremely likely that an experiment

will be carried out in this area, however, the exact experiment that will be performed is still under consideration by the industrial participants.

Interest in the 200-mile limit experiment has to date come from government agencies. However, since the implementation of the 200-mile limit has not yet been clearly defined, the only experiment considered has been a feasibility experiment for the detection of vessels using the SAR.

Interest in the Ocean Routing experiment has been gauged to be moderately high, however, strong definitive interest statements from the industry have not been received.

#### Availability of SEASAT Data

All the northeast Canadian experiments require the use of a Shoe Cove receiving station in order to make data available to users.

Real-time data requirements for all the experiments making use of the SAR (see Section 4) will be constrained by the ground processing capacity for that instrument. There is variation in the data availability for these experiments based on their location and dependence on instruments. For instance, ceteris parabus, data would be considered more available for an experiment which derived half its usefulness from SAR and half from VIR than it would be for an experiment totally dependent on SAR data.

Data for the 200-mile limit experiments (United States and Canada) could easily be made available by placing vessels of different classes in specific locations during SEASAT overpass. Therefore, possible ground truth measurements are readily available and controllable.

Data availability for the Marine Mammal experiment seems limited by virtue of the fact that it requires SAR data on a chance event. It will not be possible to control the ground truth possibilities.

Data for the On Ice Seismic experiment is, on the other hand, more available because the ground truth measurements can be controlled to a certain extent by those working in the area.

A freak wave in the Agulhas Current is a rare event lasting for a very short period of time. Because of resolution requirements it would appear that the SAR would be needed to image this event. It would be extremely fortuitous if the locations of the SEASAT-A SAR swath and the freak wave were to coincide. Moreover, an SAR receiving station in South Africa is not now planned.

Due to the nature and location of the gyres or large circulation patterns in the Beaufort and Labrador Seas, both SAR and ground truth measurements could be difficult to obtain.

#### Ability to Demonstrate Benefits

Several of the experiments, notably the Valdez Tanker Routing and the Alaskan Sea Ice experiments, will have limited ability to demonstrate benefits due to a low number of possible observations and the associated statistical problems.

#### Ability to Generalize Results

The 200-Mile Limit experiments will generalize extremely well in that, if vessel identification is possible with SEASAT-A, an operational SEASAT would be able to provide the same service for all countries with coastal areas. Therefore, the only variation in the generalization will stem from the economics of the ocean industries for specific countries.

Generalization in the Snow Water Equivalent will be limited by the peculiarities of the specific river basins in question.

Each of the other attributes is relatively straightforward with respect to the definitions presented earlier, except where noted by footnotes in Table 5.1.

### 5.1 Experiment Ranking

It is noted above that the ratings given each experiment by attribute provide only an ordinal ranking of experiments within each attribute. Consequently, the ratings should not be used in a utility function for the purpose of ranking the experiments. It is possible, however, to gain some insights for experiment selection without resorting to the use of utility functions. Accordingly, a first screening of the experiments is presented below making use of a lexicographic ordering scheme.

Recognize that the "ideal" experiment would be rated a 10 in each attribute. Recognize also that a low rating in any attribute is undesirable. Thus, a maxi-min evaluation is proposed. In this evaluation, the rating given to each experiment is the lowest rating given to any evaluated attribute of the experiment. These ratings are given in the right hand column of Table 5.1. The strategy is then to recommend those experiments that have the highest minimum ratings.

Using a maxi-min ordering, the Offshore Oil and Gas experiment ranks top, followed closely by Polar Gas Transport, Ocean Routing, Alaska Crab and Canadian-based offshore oil experiments. The experiments receiving lower ratings should not be summarily dismissed. Rather, a more careful evaluation of these should be made. Certainly, the Canadians should be encouraged to participate in the SEASAT program to the maximum reasonable extent. Their work should provide a valuable contribution to both the benefit evaluation and the technology development/transfer processes.

Other experiments, such as the 200-Mile Limit or the Tuna Fisheries, should receive serious consideration. The 200-Mile Limit experiment is a potential aid to another federal agency despite the low economic significance that can be attached to this experiment at the present time. Although at the time of this report the continuation of the U.S. tuna fishing industry is in serious doubt, if the present legal questions can be resolved the experiment could prove to be desirable on the basis of its expected low cost and extent of user participation.

## APPENDIX A

MARINE DATA PRODUCTS AVAILABLE TO THE  
EASTERN TROPICAL TUNA FLEET

The following is a description and some samples of information currently supplied by station WWD to the eastern tropical tuna fleet. The source of these data is the U.S. Department of Commerce, NOAA, NMFS, Southwest Fisheries Center, La Jolla.

Synopsis of Marine Products Provided by Radio Station WWD

## 1. Radio Facsimile Products

## A. Wind and Weather Analysis and Forecast, Figure A.1

- a) Time of Issue - Daily - Monday thru Sunday during the entire year at 2300 GMT (1600 PDT): Valid time of chart 1800 GMT that date.
- b) Broadcast Frequencies\* - 8444.1 and 17,408.6 kHz.
- c) Provided by - National Weather Service Forecast Office, Redwood City, Ca.
- d) Prime user - Tropical high seas tuna fleet. (Also copied and used by merchant ships.)
- e) Area covered - From the west coast of North and South America westward to 160°W between 20°S and 37°N.
- f) Content - Depicts wind speed, wind direction, position of the ITCZ, cloud cover, positions of severe weather, initial and forecast positions of tropical disturbances.

## B. Sea and Swell Analysis, Figure A.2

- a) Time of issue - Daily - Monday thru Sunday during the entire year at 2310 GMT (1610 PDT) - Valid time 1800 GMT that date.
- b) Broadcast Frequencies\* - 8644.1 kHz and 17,408.6 kHz.

---

\*Frequencies are carrier frequencies and broadcasts are made on the upper sideband.

- c) Provided by - National Weather Service Forecast Office, Redwood City, Ca.
  - d) Prime User - Tropical high seas tuna fleet. (Also copied and used by merchant ships.)
  - e) Area covered - From the west coast of North and South America westward to 160°W between 20°S and 37°N.
  - f) Content - Wave height, swell height, swell direction, swell period, and areas of rough seas.
- C. Weekly Mean Sea Surface Temperature Analysis (Tropical Area), Figure A.3
- a) Time of Issue - Weekly - on Thursdays during the year at 2320 GMT (1620 PDT). Based on data from the previous Thursday thru Wednesday (7 days).
  - b) Broadcast frequencies\* - 8644.1 and 17,408.6 kHz.
  - c) Provided by - Real-Time Fishery Systems staff - Southwest Fisheries Center, La Jolla.
  - d) Prime user - Tropical high seas tuna fleet.
  - e) Area covered - From the west coast of North and South America westward to 160°W between 10°S and 40°N.
  - f) Content - Weekly mean sea surface temperature (SST) isotherms derived from weekly 1° square averages of SST which are hand contoured. Contour interval 2°F with areas of sparse data coverage indicated by dashed isotherms.
- D. Weekly Mean Mixed Layer Depth Analysis, Figure A.4
- a) Time of Issue - Weekly on Fridays during the year at 2320 GMT (1620 PDT). Based on data from Thursday of the previous week thru Wednesday (7 days).
  - b) Broadcast Frequencies\* - 8644.1 and 17,408.6 kHz.
  - c) Provided by - Real-Time Fishery Systems staff - Southwest Fisheries Center, La Jolla.
  - d) Prime user - Tropical high seas tuna fleet.
  - e) Area covered - From the west coast of North and South America westward to 160°W between 10°S and 30°N.

- f) Content - Weekly mean mixed layer depth (MLD) derived from several numerical models that compute the MLD over 5° squares. The results are hand contoured at 50 feet depth intervals. Areas of sparse data are indicated by dashed contours.

E. Weekly Mean Sea Surface Temperature Analysis (Temperate Area)

- a) Time of Issue - Weekly on Friday during the albacore fishing season (approximately July thru October) at 1700 GMT (1000 PDT). Based on data from Thursday of the previous week thru Wednesday (7 days).
- b) Broadcast Frequency\* - 8644.1 kHz.
- c) Provided by - Real-Time Fishery Systems staff - Southwest Fisheries Center, La Jolla.
- d) Prime user - Albacore tuna fleet and several coast stations.
- e) Area covered - From the west coast of North America westward to 141°W between 28°S and 52°N.
- f) Content - Weekly mean sea surface temperature (SST) isotherms derived from weekly 1° square averages of SST and hand contoured. Contour interval 2°F.

2. Verbal Broadcasts via Radio

A. Daily Albacore Fishing Information

- a) Time of Issue - Twice daily - Monday thru Saturday morning during the albacore fishing season (approximately July thru October) at 1315 GMT (0615 PDT) and at 0045 GMT (1745 PDT). Saturday morning broadcasts are at 1415 GMT (0715 PDT). Broadcasts are updated at 0045, Monday thru Friday.<sup>1</sup>
- b) Broadcast frequencies - 4409.4, 8789.6, 13147.6 and 17408.6 kHz.<sup>1</sup>

<sup>1</sup>Broadcasts of daily albacore fishing information are issued from other sources as follows:

KFX (Astoria Marine Operator) on 2589 kHz at 0600 and 1945 PDT.

NMC (Point Reyes Coast Guard) on AM compatible frequency 2670 and on SSB carrier frequencies 4383.8, 8732.1, 13147.5 kHz at 0645 and 1945 PDT.

KNPT (Newport, Oregon) on commercial AM 1310 at 0615 and 1915 PDT.

KRED (Eureka, California) on commercial AM 1480 at 0615 and 0915 PDT.

- c) Provided by - Albacore Fisheries Program staff and the National Weather Service, Forecast Office, Redwood City, Ca.
- d) Prime users - Albacore fishing fleet, fish buying stations and canneries, coast stations, and sport fishing boats.
- e) Area covered - Offshore of the west coast of United States, Baja California and British Columbia out to 140°W.
- f) Content - The broadcast is divided into two parts, the first is entitled fishing information, which contains active centers of fishing, typical fishing scores, size of fish, surface and sub-surface water temperatures and other appropriate information. The second part contains weather and sea state information including large-scale weather features, regional wind, weather and sea state conditions between 20 and 250 miles offshore and storm development.

#### B. Tropical Storm Advisories

- a) Time of Issue - Daily - Monday thru Sunday as occurring during the entire year at 2310 GMT (1610 PDT). Used to supplement tropical facsimile advisories considered in 1A & B above.
- b) Broadcast frequencies\* - 4409.4, 8789.6, 13147.5 and 17408.6 kHz.
- c) Provided by - Real-Time Fishery Systems staff members.
- d) Prime user - Tropical high seas tuna fleet.
- e) Area covered - From the coast of North and South America westward to 160°W between 10°S and 40°N.
- f) Content - Contains information concerning tropical storms or other areas of inclement weather. The broadcasts contain present and forecast positions of storms, area of extent, winds to be encountered, direction and speed of the storm, pertinent sea state information and other information as required.

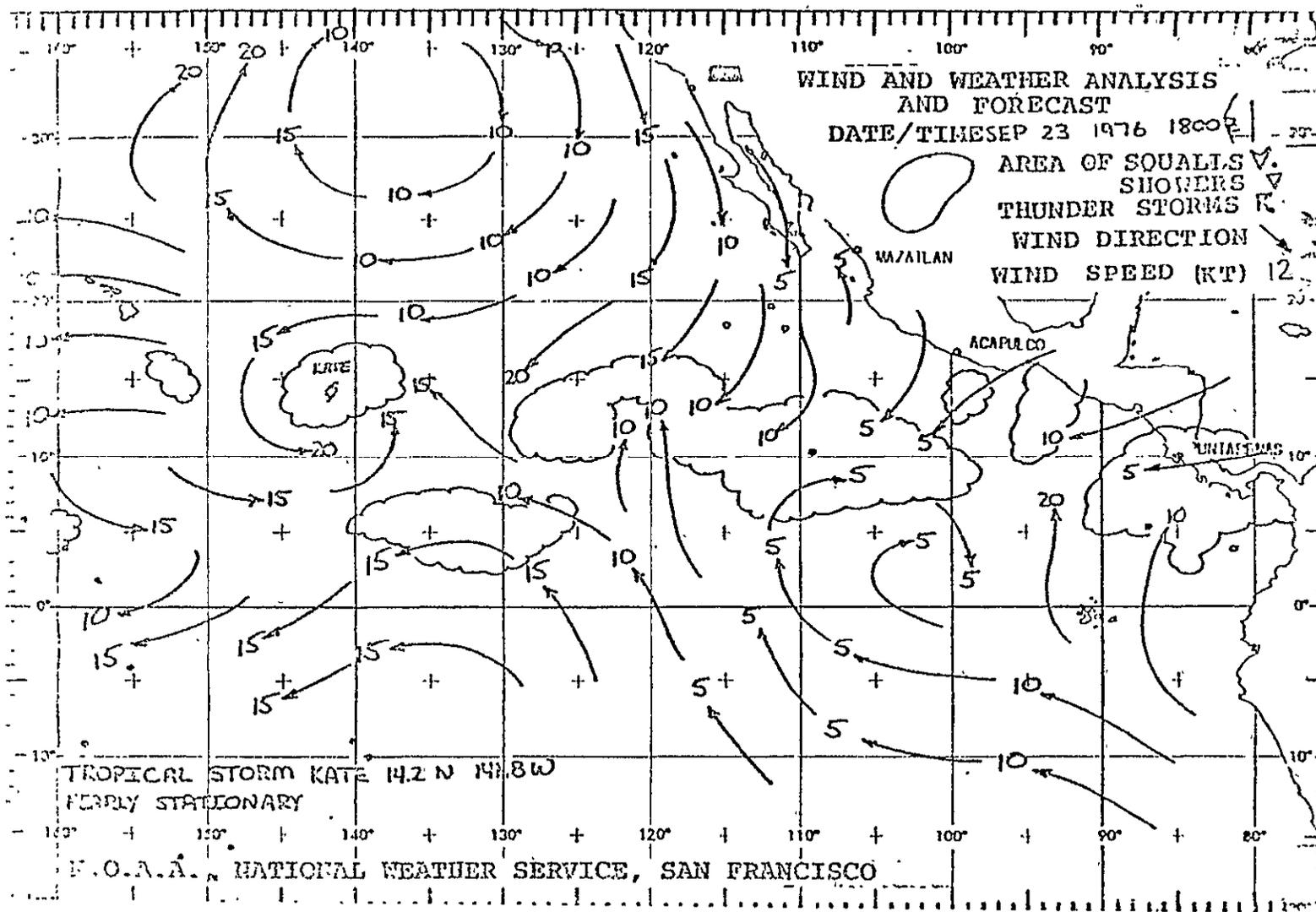


Figure A.1 Wind and Weather Analysis and Forecast

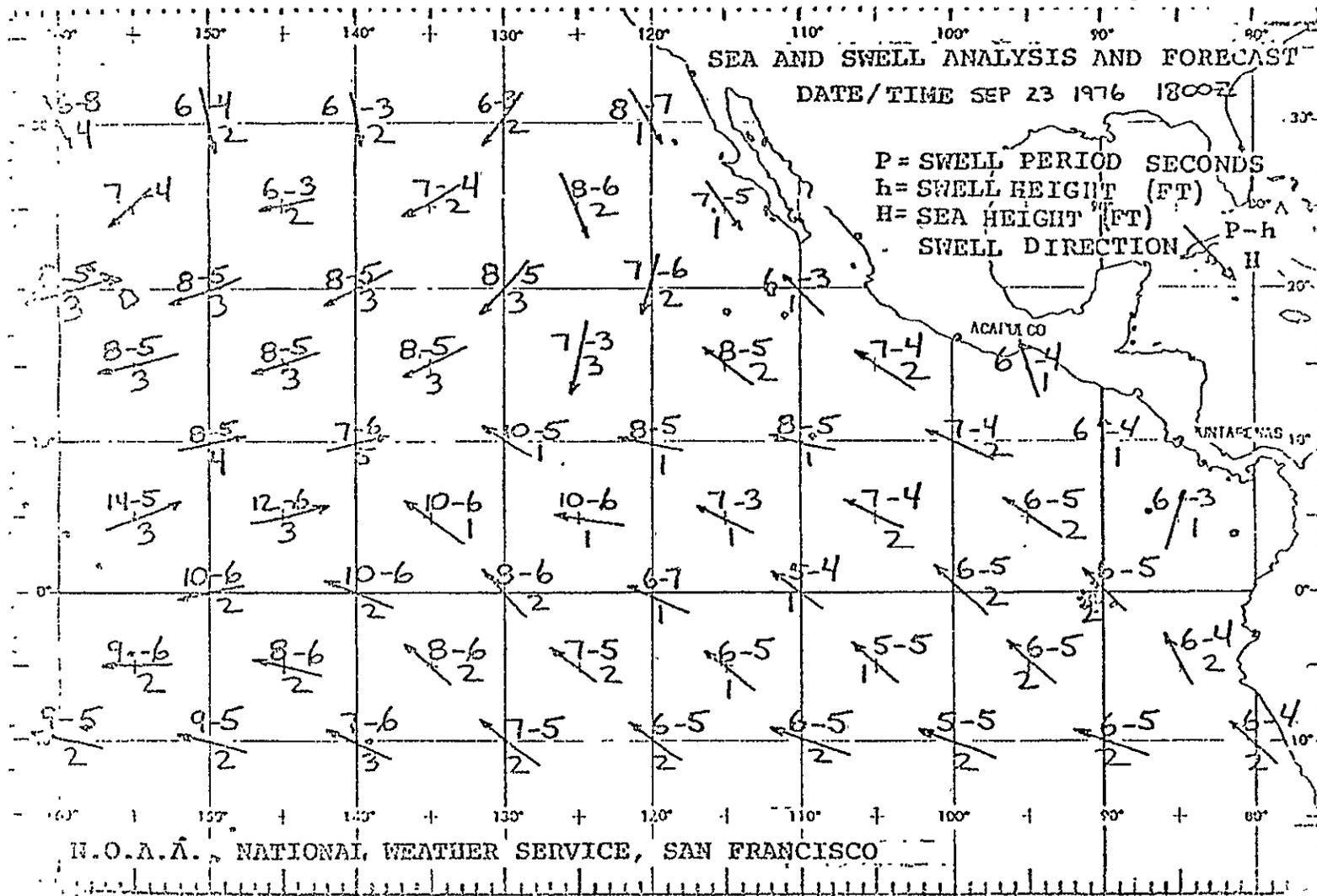


Figure A.2 Sea and Swell Analysis and Forecast

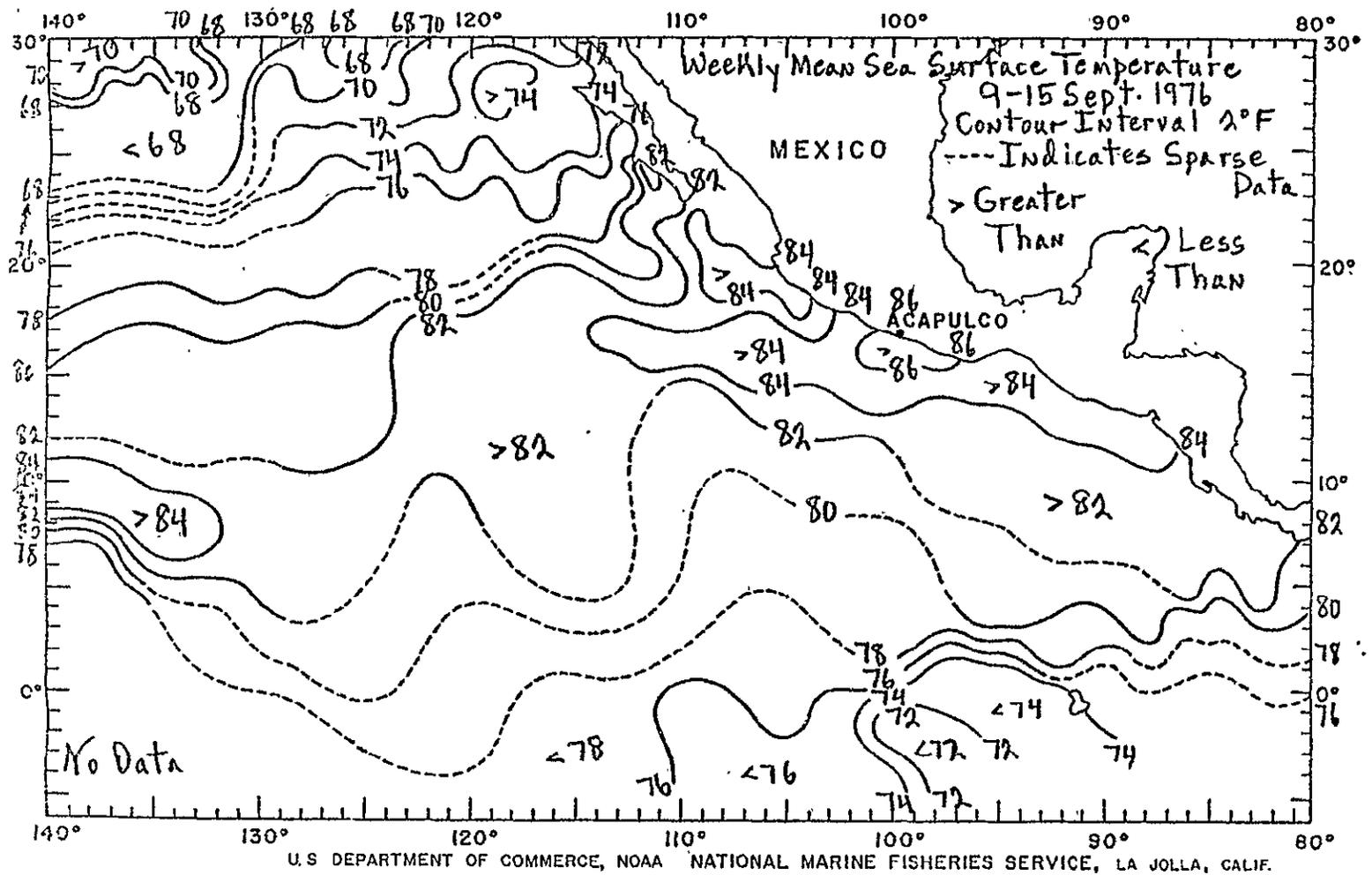


Figure A.3 Weekly Mean Sea Surface Temperature

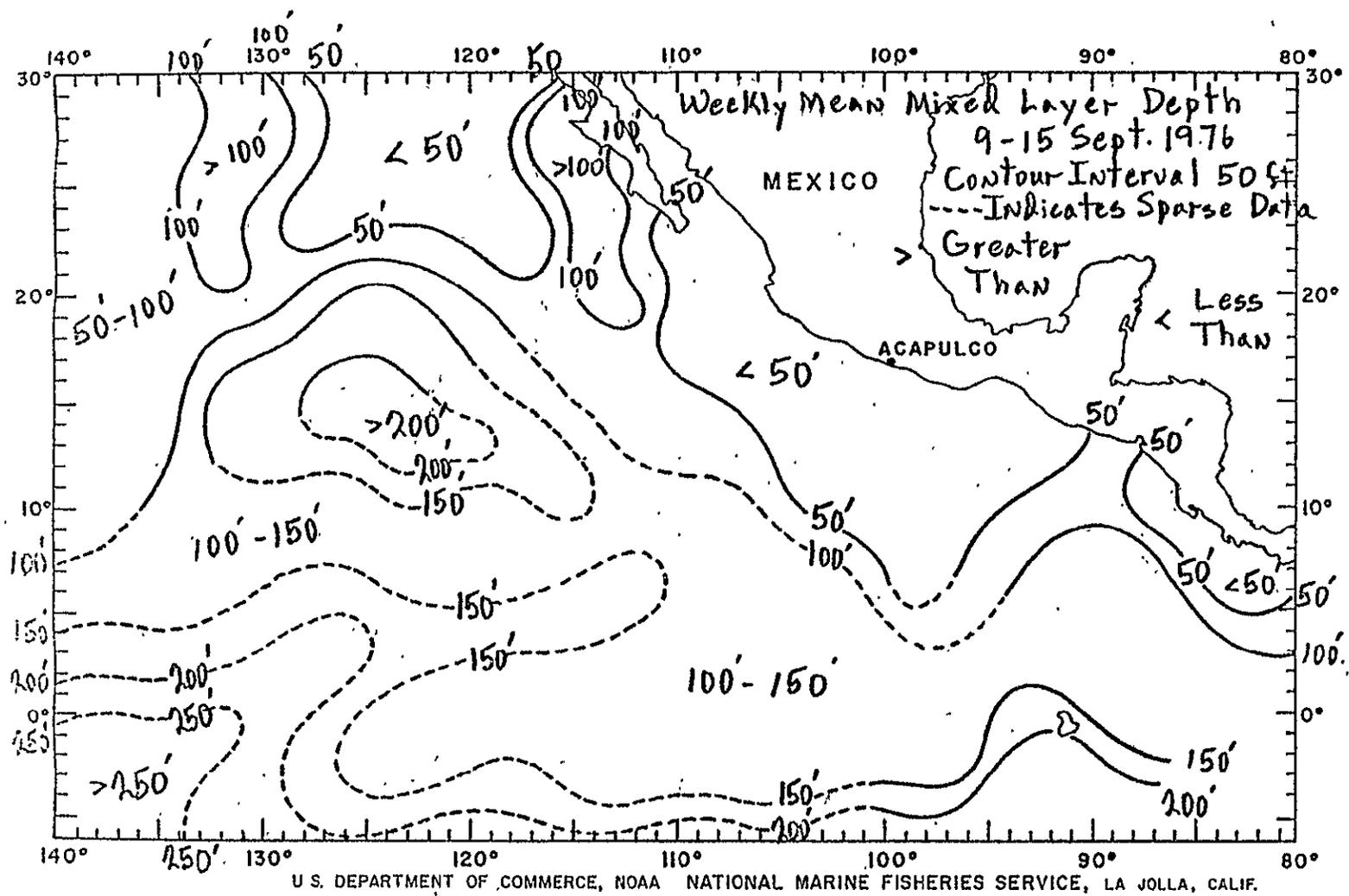


Figure A.4 Weekly Mean Mixed Layer Depth

***ECON Corporate Headquarters:***

***Princeton, New Jersey  
Telephone 609-924-8778***

***Western Office:***

***San Jose, California  
Telephone 408-249-6364***