REPORT OF THE
CODAR WORKING CONFERENCE

April 15-17, 1980
Estes Park, Colorado

Sponsored by

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Environmental Research Laboratories/Wave Propagation Laboratory,
Office of Ocean Technology and Engineering Services,
and
National Ocean Survey/Coastal Wave Program

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SUMMARY

The Coastal Ocean Dynamics Application Radar (CODAR) Working Conference was conducted at Estes Park, Colorado on April 15-17, 1980. The objectives of this conference were to present the development of a prototype CODAR system to potential users and industrial manufacturers, to listen to their ideas on appropriate system configurations and specific applications problems, and to promote discussion on concerns about the transition from prototype hardware to a commercially available system.

This report documents the conference working group discussions which prompted a reevaluation and modification of the transition engineering plan for the CODAR system. It also discusses applications and requirements perceived by the potential users and manufacturers as well as CODAR marketability.

As a result of the vigorous and productive interaction among the conference participants, who produced many helpful ideas and suggestions, the NOAA CODAR team has modified its transition engineering plan. Under the new plan, prototype CODAR systems will be supplied to NOAA oceanographers for their own research work. Limiting early prototype use to NOAA minimizes the risk of technology failure from unguided, premature systems applications, and improves the efficiency of the transition engineering program by enabling cooperative field experiments between the Wave Propagation Laboratory and NOAA's Oceanographic Laboratories. System specifications will ultimately be tailored to NOAA's operational requirements. This will lead the way to a competitive procurement of systems for NOAA, and CODAR production will be transferred to a manufacturer who will make his own marketing decisions.

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INTRODUCTION

The Wave Propagation Laboratory (WPL) of the National Oceanic and Atmospheric Administration's (NOAA) Environmental Research Laboratories (ERL) has developed a portable high frequency Coastal Ocean Dynamics Application Radar (CODAR) system. This radar system measures and employs the Doppler spectrum of the sea-echo signal to extract ocean surface current and wave parameters over several thousand square kilometers of ocean. Although the system capability has been demonstrated in several field experiments, CODAR is presently in the prototype state of development.

To span the gap from prototype to production, the NOAA Office of Ocean Engineering (OOE), now called the Office of Ocean Technology and Engineering Services (OTES), initiated a multi-year Transition Engineering Program that will result in the construction of a fully documented and tested CODAR system. Because the involvement of industry and the community of potential users is an important element in this phase of development, a CODAR Working Conference was convened with the following objectives:

- Summarize the present state of development of CODAR and describe ongoing and planned applications for potential users and manufacturers;
- Provide an opportunity for potential users to present their ideas about appropriate system configurations and specific applications problems; and
- Provide industry with a view of the potential market for CODAR and give them an opportunity to express their views on methods for system commercialization.

Approximately 50 potential users, industrial manufacturers, and NOAA scientists participated in the conference (see Appendix A). The interaction achieved among these participants will assist in the "transition engineering" process designed to span the gap between a research instrument and an operational remote sensing tool. For the process to be successful, the researchers, manufacturers, and users must learn to speak each other's language and to appreciate each other's needs and points of view. The CODAR conference provided a forum for this to occur.

For additional information on the CODAR system, Appendix B provides an abbreviated bibliography on high frequency (HF) sea-state radar and its applications. Also, Appendix C lists the names and phone numbers of the CODAR team members who may be contacted for details on CODAR.

II

STRUCTURE OF CONFERENCE

The CODAR Working Conference was held on April 15-17, 1980, at Estes Park, Colorado. The agenda for this meeting is presented in Table 1.

On the morning of the first day, members of the CODAR team made presentations on the objectives, philosophy, schedules, theory, and hardware of the CODAR system. The early afternoon session was devoted to presentations by oceanographers with experience in using the system. The participants were then divided into three working groups, each with an even distribution of users and manufacturers. The working group discussions are summarized in the next section of this report.

In addition to the discussion sessions, the participants had an opportunity to express themselves formally by means of a questionnaire which covered various aspects of the transition engineering problem. Responses to this questionnaire are tabulated in Appendix D.

TABLE 1

CODAR WORKING CONFERENCE AGENDA

April 15-17, 1980

Estes Park, Colorado

Monday, April 14	
6:00 - 7:30 PM	Registration and Reception
Tuesday, April 15	
8:00 AM	Registration
8:30 AM	Introduction (Objectives, Philosophy, Schedule/Tasks) William E. Woodward, NOAA Office of Ocean Technology and Engineering Services
9:30 AM	Theory Donald E. Barrick NOAA Wave Propagation Laboratory
10:30 AM	Break
10:45 AM	Hardware Michael W. Evans NOAA Wave Propagation Laboratory
11:45 AM	Discussion
12:15 PM	Lunch - The Inn Dining Room
1:30 PM	Presentations by Oceanographers Having CODAR Experience A. Shelby Frisch, NOAA/WPL Mona Janopaul, NOAA/WPL Ronald Kopenski, NOAA/WPL
	Overview of NOAA National Ocean Survey, Coastal Wave Program Dan Tracy, NOAA/NOS
3:00 PM	Break
3:30 PM	Working Group Sessions
5:30 PM	Social Hour
6:30 PM	Dinner (on your own)
8:30 PM	CODAR Personnel Available for Informal Discussion
Wednesday, April 16	
8:30 AM	General Session
9:00 AM	HF Radar Work at Stanford Research Institute Joseph W. Maresca, Jr., SRI

TABLE 1 (Continued)

Wednesday, April 16 (Continued)

9:30 AM	Break
10:00 AM	Working Group Sessions
12:15 PM	Lunch - The Inn Dining Room
1:30 PM	Working Group Sessions
3:15 PM	Break
3:30 PM	Presentations of Summaries to All Participants Hugh Milburn Tom Bartholomew William E. Woodward
	Discussion Donald E. Barrick
	Final Wrap-up William E. Woodward
5:30 PM	Social Hour
6:30 PM	Dinner (on your own)

Thursday, April 17

8:30 - 11:30 AM	CODAR Personnel Available for Informal Discussion

III

REPORT OF THE WORKING GROUP SESSIONS

In mid-afternoon on the first day of the conference, the attendees were divided into three working groups, each with an approximately equal representation of users and manufacturers. The three groups were all given the same charge: to consider applications and requirements for the CODAR system, and to discuss ideas and concerns about CODAR in general and the transition engineering phase of development in particular. Following is a summary of the working group discussions.

Applications

Although the particular CODAR system that WPL has developed may not be immediately suitable for all of the applications summarized below, the CODAR concept is sufficiently flexible to adapt to specific requirements by changing operation parameters such as radar frequency and pulse length.

The applications perceived by the working groups encompassed virtually all required measurements of surface currents and/or waves over areas as large as 10^3 km^2. It is important to note that the large spatial coverage capability with a grid size of 1 to 3 km (for surface currents) is a major benefit of the CODAR technique. However, with additional development, the technique may be applied, with appropriate design changes (higher frequency, shorter pulse length), to making measurements over areas with grid sizes as small as 0.5 km.

Six general categories of CODAR applications can be summarized:

Research. This application is for the continuing effort to further understanding of oceanic physical processes. It involves, among other things, investigations of sediment transport processes, coastal and estuarine physics, interactions of waves and currents, and wind-wave generation, propagation, and decay. The results of each of these investigations may be directly applied to one or more of the other five categories.

Fisheries Management. The NOAA Fisheries representatives explained the need in their organization for surface current measurements over large areas. The measurements would assist in characterizing the ocean processes that are critical in the development of yield models and harvesting forecasts for species that spawn offshore, yet rely on natural ocean processes to be carried inshore to mature in a safe estuarine environment, as well as for species that spawn in estuarine areas and are transported offshore in a larval stage and do not survive. Also, locating nutrient-rich upwelling zones, by CODAR for example, would be of value in determining areas of fish stock concentration.

Engineering/Construction. A need was expressed for wave height and direction information as well as current velocity measurements for inputs to the design and construction of offshore platforms (both fixed and tethered floating), as well as shoreside structures (jetties, piers, bulkheads, etc.). The cost of these structures is inversely related to the amount and quality of the environmental data used in the design. Oil company representatives pointed out that because existing data are scarce and extrapolation or predictions based on known data may differ by 50% from actual conditions, offshore structures are typically over-designed with the resulting undesirable higher costs. The offshore structures design application can be for areas hundreds of km offshore which would require CODAR operation from fixed platforms or ships. Although this type of offshore operation is considered possible, further research work is necessary to determine the effect of a platform or ship's superstructure as well as a ship's motion on the measurement.

Operations. Applications of CODAR in this category greatly impact safety. The NOAA National Weather Service (NWS) expressed a need for wave data inputs to develop, tune, initialize, and validate offshore and near-shore forecast models and to monitor the current and wave conditions at river and harbor entrances which pose a threat to life and safe navigation. Although no Coast Guard representatives attended the conference, the utility of a CODAR system to support search and rescue operations as well as vessel traffic management was highlighted by many attendees. In addition, the application of current measurements by CODAR for prediction of ice floe and iceberg trajectories, particularly for platform avoidance, was expressed as a very real need.

A representative from the United Kingdom outlined a rather unique application for CODAR in his country. Attempts to generate electric power from the wind have moved from land to coastal waters in the UK because of the noise and danger associated with the generators. Coastal environmental information, particularly the wind field, which could be inferred from wave height directional spectra, is needed in real time to control the direction and adjust the operation (i.e., manage the power load) of these devices.

Surveys. The NOAA National Ocean Survey (NOS) has a continuing program to perform surveys of estuarine and coastal circulation in selected areas of the United States. NOS also has a Coastal Waves Program (CWP), a new program whose mission is to develop a wave climatology data base (on a national scale), to provide real time directional wave data for forecasters, to develop and validate wave hindcast models, and to evaluate wave measurements. If CODAR can provide adequate resolution and accuracy in direction and amplitude at a reasonable cost, it will provide many of the measurements needed for the projected national wave measuring network and the testing and development of models. CODAR is being considered as a prime candidate for technology to support these two measurement programs.

Environmental Assessment. The most obvious application of CODAR in this category is in support of operations related to oil and/or hazardous material spills. Logistics, evasive actions, and cleanup operations can be planned and coordinated on a rational basis if the temporal and spatial current conditions can be measured synoptically at the site of an accidental spill. Studies of the fate and effects of particular pollutants also require measurements of the physical processes, such as currents and waves, associated with the distribution of the material.

Requirements

One of the objectives of the conference was to provide a forum for potential users to present their ideas about system design and configurations appropriate to their applications. Because the design of a system must necessarily be based on measurement requirements and engineering specifications, a reasonably formal, though not comprehensive, expression of requirements was solicited from the attendees via the questionnaire. The questionnaire responses are included in Appendix D, and a summary of the discussions of the working groups relative to system requirements is provided here.

In general, the discussions centered on four system characteristics that impact on requirements: a) measurement range (distance from antennas); b) size of measurement cell; c) real time vs. non-real time data processing; and d) the level of documentation of the control and processing software.

Range. For some, the maximum projected range of 76 km was considered too short. For oil company applications and the cold ocean research interests, 150 km to 300 km ranges are desirable as is operation from offshore platforms.

Cell Size. The 1.2 km cell size of the present CODAR system (utilizing an 8 μs pulse) seems to be at the upper limit of desired cell size for many. There was a strong feeling that for current measurement, a cell size on the order of 500 m x 500 m is required for many applications.

Real Time Data Processing. A clear message from the participants indicated that in all but a few applications, there seems to be no requirement for processing the collected data in real time. The participants did feel, however, that it would be valuable to provide, for current measurement for example, a capability to periodically produce a map with only a few vectors to use as an indicator of the quality of the data.

Software Documentation Level. A general feeling in industry is that there is never any such thing as a standard software package. Any software package is typically user oriented, and although it may have a basic core, it is continually evolving. In most cases, the level to which software is to be documented (and "standardized") is a marketing decision and may be different depending on the application. NOAA must consider this when procuring systems for NOAA use. However, the general feeling is that, at this point, any transfer of CODAR to industry must be accompanied by full and complete software documentation (control and processing; see Appendix E) which can then be tailored appropriately, depending on the expected or intended application.

General Issues About CODAR and the Transition Engineering Effort

Commercial Marketability. One of the key areas of discussion during the working sessions was the commercial marketability of the CODAR system. The general feeling was that if the intention of the transition engineering program is to seek a single manufacturer to produce the system in quantity, then appropriate incentives or motivations must exist. These incentives may include exclusive licensing agreements with the Government or sole source procurement processes, but the ultimate motivation for a manufacturer to develop the CODAR system into a product must come from a large, well-defined market from which adequate profits can be projected. The consensus was that although a wide spectrum of potential applications could be developed, a quantitative study of requirements, upon which a fiscal analysis could be based, does not yet exist. And without this, no large company (i.e., one of sufficient size to house the necessary hardware, software, and production capability) will even consider becoming involved. The alternative is to rely on small specialized companies to build the components which then must be integrated into a complete system. The system cost will be affected significantly by the approach taken, as well as by the total number of systems expected to be produced.

There was a feeling among some participants that because the CODAR system has had limited exposure in the oceanic community, the confidence level in the system on the part of potential users is not high enough yet to make it marketable. This problem is being solved in part by an increase in professional papers relating to oceanographic applications of CODAR, and through the transition engineering program with conferences of the type reported here.

The NOAA Office of Ocean Engineering (OOE) prepared a first level analysis of the market within NOAA as the transition engineering program was being conceived. Many at the conference felt that this should be continued by OTES and expanded to include at least the Government-wide, if not the entire, market. The rationale for and the appropriateness of NOAA performing a market survey, however, is questionable and could be justified only if needed to satisfy the objectives of the transition engineering program. At this time that does not seem likely, especially in light of the recent NOAA oceanic engineering policy statement that requires oceanic engineering and technology services to be directed principally to NOAA as a first priority and only to other agencies under special circumstances. In other words, a market survey does not seem necessary if NOAA is to build systems only for itself.

Why a Multi-Year Transition Engineering Program? The morning of the first day of the conference was dedicated to bringing the participants up-to-date on the present state of development of CODAR and to outlining the details and objectives of the ongoing transition engineering programs. After listening to the presentations, many of the attendees concluded that the CODAR system hardware is relatively straightforward and can be easily built, and that a transition engineering program lasting until FY-86 does not seem necessary. They concluded that the system seems basically ready to use.

The system is not yet ready to use and the issue is best addressed in the following way. The CODAR system can be considered to be basically a data collection system that in simplest terms illuminates the sea surface with a pulse of HF energy, receives the energy backscattered from the outgoing pulse, and calculates the Doppler spectrum of the return. The most difficult part of any system of this type is the interpretation of the collected data. The problem is analogous to Landsat, i.e., satellite construction was straightforward but interpreting the collected data is another story. The ability to extract useful information from the data and the description of system characteristics and performance are the key elements in the development of a useful measurement tool of this complexity. The hardware may be relatively routine but the total CODAR system characteristics and their impact or effect on data interpretation or on the capability of extracting useful information are not yet bounded. CODAR is still in the exploratory development phase and the CODAR team is reluctant to allow CODAR to be put into operational service until its performance can be adequately understood and documented. At the NOAA Wave Propagation Laboratory, past experiences in failure of technology, caused by premature applications of research tools, illustrate the need for a sensible, stepwise, rigorous, "multi-year" process that here is called transition engineering.

Why is NOAA Doing Transition Engineering? NOAA (specifically the Ocean Technology and Engineering Services Office) has created this CODAR Transition Engineering Program to provide the necessary coupling between the research efforts and the operational activities in NOAA. The objective of the transition program is to insure the development of a unique ocean measurement system that can be exploited by NOAA.

State of Development of the CODAR Hardware/Software Elements. A significant level of uncertainty prevailed among the participants at the conference with regard to the actual state or level of development of the CODAR software and hardware required for measuring surface currents and for measuring waves. Appendix E addresses this issue and attempts to clear up any misconceptions about the system and its state of development.

Methods for Transferring CODAR into the Marketplace. One approach would be for the Government (in particular, NOAA) to take the initiative and act essentially as its own systems contractor to identify the NOAA requirements for CODAR, translate them into system specifications, and do the necessary subcontracting on a competitive basis to procure the systems that would satisfy the needs of NOAA. The variety of technical disciplines that are part of CODAR might necessarily require contracting with several different companies in this "bits and pieces" approach. As NOAA begins to deploy and operate the systems, the technology would become more visible and accepted in the community. The likely result would be a better defined and more attractive market to which industry can then respond on their own.

NOAA could also contract for a "reprocurement package" but this is typically a very expensive approach. The contractor who puts the package together essentially turns over all chances of ever building the system because he gives out all of the information needed for anyone to build it. Therefore, the contractor must include in the cost of the package, not only any profits he thinks he might have made if he were to build it, but also sufficient costs to underwrite the guarantee that is typically given of the accuracy of the drawings.

An alternative method would be for a manufacturer to acquire the drawings and documentation for CODAR which are in the public domain, take the risk, and attempt to fabricate and sell CODAR systems in the marketplace. Because the CODAR system is patented, it would also be necessary to acquire a license from the patent assignee (the U. S. Government, Department of Interior) to build the system. However, market uncertainty, as well as some technical uncertainty (see below, Frequency Allocation), prevent industry from carrying the ball at this time.

Frequency Allocation. The eventual routine use of the CODAR technique raises the issue of official allocation of a portion of the radio (electromagnetic) spectrum suitable for its operation. The existing CODAR system operates in the very congested 25 MHz region of the spectrum presently specified for land mobile, fixed and amateur use in discrete, relatively narrow (as small as 10 KHz) frequency bands. Because CODAR is a pulsed system (typically 8-16 μs pulse durations), the RF bandwidth is on the order of 200 KHz. For these reasons, concern was expressed at the meeting about the chances for receiving an allocation in this region of the spectrum.

A NOAA Radio Frequency Management Officer who attended the meeting outlined the process for requesting an allocation and indicated that there are two organizations responsible for managing the spectrum, one for Government use (The National Telecommunication and Information Agency; in particular, its policy body, the Interdepartment Radio Advisory Committee-IRAC) and another for non-Government use (The Federal Communications Commission). He suggested making parallel requests for a frequency allocation to each organization and indicated that comprehensive technical information must accompany a request for a frequency allocation. Details of the proposed system, such as location, frequency range, bandwidth, emission, power, estimated time of operation per day, week, etc., as well as the degree of flexibility in these technical parameters, must be provided. Also, the extent of operating frequency flexibility that should be included for compatibility with foreign country frequency allocations, the perceived applications, and the estimated size of the potential market must be considered.

The process of requesting the new frequency is expected to be a lengthy one, and there is general agreement that serious efforts should begin immediately. Technical information is being prepared for a formal allocation request to the Spectrum Planning Subcommittee (SPS) of IRAC through the Department of Commerce SPS representative.

IV

REVISED TRANSITION ENGINEERING PLAN

The CODAR Working Conference was convened to exchange information. It was felt that the time was right to bring the oceanic community and potential manufacturing community up-to-date on the CODAR system development and to inform them of the elements and objectives of the CODAR Transition Engineering Program, i.e., the program aimed at converting the system from a research tool to an operational device. Additionally, it was felt that ideas and viewpoints on requirements and applications for CODAR, as well as on the proposed program of transition engineering, should be solicited from the community to insure a responsive effort.

The vigorous interaction at the conference has given the NOAA CODAR team a better focus on the situation and has motivated a reevaluation and optimization of the transition engineering plan. The original plan did not show CODAR systems as being available for use until FY-86. This was the projected date for a system that would be fully and completely documented and 100% perfect in its capability and operation. The message came across loud and clear at the conference that FY-86 is much too long to wait, and that benefits would be gained by placing engineering prototypes in use much sooner, even though they may not be 100% perfect.

The CODAR team has thus revised its thinking and modified the transition engineering plan (see Figure 1) along the following lines. By mid FY-81 sufficient hardware and software documentation will be available to fabricate a CODAR system dedicated principally to current mapping but capable of being easily modified to collect data for wave height directional spectra measurements as that capability evolves. At least two, but no more than four, of these systems will be delivered by mid FY-82 for exclusive use by one, or perhaps two, of NOAA's research laboratories, such as the Pacific Marine Environmental Laboratory (Seattle) and/or the Atlantic Oceanographic and Meteorological Laboratory (Miami). The objective is to control the application of a prototype piece of technology, the performance of which is not yet fully understood. By deploying these prototype systems within NOAA, rather than outside NOAA,

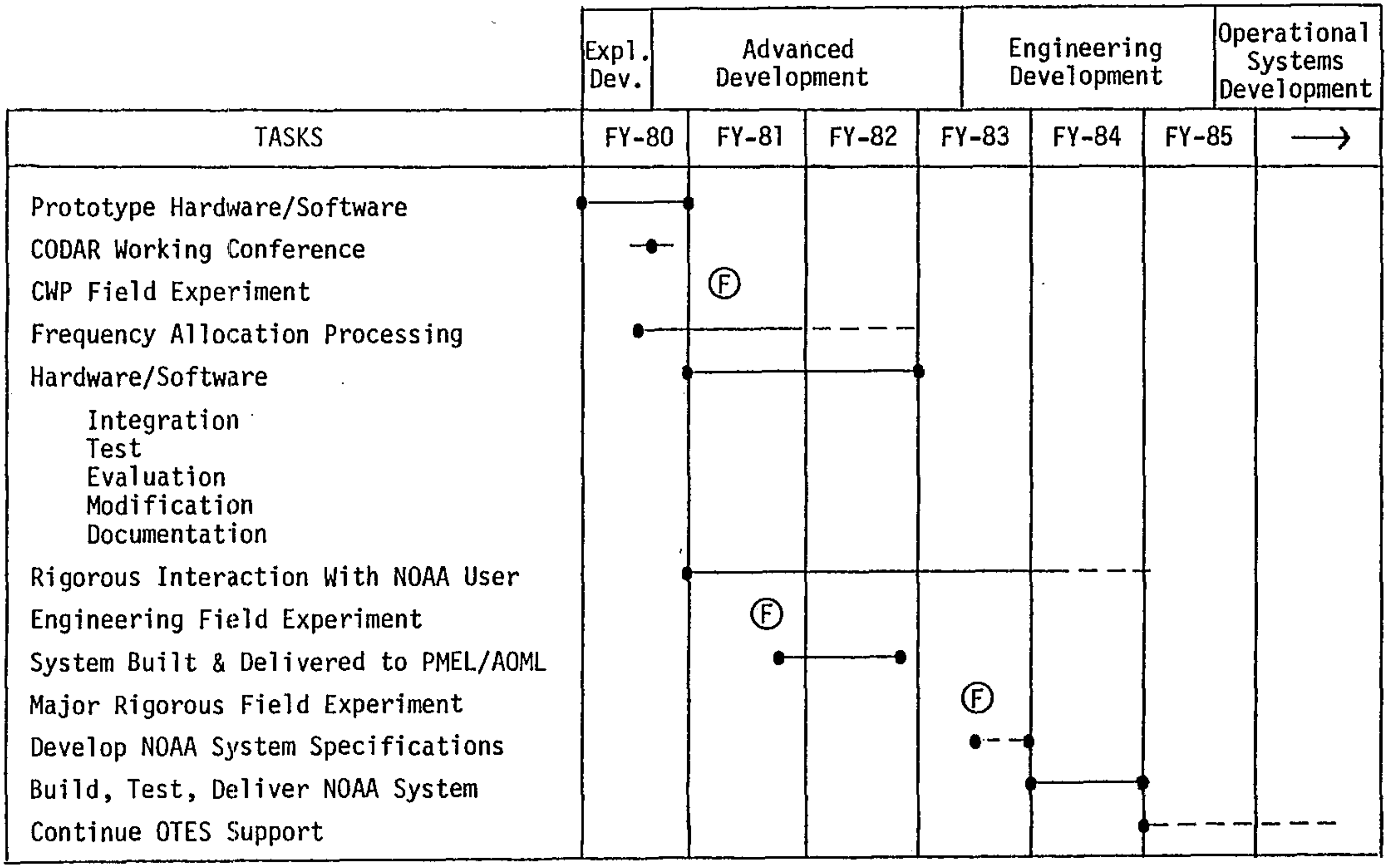

Figure 1. Schedule for Transition Engineering Plan

the necessary and vital interaction between the research team (WPL) and the user team (PMEL/AOML) can be optimal and continuous, thus minimizing the risk of technology failure from unguided premature system applications.

From FY-81 through FY-83 the CODAR system will be tested in the lab and in the field, by WPL with PMEL/AOML. Also during this time, a NOAA organization or program will be identified and interaction will begin with them to develop requirements for a CODAR system to be used operationally. A system to respond to these requirements will be designed and specifications will be prepared. Then, this system(s) will be procured on a competitive basis. It is anticipated that the bidder who is awarded the contract to manufacture this NOAA system(s) will be the most likely source of CODAR systems for others in the community, provided that nobody else has taken on the job themselves by that time. In other words, CODAR will be effectively transferred to a manufacturer who can then make his own decision about going into production, should the market warrant it. Because the size or nature of the entire CODAR market or potential market will not directly influence the transition process described above, the marketing role of the CODAR team outside of NOAA will be minimal.

The revised approach seems to be in line with the feelings of those who attended the conference and is the most expeditious and sensible way to effect the transition of CODAR technology with the NOAA resources that are presently available.

APPENDIX A

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APPENDIX B

BIBLIOGRAPHY ON HF SEA-STATE RADAR

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APPENDIX C

CODAR TEAM MEMBERS

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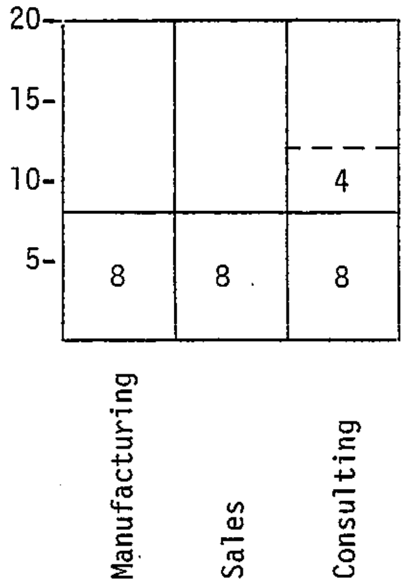
APPENDIX D

CODAR QUESTIONNAIRE RESPONSES

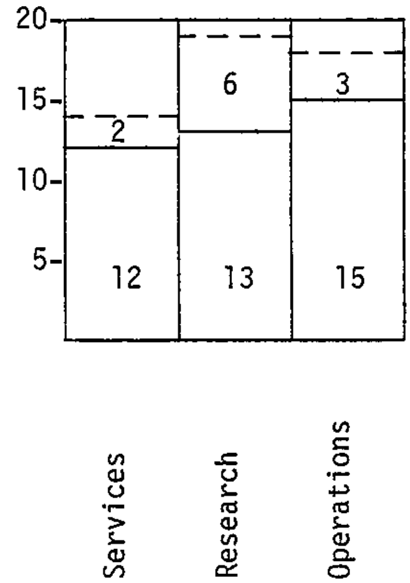
In addition to the attendees at the CODAR Working Conference, several "non-attendees" responded to the questionnaire. The number of attendees and non-attendees who responded to each question is given in parentheses following each question. Responses from both groups are presented in histogram form for most questions. The solid line on the histogram represents the responses of the attendees, and the broken line represents the responses of the non-attendees.

2. Your interests: (Attendees - 22, Non-attendees - 6)

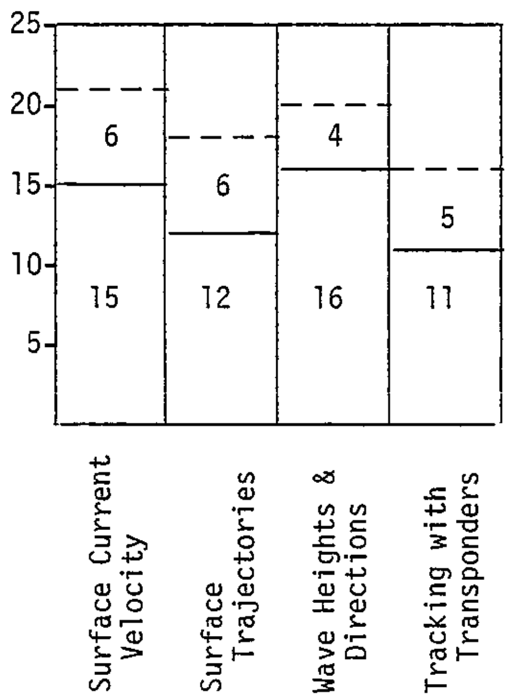
a. Commercial



b. Applications



3. A CODAR system can be used to measure surface currents and ocean waves, and it can be used to track buoys or vessels with transponders. Which are the kinds of measurement capabilities that interest you? (Attendees - 18, Non-attendees -6)



4. How will the data be used? (Attendees - 12, Non-attendees - 6) (There were no significant differences between the responses of attendees and non-attendees.)

- Forecasting models
- Model calibration and verification
- Now-casting
- Pollution transport analysis and control
- Environmental assessment
- Sediment transport analysis
- Iceberg tracking
- Wind/wave/surface current interaction studies
- Shore structure designs
- Engineering designs
- Development of oil spill trajectories
- Inlet hydraulics studies

5. The present CODAR range is approximately 70 km from shore and minimum resolution cell size is 1.2 km x 1.2 km. These parameters may be modified if required for particular applications.

   a. What are the estimated ranges of currents and/or waves you will measure?

   Currents (Attendees - 5, Non-attendees - 6)

Attendees	Non-attendees
0-150 cm/s	0-100 cm/s (2)
0-250 cm/s	0-150 cm/s (2)
0-300 cm/s	0-250 cm/s
10-100 cm/s	150-250 cm/s
25-400 cm/s	

   Waves (Attendees - 5, Non-attendees - 0)

Height	Period
0-4 m	0-6 s
0-10 m	$H_{1/3}$
0-15 m	4-16 s
2-15 m	4-20 s
0-20 m	0-15 s

5. Continued

b. What are the desired resolution and the allowable uncertainties in your measurements?

Currents (Attendees - 5, Non-attendees - 4)

Attendees		Non-attendees	
Resolution	Accuracy	Resolution	Accuracy
2 cm/s	± 5 cm/s	5 cm/s	± 3 cm/s
10 cm/s	±20 cm/s	5 cm/s	± 5 cm/s
10 cm/s		5 cm/s	±15 cm/s
20 cm/s	±25 cm/s	5 cm/s	

1-3 cm/s Desirable, 3-5 cm/s Acceptable — Low current areas (0-25 cm)
2-5 cm/s Desirable, 10-15 cm/s Acceptable — High current areas (50-150 cm)

Waves (Attendees - 4, Non-attendees - 0)

Spectral energy estimates 10%; Direction estimates within ± 5^{o}

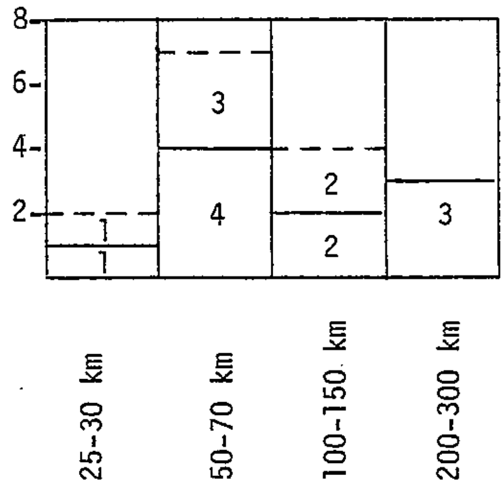
Wave height: 0.1 m ± 0.2 m
Wave direction: 5^{o} ± 5^{o}
Wave period: 0.1 sec ± 0.1 sec

Accuracy 10% of wave height

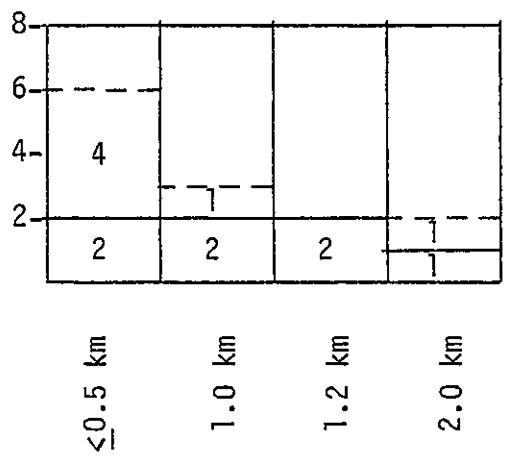
Wave height: ± 0.1 m
Wave period: ± 0.5 sec

5. Continued

c. What is the desired maximum measurement range from the antennas? (Attendees - 10, Non-attendees - 6)

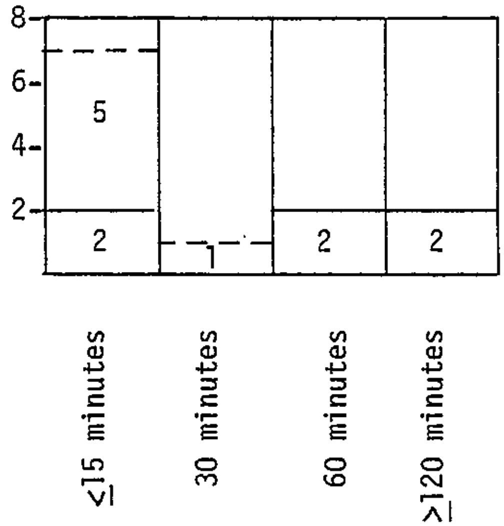


d. What is the desired measurement cell spatial resolution? (Attendees - 7, Non-attendees - 6)



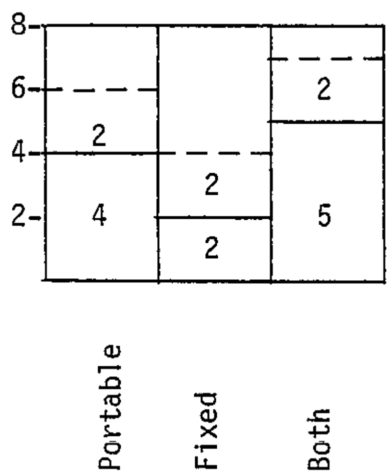
5. Continued

e. What is the desired measurement temporal resolution? (Attendees - 6, Non-attendees - 6)



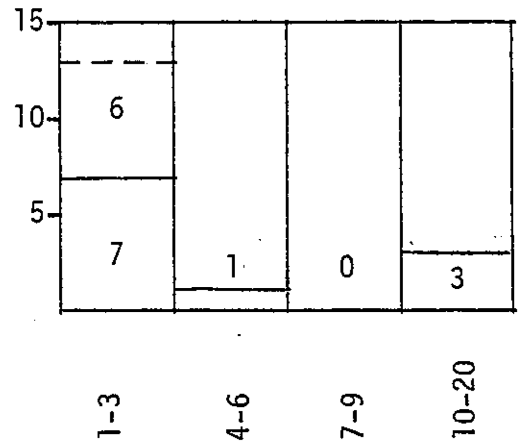
6. CODAR Application Scenario:

a. Portable or fixed (long term) operation? (Attendees - 11, Non-attendees - 6)

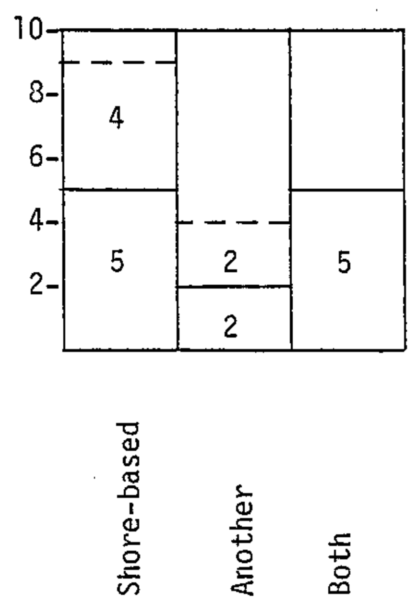


6. Continued

b. How many stations? (Attendees - 11, Non-attendees - 6)

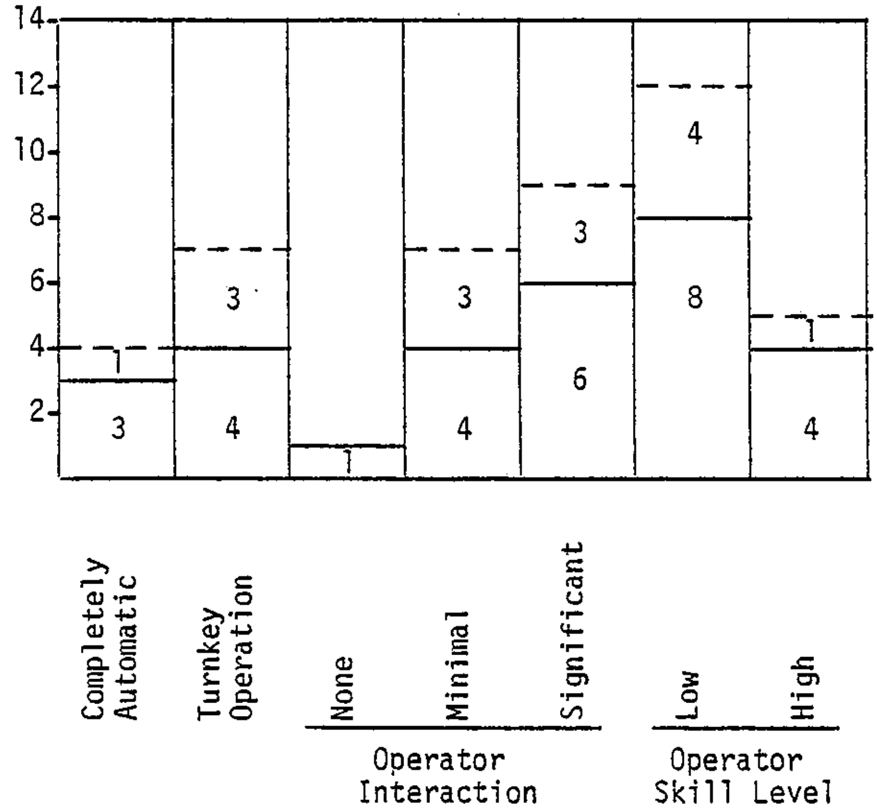


c. Is a shore-based system (antennas on the beach) applicable to your needs or is operation from another platform desirable? (Attendees - 12, Non-attendees - 6)

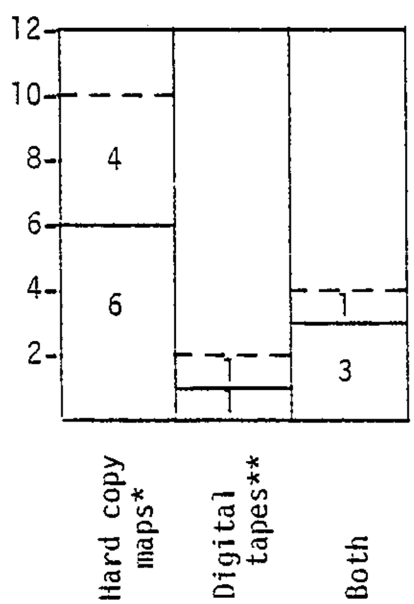


6. Continued

d. Which of the following best describes a system that would apply to your needs? (Attendees - 12, Non-attendees - 6)



e. What is the desired output product? (Attendees - 10, Non-attendees - 6)

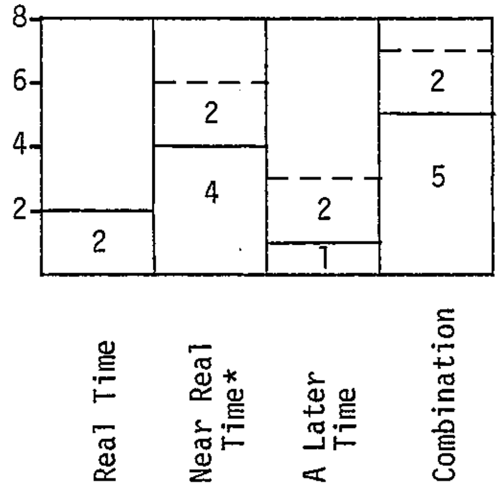


*Hard copy maps of average current vectors.

**Digital tapes of current vector time series.

6. Continued

f. Is the output product desired in real time, near real time, or a later time? (Attendees - 12, Non-attendees - 6)



*How much time between collecting and processing?

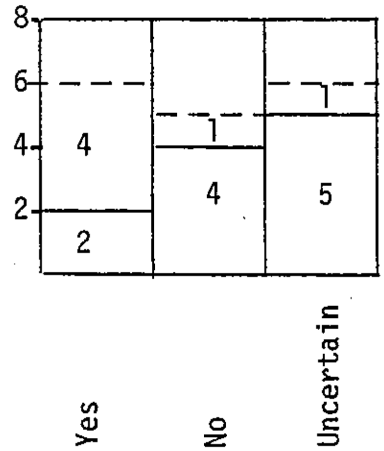
Responses ranged from 30 minutes to one month, with the most frequent response being two weeks.

g. What would be a typical data sampling scheme? (Attendees - 7, Non-attendees - 5)

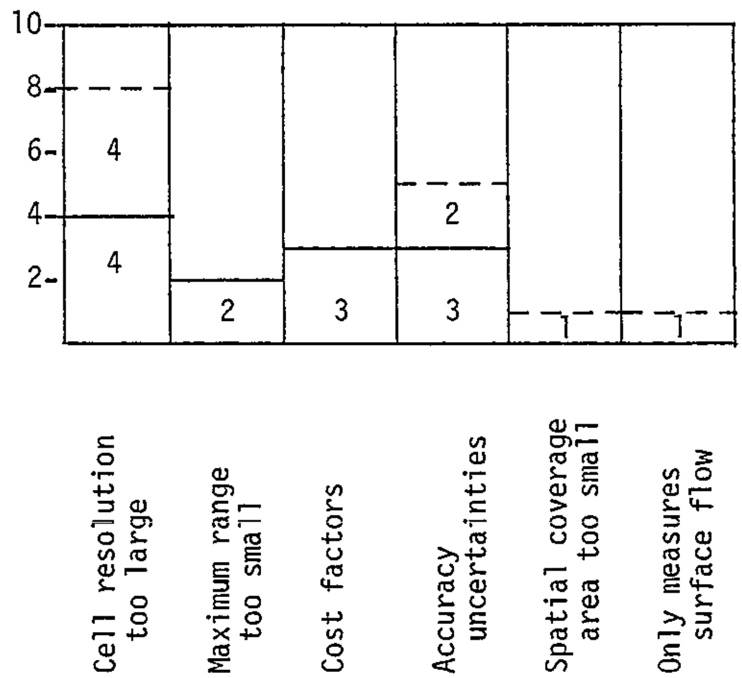
	Continuous Operation (Minutes)	Frequency Required (Hours)	Time Period (Days)
Attendees:	2-5	1/2	Pre-set
	10-15	Several tidal scales	Several times a season
	12	1	
	17-20	1	
	36	6	120
		1	
		2	
Non-attendees:	12	1/2	3
	12	1/2	7
	12	1	10-12
	12	1	14
		or 2	30
	12	1	365

6. Continued

h. If the CODAR system were modified to include precision position fixing for vessels, would you use this capability? (Attendees - 11, Non-attendees - 6)



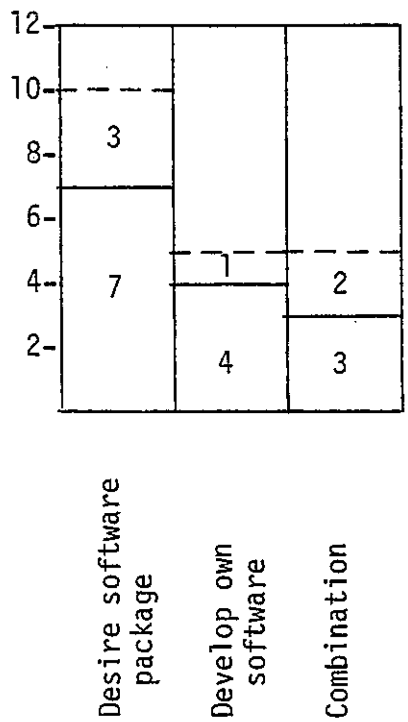
7. Describe the CODAR system characteristics that you feel would limit the system's utility for your applications. (Attendees - 9, Non-attendees - 6)



8. From a technical point of view, do you see CODAR as a feasible product in terms of manufacturing complexity? (Attendees - 13, Non-attendees - 1)

Yes - 14
No - 0

9. Would you want a complete signal processing software package capable of producing maps, realizing that this might not be optimal in all applications, or would you prefer or attempt to develop your own software? (Attendees - 14, Non-attendees - 6)



APPENDIX E

STATUS OF CODAR SYSTEM DEVELOPMENT

The CODAR team has designed a second-generation CODAR system to incorporate refinements developed over several years of field testing and interaction with users, as well as those made possible by advancing technology. Although the new version is considerably more flexible than the old, the hardware is less expensive and more compact.

Approximately three complete CODAR stations will be produced by early 1981. Two units will serve as an interim research vehicle for oceanographic experiments in which WPL will participate. A third unit will function as a development testbed for the first production version.

Following are more detailed status reports on the major CODAR tasks.

Signal Processing Software

As the key element of the CODAR system, the signal processing software has received approximately 70% (10-12 man-years) of the CODAR team's developmental effort. The software consists of an algorithm that estimates the radial current component, as a function of range and azimuth, using the Doppler spectrum and phase of echoes received by the four whip antennas. Other algorithms further process and display surface current maps for various oceanographic applications. In addition, new algorithms are being developed to extract ocean wave directional spectra from CODAR signals.

Surface Current Maps. The current-estimating algorithm continues to evolve through stages of increasing output quality and reliability. To effect these improvements, the CODAR team has focused on reducing the errors introduced in the angle-computing algorithm and on improving its efficiency. This new algorithm keeps track of different spectral contributions to each range-azimuth bin and will permit rejection of non-Bragg-line contributions to the velocity measurement, such as those caused by noise and second-order scatter.

By greatly refining the bookkeeping and eliminating many I/O steps, the confidence limits of current estimates have been improved recently by about a factor of ten (from about 100 cm/s to 10 cm/s) and the processing time has been reduced by about half. It now takes 2 to 4 minutes to process 1 minute of data, but further refinements are expected to bring the processing ratio down to unity, as required by a real time processor.

Working versions exist of several other processing refinements, such as algorithms to integrate across the radar baseline and for extending the radar coverage area using the continuity equation. Another routine method for studying CODAR data is a Fourier decomposition of surface currents into tidal components to permit separation of wind-driven and tidally-driven currents. These refinements are now about 80% operational.

By September 1980, a turnkey or cookbook version of the current-mapping processor should be available to the CODAR analysis team. A prototype on-line processor, including on-line diagnostics, is expected to be ready by October 1980. A "final," more accurate version suitable for wider dissemination should be complete early in 1981.

The problem of how to examine and interpret the massive quantities of current data CODAR produces has been addressed by developing software to display current-map motion pictures. This display capability, which incorporates sophisticated two-dimensional filtering algorithms, can be tailored to specific measurement requirements, such as time varying current-vector maps, synthetic drifter tracks, convergence contours, and tidal ellipses.

Wave Directional Spectra. By processing second-order spectral information in the radar echoes, an ability has been demonstrated to compute the directional spectrum of the ocean waves within the radar beam. The mathematical tools for inverting Doppler spectra to extract wave directional spectra have already been developed and verified in several HF narrow-beam radar tests. Some refinements of these inversion methods are now underway to extend their applicability to wave periods as short as 3 or 4 seconds with a 25-MHz radar.

Antenna designs and processing software are now being developed to extract wave directional spectra from compact antennas analogous to the phase measuring array for current mapping. Data from a crossed-loop receiving antenna used during MARSEN measurements are being analyzed for wave spectrum, assuming spectral homogeneity over the covered area. A 16-element circular whip array being designed will permit some angular resolution of wave field inhomogeneities.

The main hardware changes required for CODAR wave directional spectrum measurements are in the antennas. The rest of the data collection hardware is the same as for current-mapping applications.

Control Software

The present version of the CODAR control software has been operational for about two years and will remain functionally the same in the second-generation CODAR. To improve its internal efficiency, however, the code is being rewritten and some minor changes in the SPI board are being made. These changes should be finished by March 1981.

The major functions of the control software are a control panel emulator, an automatic receiver gain control, and receiver diagnostics.

Panel Emulator. A CRT display facilitates CODAR control tasks by displaying sets of questions for the operator to answer while setting up a radar run. This is how the operator enters the run schedule and other parameters needed for processing, such as latitude, longitude, antenna orientation, pulse width, and integration time. The controller then operates the radar for the specified run time.

Automatic Gain Control (AGC). An automatic receiver gain control as a function of range has been designed to prevent saturation at the input of the receiver A/D converter and so that the dynamic range of the data will be preserved. To accomplish AGC, the received echo signal level is automatically measured as a function of range prior to each data run, and the receiver's output level is adjusted accordingly.

Receiver Diagnostics. Abnormal operation of radar system components can now be checked on-line using a set of diagnostic and calibration algorithms. For example, a program to balance the receiver I-Q channels in amplitude and phase can now be used in the field. The fast-Fourier transform is being replaced with a maximum-entropy spectral estimator to speed up and increase the reliability of this adjustment.

Measurement Hardware

Receiver. Two preproduction prototypes of a second-generation CODAR receiver will be delivered by Erbtec Engineering by mid-September 1980. These units will be evaluated in field experiments at Duck Island, North Carolina, during October. Following these tests, the two units will be delivered to the German team. Three more units will be procured before the end of 1980 for use by the CODAR team in oceanographic experiments and for system refinements.

Although the unit cost of the new receiver will be about $16,500, 40% that of the prototype Barry receiver, many refinements to this already excellent design have been added. Among them are:

- Built-in transponder-interrogation hardware;
- Built-in 10-W transmitter power amplifier;
- Modular design using plug-in printed-circuit boards that permit hardware reconfiguration in the field;
- Extensive diagnostic capabilities that permit computer testing of internal receiver functions, such as cabling integrity and A/D calibration; and
- Computer-controlled radar frequency and IF-filter bandwidth.

During 1981, the receiver will continue to be tested to establish and minimize the sources of error that it introduces into the current measurements. The receiver modifications required to operate the CODAR system at VHF will also be developed. By October 1981, the CODAR team expects to complete testing and to arrive at an electrical and mechanical design suitable for commercial production.

Antenna System. No major changes in the design of the transmitting or receiving antennas or the antenna multiplexer have taken place, so the CODAR team plans to retain the basic antenna configuration used in several field tests, unless special measurement needs arise. The only refinements will be for additional environmental protection. The workshop participants provided useful suggestions for this aspect of the system.

Two new antennas that will permit wave directional spectrum measurements are now being built and tested. One is a crossed-loop receiving antenna, and the other is a 16-element circular whip array.

Power Amplifiers. The improvement in signal-to-noise ratio and a modest increase in maximum range have led the CODAR team to experiment with RF amplifiers to boost CODAR's radiated power. Commercially available amateur power amplifiers (ETO Alpha-76) have been modified to deliver 7-kW of peak pulse power. A prototype compact 50-kW power amplifier is being constructed using an oil-cooled Eimac tube. A production goal is envisioned of a 15-kW final amplifier and driver in a 7-inch rack-mounted package, but this development project is receiving low priority because the technology is known.

Telemetry. During the MARSEN experiment last year, VHF radio telemetry was set up to transfer data between CODAR sites, allowing the production of current-vector maps within hours of collecting the data. Such telemetry is essential to future real time current mapping, search and rescue, and oil-spill monitoring.

Doppler Transponder. The CODAR team has built and field tested a compact Doppler transponder for tracking the velocity and position of ships or floating objects such as drifter buoys. Maximum-entropy spectral analysis, using sampling times as short as 4 seconds, permits accurate tracking without the need for accurate differential position measurements. More units will be produced for environmental conditioning and further testing.

Computer. The second-generation CODAR system replaces the Digital PDP-11/34 minicomputer with an LSI-11/23 microcomputer. Although the LSI-11 performs the same functions as its predecessor, at nearly the same speed, its cost is about one-third and it occupies about one-fourth the space. CODAR team members are now packaging and integrating the LSI-11 and expect this subsystem to be operational by October 1980.

Signal Processing Interface (SPI). The SPI performs some demultiplexing of the signals received by the four antennas, computes and applies the AGC function with range, and generates all the timing signals required for radar operation. It also averages the received signal over 128 samples, using a Blackman-Harris window to filter high frequency noise from the data.

A new SPI design was necessary to accommodate the change from the PDP-11/34 minicomputer to the LSI-11/23 microcomputer. Designed and produced by Otrona, Inc., a prototype of the new SPI is now undergoing final testing. A printed-circuit board version will be delivered by December 1980.

Because of technological advances since the last design, the amount of logic circuitry has been reduced by about 40%. The new SPI has been more thoroughly integrated with the digital components of the receiver, and the new logic design permits rewiring to more readily accommodate radar operating changes, such as the number of antennas, pulse rate, and pulse width. A separate experimental software-programmable SPI is also being developed for research applications.

Peripherals. Two 3M cartridge drives will replace the industry-standard, 7-in-reel magnetic tape drive for data recording. The new units are smaller, more reliable, easier to use, and store more data.

A digital VT-100 control console is replacing the Lear-Siegler units. The VT-100 is easier to use and more flexible; for example, it allows simultaneous displays of multiple programs as well as data plots.

Small, hard, sealed disk drives have been used in field tests of on-line processing. Such a random access device can be incorporated in a CODAR station when real time current maps are desired.

Documentation

Obviously, any new technology such as CODAR experiences rapid and continual evolutionary change, which means that any documentation is always somewhat obsolete. Most of the theoretical and operational features of CODAR have been and will continue to be documented in journal papers. However, the CODAR team recognizes the need for explicit and more detailed system documentation designed for several kinds of CODAR users. The completion of the second-generation CODAR system provides a convenient and logical place to "freeze" the system for documentation purposes.

Early in 1981, the CODAR team will begin writing a three-part special report on CODAR. Part 1 will be a self-contained account of the theoretical foundations of CODAR, including the relevant aspects of sea-scatter theory, as well as the mathematical foundations of CODAR signal processing for extracting current and wave information. In effect, Part 1 could be titled, "How It Works."

Part 2 will explain to oceanographers and other users what kinds of measurements CODAR is good for, how to set up and operate a CODAR system, how to process and interpret CODAR data sets, and how to assess the errors in current and wave measurements under different conditions. Part 2 will therefore tell "How to Use It."

Part 3 will consist of complete engineering specifications of a CODAR system, in sufficient detail to permit duplication of the system by any competent engineering team. The specifications will also contain enough explanation of design features that independent modifications for special uses will be possible. Because engineering specifications evolve with the system, modular updates of Part 3 will be provided as demanded by system refinements.

The above three volumes should be completed by early 1982.