# CHAPTER 6

# 94320-J Modelling and Information Services

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Cordova, Alaska

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**Project 94320-J (SEADATA)**

# INFORMATION SYSTEMS AND MODEL DEVELOPMENT

# FY94 REPORT

**March 15, 1995**

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# CONTENTS

# EXECUTIVE SUMMARY

In this executive summary the specific annual objectives and milestones for each SEADATA subproject are reproduced from the FY94 Detailed Project Description. Target time for completion of objectives is given as weeks or months After StartUp (ASU) of the program. The current status is shown in **non-serifed** typeface. Italicized page numbers are references to further discussion in the following detailed report.

## SD94-1 Field data communications

FY94 Objectives: Implement, on a demonstration scale, near real-time data communications between SEA field survey platforms and the SEA data ingestion site. Establish transmit capability for at least one moored site, transmit and receive capability for at least one SEA survey vessel, and transmit capability suitable for use with a vessel of opportunity.
2.5 mos ASU: communications for first buoy and survey vessel operational.

***CURRENT STATUS*: A prototype communications system for near-realtime data transfer between SEA field survey platforms and PWSSC base station is operational.**

*Details: page 15*

***FY94 ACCOMPLISHMENTS*: Comprehensive assessment of existing PWS communications infrastructure completed. Design plan for repeater-based VHF packet-radio communications system completed. Permission for use of existing USFS and ADEC repeater sites obtained. FCC license obtained. Base station and repeaters at Heney Ridge and Naked Island installed and tested. Data transfer system developed.**

## SD94-2. Data management

### SD94-2.1. Coordination.

FY94 Objectives: Coordinate the data management project with the needs and interests of SEA participants and the EVOS Trustee Council.
5 wks ASU: approach finalized

***CURRENT STATUS*: Coordination efforts are ongoing.**

***FY94 ACCOMPLISHMENTS*: Data system concept based on the EOSDIS definitions of data levels developed and used to clarify complementary roles of SEA projects and SEADATA.**

### SD94-2.2. SEA data services.

#### SD94-2.2.1 Flat file database.

FY94 Objectives: Establish an online flatfile database, using a UNIX file server and native file system along with one or more of the widely used self-describing data formats (CDF, HDF, NEONS).
3 wks ASU: specification and request for quotes.
6 wks ASU: delivery.

***CURRENT STATUS*: Flat file system established and in use.**

*Details: page 8*

***FY94 ACCOMPLISHMENTS*: Hardware specification and acquisition completed on time and under budget. Hierarchical storage system and backup procedures developed. FY94 field data migration completed for all physical oceanographic, hydroacoustic, AVHRR, zooplankton and fish trawl data.**

#### SD94-2.2.2. Data ingestion

FY94 Objectives: For each project and each sensor or sampling effort, develop procedures for moving data from the field to the SEA archive.
6 wks ASU: ingestion plan, hardware specifications and request for quotations
10 wks ASU: ingestion system and procedures operational.

***CURRENT STATUS*: Ingestion procedures established.**

*Details: page 7*

***FY94 ACCOMPLISHMENTS*: Systems for transport of physical media and file uploading developed and in use. Near-realtime ingestion system ready for FY95 field use.**

### SD94-2.2.3. Mass storage

10 wks ASU: Finalize requirements and configuration for SEA mass storage.
13 wks ASU: deliver

***CURRENT STATUS*: Completed.**

*Details: page 7*

***FY94 ACCOMPLISHMENTS*: Mass storage systems specified and delivered.**

### SD94-2.2.4 and 2.2.6 Quality control, availability and security

18 wks ASU: Complete FY94 plan for QC, availability and security; implement

***CURRENT STATUS*: A comprehensive concept of quality control for SEA data is still under development. The security procedures implemented in FY94 are currently limited to those provided by UNIX System V Rel 4.**

### SD94-2.2.5. Relational database.

FY94 Objectives: Select and implement a relational database sufficient to support the SEA project in FY94.
15 wks ASU: selection and order

***CURRENT STATUS*: The relational database "Orion" is installed. A new prototype data management architecture for FY95 has been designed and a working prototype is due in May 95. Longterm collaborative development of the "Aurora" dataserver continues.**

*Details: page 8*

***FY94 ACCOMPLISHMENTS*: FY94 activity exceeded DPD objectives. This was possible due to non-EVOS funding provided to SEA by a codevelopment agreement with Xidak, Inc., and AVL. (see following full report for details).**

### SD94-2.3. Site access

FY94 Objectives: Establish (1) Wide area connections needed for Internet access to SEA operations in Cordova; and (2) A limited scale local area network (LAN) to connect the majority of SEA investigators within Cordova.
6 wks ASU: dedicated 256kbs telecommunications link to Internet.
12 wks ASU: limited scale local area networking of Cordova investigators

***CURRENT STATUS*: A dedicated Internet link to SEA in Cordova is established. A LAN interconnecting all SEA investigators within Cordova is operational. This establishes connectivity among all current SEA researchers and most external data sources, regardless of location.**

*Details: page 7*

***FY94 ACCOMPLISHMENTS*: Survey of current data-communications options completed; local channel, leased terrestrial and satellite links established; connecting hardware and software specified, obtained, installed and configured.**

### SD94-2.4. Remote sensing data

FY94 Objectives: Near real-time acquisition, archiving, screening, and reduction, referencing, clipping, and mounting of AVHRR sea surface temperature (and later SeaWiFS ocean color) for the PWS area. Subproject to be conducted by Dr. David Eslinger using facilities of the Geophysical Institute .

***CURRENT STATUS*: Daily near realtime AVHRR image archiving and migration to the SEA database is successfully underway. Collection of SeaWiFS data was postponed pending launch of the satellite.**

*Details: page 14*

***FY94 ACCOMPLISHMENTS*: AVHRR downlink, processing, screening and distribution procedures implemented. Archiving commenced immediately ASU. Images in both calibrated and browse formats prepared. Mosaic interface for interactive browsing implemented. All data to present transferred to the SEA database.**

### SD94-2.5 and 2.6. Remote data sources and Historical data

FY94 Objectives: Acquire selected contemporary (eg meteorological) and historical data of importance to SEA that would not otherwise be included in the SEA archive. Subprojects conducted by Dr. Gary Drew, NBS.

***CURRENT STATUS*: Acquisition and archiving of pre-1994 AVHRR, climatological and hydrological data has commenced.**

*Details: page 14*

***FY94 ACCOMPLISHMENTS*: Climatic data up to 1991 obtained, processing ongoing. Agreement reached with USGS Water Division to share hydrologic records. AVHRR projection and masking algorithms established for SEA. AVHRR archiving underway for 1985-90.**

## SD94-2.7. SEA data tools

FY94 Objectives: Demonstration scale implementation of tools for accessibility and utility of the SEA data, models, and forecasts. Subproject will begin after a relational database is added (15 wks ASU) and continue over the remaining eight weeks during which time capabilities are incrementally added.

***CURRENT STATUS*: Development ongoing.**

***FY94 ACCOMPLISHMENTS*: Xidak dataserver provides means for queries according to time, space, and across trophic levels. AVS tools support rapid review and exploration of interacting trophic levels across extended space and time scales. XMosaic is in use for previewing and overviewing large data collections over the Internet.**

## SD94-3. Descriptive model and interface

FY94 Objectives: (1) Visualization of the time varying state in the form of sequences of three dimensional renderings of each of the SEA Level 2 variables; and (2) Support for adaptive field sampling.

### SD94-3.1. Visualization

13 wks ASU: basic visualization capability, applied to bathymetry and several variables.
18 wks ASU: visualization of all Level 2 variables.

***CURRENT STATUS*: Capability for simultaneous 3-dimensional rendering of multiple physical and biological variables is established and in routine use.**

*Details: page 12*

***FY94 ACCOMPLISHMENTS*: Hardware and software specified, procured and configured. AVS networks developed for display and review of SEA data. Aurora implemented as an AVS module.**

### SD94-3.2. Support for adaptive sampling

In FY94: Provide near real-time support, including transmission of reduced data to the field and decision aid tools for field use and short term forecasts.

***CURRENT STATUS*: Ready to provide adaptive sampling support in FY95.**

*Details: page 13*

***FY94 ACCOMPLISHMENTS*: Capability for near-realtime data and graphic file transfer to field vessels via radio-modem / repeater network established. This will provide any one vessel with access to integrated data from other vessels as well as AVHRR data, in near realtime.**

## SD94-4. Numerical models

### SD94-4.1. Subsystem identification.

FY94 Objectives: Formulate an appropriate subsystem approximation for each life stage of pink salmon and Pacific herring, via survey findings on coincident distributions, feeding, dispersion, and ocean state.

***CURRENT STATUS*: Tentative subsystems identified.**

***FY94 ACCOMPLISHMENTS*: New findings for system components from FY94 sampling include (1) pollock predation switching between macrozooplankton and pink salmon fry; and (2) horizontal gradients in population density of pink salmon fry and large predators.**

### SD94-4.2. Ocean circulation model.

FY94 Objectives: Review contemporary capabilities; select the one or more approaches needed to model the ocean dynamics of Prince William Sound and its interactions with the Gulf of Alaska.

***CURRENT STATUS*: Ahead of schedule.**

*Details: page 19*

***FY94 ACCOMPLISHMENTS*: A continuously-running, 3-dimensional, wind-driven ocean circulation model developed at OPRC-RSMAS was reviewed. Collaboration commenced with Dr. Chris Mooers of OPRC-RSMAS to adapt a similar model to PWS.**

### SD94-4.3. Physical-biological model.

FY94 Objectives: (1) Review contemporary modelling approaches and their applicability to the subsystem associated with the zooplankton prey of pink salmon fry and juvenile herring; (2) Formulate a model and a plan for numerical solution as an extension of the ocean circulation model; (3) Assess feasibility and utility of a lower level implementation of the model that can be used with ocean state data from the SEA field observations and with satellite data for ocean temperature and color. (4) If the finding in (3) is favorable, implement a data-driven model of the time evolution of the plankton populations, up to but excluding planktivore grazing.

***CURRENT STATUS*: Dr. David Eslinger, IMS-UAF, is conducting this effort. (see attched at the end of this report).**

### SD94-4.4. Nekton processes.

FY94 Objectives: (1) Identify suitable subsystem (i.e., predators, competitors, and prey) for each postlarval life stage of pink salmon and herring; (2) From SEA data, identify the time varying distributions with respect to space and size of each population in the two subsystems; (3) Develop preliminary dispersion models for each population; (4) Develop numerical solutions for the trial models and simulate the time evolution of the space and size distributions of the subsystem, with diel and within season variations; (5) Develop trial models for foraging and growth and simulate the time evolution of pink salmon and herring feeding, growth, and predation mortality.

***CURRENT STATUS*: On schedule. Drs. Doran Mason and Vince Patrick are conducting this effort, with numerical solutions by Dr. Ricardo Nochetto.**

*Details: page 19*

***FY94 ACCOMPLISHMENTS*: 1-dimensional numerical models for nekton dispersion in response to temperature, foraging and risk of predation completed. Model coupling growth rate and satiation completed.**

## SD94-5. Sampling technologies

Objective: Improve efficiency and cost effectiveness of SEA sampling, with a view to longterm viability of sustained ecosystem monitoring.

### SD94-5.1 and 5.2. Depth shuttling platform and OPC

FY94 Objectives: (1) Specify and procure a towed platform capable of carrying physical, chemical, and biological sensors along a preprogrammed trajectory of periodically varying depths. (2) Extend the density and scale of zooplankton measurements through use of the FOCAL optical plankton counter.

***CURRENT STATUS*: Completed ahead of schedule and within budget. Led by Mr. E. Jin.**

*Details: page 25*

***FY94 ACCOMPLISHMENTS*: OPC loaned for one year by ADF&G Soldotna. Technical questions in integration of OPC into "Aquashuttle" researched and solved. Aquashuttle/OPC delivered, deployed and tested. System now turned over to routine use by SEA projects.**

### SD94-5.4. Acoustic tomography: review and evaluation.

Acoustic tomography is an extremely cost effective means for synoptic scale, high resolution, real-time measurements of the structure of the water column. FY94 Objective: Assess whether the efficiencies and cost effectiveness of acoustic tomography can be realized in SEA through suitable schemes of the generation of multiple paths.

***CURRENT STATUS*: Subproject conducted by Dr. Carlos Berenstein.**

*Details: page 26*

***FY94 ACCOMPLISHMENTS*: Preliminary examination of matched field processing completed. Collaboration established with Dr. Alexandra Tolstoy, Naval Research Lab, developer of the MFP approach. NSF funding provided partial support for a graduate research assistant.**

# 2. INTRODUCTION: Rationale and Objectives

The objective of SEADATA is to provide the computational and modelling resources necessary for an ecosystem-level understanding of processes regulating recovery of pink salmon and Pacific herring in Prince William Sound. This project provides the mechanisms by which data from the thirteen individual, discipline-specific studies of SEA are integrated into a single system-level representation.

To accomplish this objective, SEADATA is addressing two key groups of tasks. The first requirement is development of an interface to data from all SEA projects and remote data sources that is consistent and independent of the data source and measurement system. When seen through the interface, data on ocean state, surface conditions, plankton, fish and apex predators will share a common space and time reference. Once in this form, the multiple variables and time series of SEA can be interrogated and evaluated with multi-dimensional scientific data visualization systems in ways analogous to the use of Geographic Information Systems for surfaces. The second key component is development and application of deterministic models. A deterministic model predicts how quantities will change over a time interval and over some spatial region. Ocean current models are deterministic, as are "physical-biological" models that address jointly the ocean transport of plankton, phytoplankton production and zooplankton grazing. Likewise, nekton diffusion-advection-reaction models are of this type. Models with predictive capability are inherent to consideration of response, restoration and recovery. Specifically, understanding response implies some capability for forward and backward projections of events, risk analysis, what-if simulations, and ability to adjust projections based on updated current information. Similarly, restoration and recovery goals suggest a need for predictive assessment of strategies for moving a system from one state to another. Attainment of these capabilities is the 5-year goal of this project.

For FY94, the primary goal was to establish within SEA the centralized tools needed to build a quantitative description of the state of the ecosystem. Emphasis in this first year was placed on communications, coordinated data handling and storage, and data search-query and visualization capabilities. The key modelling objective for FY94 was intensive development of a nekton processes model, intended to mature with availability of FY94 survey data and in preliminary form also to be capable of informing the FY95 field sampling plan. Ancillary FY94 objectives of SEADATA were (a) identification of data sources and acquisition of data valuable to the modelling effort but not included elsewhere in SEA, for example historical databases and AVHRR satellite data; and (b) identification and application of improved technologies for more effective sampling, for example the Aquashuttle/OPC. During FY95-6 there will be a relative shift in emphasis: as data systems are in place and year 2 and 3 field data becomes available, progressively more of the SEADATA budget and resources will be directed to the modelling effort, in particular application of an ocean circulation model for Prince William Sound and continuing refinement of the physical-biological and nekton process models. The structure of the SEADATA project is illustrated in Figure 1; the first 2-year allocation of resources is summarized in Figure 2.

This report addresses SEADATA's FY94 achievements under the headings of (1) Data Management, (2) Modelling, and (3) Sampling Technologies.

# 3. FY94 PROGRESS

## (1) DATA MANAGEMENT

### Network Connectivity

During FY94, an early and accelerated effort was undertaken to establish connectivity among SEA researchers and access to the SEA database at the Prince William Sound Science Center (PWSSC) in Cordova. The resultant network is illustrated diagramatically in Figure 3.

A local area network (LAN) based on a core of UNIX workstations (Sun SPARCstations running Solaris 2.0) was installed at PWSSC. An Ethernet 10-base2 (thinnet) system was selected for reasons of economics and to minimize installation time. X-11 communications and server software (Hummingbird eXceed or MacX) was configured to connect IBM-compatible and Macintosh-based personal computers (PC's) to the system. The X-11 software allows PC's to function as full-featured X terminals running advanced UNIX software. In addition, in conjunction with appropriate software (SuperTCP, Frontier Technologies), this arrangement permits network file systems to be NFS-mounted for transparent file access directly from the desktop or laptop PC.

By means of an economical application of twisted pair technology, the PWSSC LAN was extended within Cordova over distances of up to 3 miles. This extended access to several sites, including remotely-housed PWSSC SEA scientists, SEA collaborators in the Cordova office of the Alaska Department of Fish and Game (ADFG), and a community accessible site used for data access and review during the October Workshop.

Internet connectivity was achieved for this Cordova network via several steps: a local loop link through the Cordova Telephone Company; a satellite data connection at 256 kbs from Cordova to Anchorage, leased from Alascom; a fractional-T1 (256 kbs) terrestrial line from Anchorage to Fairbanks, leased from the University of Alaska Computing Network; and finally a second satellite connection from UAF to Seattle, thence reaching the Internet via the NWNet system. This system provides essential communications and data transfer-sharing capabilities among SEA collaborators in Cordova, Anchorage, Fairbanks, the Lower 48, Canada and beyond. Information stored anywhere on the network is routinely accessed from distant sites, and fully featured data analysis tools can be shared remotely. Since coming online in July 1994, the network has functioned continuously with the exception of less than 2 days total downtime caused by telecommunications disruptions outside Cordova.

### Data Ingestion and Mass Storage

Hardware and procedures for migration of data from field acquisition/storage devices into the SEA archive were implemented promptly at the beginning of FY94 field season. Data ingestion was addressed in 3 ways: (i) packet radio communications (discussed below, Realtime Communications subproject); (ii) file importation after field log transcription and/or laboratory processing; and (iii) transport of physical media from the field. IBM-compatible microcomputers were used exclusively for instrument control and data-logging in SEA fieldwork. During short cruises the internal storage of the microcomputer was used for data storage; at the end of the cruise the laptop is physically returned and connected to the Ethernet for data uploading. For longer cruises the QIC-80 tape standard has been adopted. External portable tapedrive units with a standard parallel interface (Trakker, Colorado Systems) were selected as an economical and efficient mechanism of field data archiving and transfer. At the conclusion of the cruise, the tapes are restored to a PC connected to the LAN and then transferred to the UNIX file system via FTP.

A Sun SPARC-20 502 with dual processors was selected for the database host and is the host for all mass storage for SEA data. Devices obtained for mass storage in FY95 include 12GB of hard disk storage and a 6-platter quad speed CDROM. Data will be archived for off-line, low access mass storage by means of a Phillips CDROM mastering system. This means of archival storage was selected for reasons of economy ($11 per blank CDROM) and because this medium can be used to distribute SEA data to sites without Internet access.

## Database

### *Background*

The size, scope and complexity of the SEA datasets present formidable challenges for data integration. This is partly because measurement scales, time-space domains, and native formats vary widely among the projects, metadata are complicated, and multiple users may require the same set of observations for different purposes. The major challenge, however, results from the complex structure and interrelationships inherent in the nature of the data. The ultimate objective of SEA data integration is the capacity to access observations transparently from multiple projects, by 'slicing' across datasets based on these relationships. For example, a search query might seek to extract observations for plankton and nekton, sampled near a particular transect within a specified 3-dimensional spatial range, across all years but restricted to specified periods of the diel or tidal cycles, and matched with corresponding ocean current or temperature data. The datasets containing observations satisfying the query must be identified and the observations returned in a form useable by the application for which they are requested. Given the existence of thousands of data files, ranging in size from a few Kb to 40Mb or more, there is also a need for intelligent prefetching, binning or subsetting to avoid performance degradation in high-volume data-intensive applications.

There currently exists no off-the-shelf data management system capable of handling these challenges adequately and simultaneously. The present state of the art in scientific data storage is based on self-describing file formats. These afford autonomy, flexibility and portability across platforms. One example is the Hierarchical Data Format (HDF), which has recently been selected by NASA as the primary format in which EOS data will be made available. These formats alone do not, however, facilitate cross-file query and retrieval, tasks which are better served by the sophisticated indexing and search capabilities of a database management system (DBMS). However, modern relational database architecture presents limitations for the applicability of DBMS methods to scientific data. Specifically, most scientific data has a more complex structure than can be captured by current relational database systems. These conflicting demands continue to challenge DBMS designers.

In view of these considerations, a concurrent three-faceted approach to the data management problem was taken by SEADATA in FY94, as follows:

(i) short-term solutions, using existing technology, to support FY94 data collection and analysis and assist in FY95 field season planning (implemented in FY94);

(ii) medium-term solutions, based on new applications of existing technology, to support the full scale data integration needed for the expanding FY95 modelling effort (commenced in FY94, working prototype expected in May 1995); and

(iii) long-term development of new DBMS technology, to serve the functions required of a long-term public-access repository for PWS ecosystem data (ongoing).

Progress in each category is summarized below.

NOTE: Work in all three of the above areas was assisted by additional support obtained from non-EVOS sources. During May, 1994, the SEA project completed arrangements to undertake a co-development effort with Xidak, Inc., the Advanced Visualization Laboratory AVL at the University of Maryland (UMD), and PWSSC. Xidak contributed licenses for their extended relational scientific database software (Orion) and data server software (Aurora). The organization also awarded to SEA a grant for support of a graduate research assistan, which has supported the work of Charles Falkenberg. The total in-kind value of this contribution to SEA was approximately $90,000 for FY94. Support continues in FY95.

*(i) Short-term solutions:*

The FY94 objectives of establishment of an online flat file data base and preliminary implementation of a relational database have been accomplished. The flatfile system uses a hierarchical storage structure combined with UNIX file handling and file compression capabilities. Cross-project access and retrieval from this file system has been implemented for the primary visualization interface, Advanced Visualization System (AVS). In order to facilitate rapid utility of FY94 data, SEADATA has provided consultation on formatting as well as on-site programming of front-end interfaces for data conversion.

During July 94 a programmer/developer from Xidak visited PWSSC at no charge to EVOS, to install the relational database "Orion" and provide introductory training. Orion is a fully featured, multiplatform, extended relational, SQL-based DBMS which provides concurrency protection and a multilingual programming environment. Its intent is to offer scientific applications a "hybrid DBMS" which couples extended relational DBMS with both object-oriented and conventional programming methodologies, in attempt to facilitate handling of complex data structures. The PWS bathymetry data set was loaded into the database and has since been a frequently used test data set for remote query and visualization trials. The Xidak dataserver interface system under development, "Aurora", will extend and build upon the Orion base (see *(iii)* below).

*(ii) Architecture prototyping*

The FY94 activity of Charles Falkenberg, supported by Xidak, has focused on prototyping a data management architecture which provides relational DBMS advantages without sacrificing the portability and flexibility of scientific file formats. The design phase of this effort is complete and the project has reached the stage of database population, with a working prototype expected before May 95. The innovative architecture designed by Mr. Falkenberg uses an archive of HDF datasets *in conjunction with* storage of metadata in an extensible DBMS. The DBMS metadata will provide spatial indexing and search facilities for datasets in the HDF archive, and return objects designed to support specific applications. The datasets can also be used independently, without referencing the DBMS, thus maximizing flexibility for individual SEA researchers in the tasks of maintaining and updating their data.

The components of the architecture are:
* HDF archive
** Relational database of metadata
*** Mosaic server for individual file access

* *The Hierarchical Data Format (HDF)* standard accommodates multidimensional arrays and permits multiple datasets, each using any of 6 data types, to be written to a single file in hierarchical fashion. The 6 possible data types are:

- raster image, 8 and 24-bit
- text datatype, for storing documents, annotations and text metadata
- color palettes used to map colors to values during visualization
- multidimensional arrays
- tables for relational data

The software that supports this format is developed and distributed by the National Center for Supercomputer Applications (NCSCA) at the University of Illinois. It includes a library of accessors for each standard data type and a set of lowlevel accessors for extending the system to handle a new type. Library calls are accessible from C or FORTRAN programs and are available with documentation, free of charge. The HDF format is referred to as "self-describing" because it provides accessors which reveal the definition of the sample data or the attributes in any file. Attributes can be defined in a simple way, and given a value, which further defines the data. This internal description, along with a facility to translate data across multiple hardware platforms, makes the format portable as well.

Each SEA dataset in the HDF archive will have a unique identifier; a single HDF file may contain multiple datasets. The files can be stored on different disks or different physical workstations, and will be locatable by pointers in the indexing DBMS. The system can also index datasets outside the HDF archive, for example files located at NOAA, NASA, or another research location. Such files could be downloaded when requested or copied into the HDF archive and treated like an internally-generated file.

** *The Relational DBMS* component of the architecture will primarily house the SEA metadata (data about the data). This component is being designed to provide general as well as application-specific functionality. General functionality includes name service and a variety of spatial and non-spatial indexes over the metadata. Specific functionality in the form of query objects, for example to facilitate retrieval of trophic coupling information, is also included. The "Illustra" DBMS is one of the products proposed for this task. Illustra is an extensible DBMS which optimizes queries based on user-defined datatypes.

*** *The Mosaic Server interface* is the last component of the planned medium-term SEA data architecture. This standard hypertext-driven graphical user interface is the mechanism selected to give individual researchers off-site, as well as external researchers, easy access to the HDF archive. The interface will display a 3-d map of Prince William Sound and allow selection of regions and specific datasets. The database will return a list of HDF files satisfying the researcher's query. HDF files in which the datasets are located could then be downloaded through the standard Mosaic interface and operated on locally if desired.

The prototype architecture design completed in FY94 is summarized in Figures 4a, b, and c.

*(iii) Dataserver development*

Long-term development of a data management system is focusing on the Aurora system in conjunction with Xidak, Inc. Aurora is a data-server designed to meet specialized scientific data handling needs. It provides on one hand a ***logical data model*** and on the other an *applications program interface (API),* jointly positioned to bridge the span between individual datasets and the scientific applications using them, such as visualization or modelling software (Figure5). The logical data model seeks to provide a uniform domain-dependent view of the data, independent of the original source or physical storage representation. Details of physical storage are transparent to the user; programmers can select among multiple physical memory representations, depending on an application's requirements. Using the logical data model, each dataset is composed of an arbitrary set of typed, named values, with attributes organized into a multiple inheritance class hierarchy, supporting both regular and irregular gridding systems. Because Aurora uses a logical model based on datasets instead of a file format based on files, it can support datasets larger than a single file system and offers true parallel I/O processing for huge datasets. Finally, Aurora uses a combined coarse-grain/fine-grain management strategy: the coarse-grain component involves selecting datasets based on dataset attributes, using an extended SQL-compliant query language; fine-grained searching then involves extraction of a subset of values from within the selected datasets, based on either a space-time region or on the sample values (Figure 6). Achievement of these capabilities will make the system unique among today's scientific data management systems and provide precisely the longterm data handling functions required by the SEA program.

Progress in FY94 included development, by Charles Falkenberg and Ravi Kulkarni, of API software that enables the Aurora dataserver to read and write AVS formatted data and to run as an AVS library module. This software is now part of the SEADATA descriptive model interface tools and was demonstrated at the October Workshop. The cooperative agreement with Xidak provides SEA with the means to participate in the continued development of specific features and functions of its scientific database. However, since the Xidak approach is an "open systems" approach, this collaboration does not exclude the use or ultimate selection of other databases by SEA.

## Descriptive Model/Visualization

The term "descriptive model" has been used in the SEADATA project description to denote a *qualitative* rather than quantitative picture of the ecosystem. Whereas numerical modelling aims to provide quantitative predictions based on measured data and an understanding of the processes (model) governing the system, descriptive modelling provides a series of "snapshots" of the state of the system in the absence of a complete model and hence with only partial information for interpolation and regridding.

The stated descriptive modelling objectives for FY94 were

a. Visualization of the time-varying state of the ecosystem in the form of sequences of three-dimensional renderings of the SEA variables, and

b. Support for adaptive field sampling (through capacity for near-realtime transmission of field data, visualization, and re-transmission of processed images to field sampling stations).

a. Visualization

The FY94 goal of a three dimensional rendering of key physical and biological variables has been achieved. FY94 achievements are summarized below, under the categories of (i) resources now in place to serve SEA descriptive modelling needs; and (ii) illustrations of the application of these resources in FY94.

*Visualization Resources:*

The SEADATA project was responsible for selection and installation of the UNIX hardware and software resources required both for data display and analysis by the individual projects at PWSSC and for SEA visualization and development of descriptive models. The primary visualization platform is a SUN SPARCstation 20 with 128 MB of memory and SUN ZX graphics acceleration for 24bit, three-dimensional images. The primary software for system level description is Advanced Visualization System (AVS) along with ARCINFO, IDL, S-Plus, and PV-WAVE. All FY94 objectives for the acquisition and installation of required hardware and software were met on schedule and within projected costs. The FY94 budget was minimized by negotiating for SEA discounts near those extended to academic institutions. In nearly every case those discounts were obtained. In special cases software was obtained at no cost to the Trustee Council (for example, two licenses for Interactive Data Language (IDL), valued at over $5500, were provided through collaboration with the Rosenstiel School of Marine and Atmospheric Science (RSMAS) at the University of Miami).

Advanced Visualization System (AVS) scientific data visualization software was selected to serve the global visualization system needs of SEA. AVS is a sophisticated system which provides powerful, interactive data-viewing capabilities including 3-dimensional geometry-based rendering. AVS users construct visualization applications by combining software components into executable *flow networks* (Figure 7). These components, called *modules*, implement specific functions in the visualization process, such as data importing, transformation or filtering, mapping into 3-dimensional geometries, and rendering for display. AVS includes a rich library of modules. It also allows users to create tailored modules for specialized applications, using C or FORTRAN, and dynamically load these into existing AVS networks.

SEADATA provides several levels of support for SEA visualization activities, including:
- C programming to create customized modules for the AVS library, in conjunction with AVL;
- network design and construction for joint display of variables from multiple SEA projects; and
- technical support to assist AVS users in individual SEA projects with data display tasks.

*Visualization Applications in FY94:*

During FY94, AVS has been used to develop a library of tools able simultaneously to display oceanographic and biological data from all of the SEA projects as well as from data sources outside SEA. The AVS analysis and visualization tools are tightly integrated with the search and query capabilities of the Aurora dataserver software from Xidak. This has been possible through the implementation of the Aurora dataserver software as an AVS library module (see Data section, above).

Progress to date includes the simultaneous display of
- NOAA-NOS bathymetry data
- AVHRR sea surface temperature
- one or more variables from CTD casts (depth, temperature, salinity)
- ADCP current vector data
- one or more variables from Aquashuttle trajectories
- acoustic assessments of fish abundance
- video images from aerial surveys

In addition, specialized time and spatial "slicing" modules allow interactive, simultaneous display of sampling locations for all of the above plus
- trawl locations
- nearshore and offshore acoustics transects
- phytoplankton, zooplankton and nutrient sampling sites

for specified geographic and time-bounded regions (Figure 8).

Figure 9 shows a 3-dimensional rendering of PWS bathymetry, overlaid by aerial flight paths (red lines) and selected acoustic transect (vertical sheets), CTD-temperature (vertical columns), and aquashuttle (undulating lines) data from July 94 cruises. Figure 10 is a more detailed 3-d view of selected hydroacoustic transects in Montague Strait. Figure 11 displays a 3-dimensional current vector map created by AVS from ADCP current data collected during the September 94 SEA-OCEAN cruise.

b. Support for Adaptive Sampling

Many of the data analysis and visualization tools now on-line can provide near realtime preliminary results. In addition, sea surface temperature from AVHRR satellite sensors have been available since late June (see Remote Sensing, below). The schedule for commencing near realtime data communications between SEA survey vessels and the base station at PWSSC was delayed during FY94, for reasons discussed below (Realtime Field Data Communications, below). However, all components are now in place to support adaptive sampling in the FY95 field season.

Specifically:

- The radio-communications repeater network is in place, providing coverage of both Eastern and Western PWS (see Realtime Field Data Communications, below); and
- Hardware and software capabilities have been configured and refined to permit near-realtime transfer of both text and graphics files between the PWSSC base station and field survey vessels. This means that vessels in the field can be informed by daily satellite sea surface temperature images, as well as by near real-time results of concurrent but non-spatially overlapping survey efforts. These can be integrated using the descriptive model visualization and display tools at PWSSC before re-transmission to the field.

## Remote Sensing Data

The FY94 objective of the Remote Sensing subproject was to provide SEA with complete, current, AVHRR satellite sea surface temperature data for the North Gulf of Alaska, including Prince William Sound, in near realtime. Similar goals for SeaWiFS ocean color data were postponed as that satellite was not launched during FY94.

Downloading, processing, compilation and archiving of the AVHRR satellite images is being conducted for SEA by Dr. David Eslinger and L. J. Miller of the Institute of Marine Science, University of Alaska, Fairbanks (IMS-UAF). During FY94 they completed installation of the hardware and software required for (i) capture of data from all overpasses of the NOAA AVHRR satellites; (ii) calibration and space-time referencing of the data; (iii) cloud and terrain masking; and (iv) archiving of images and distribution of the data. Initial collaboration was conducted with Dr. Gary Drew, NBS, to select a "standard" projection for SEA, to establish the boundaries of the region of interest in SEA, and to establish a common set of cloud and terrain masking algorithms (see Historical Data, below).

Capture of daily AVHRR satellite data commenced in June. IMS-UAF has mounted a Mosaic server on the Internet (URL http://summit.ims.alaska.edu), which supports interactive browsing of the available SEA AVHRR images. All temperature sea surface temperature data are shown in GIF image format (reduced spatial and data resolution) to facilitate review and selection of required images from all available passes. All images from June 1 to the present date have been ported to the SEA data archive for easy access by SEA researchers. As mentioned above, hardware and software capabilities are in place for transmission of daily images to field survey vessels.

Figure 12 shows an example of a panel of AVHRR images displayed by Mosaic.

## Historical Data and Data from Non-SEA Sources

The long-term objectives of this subproject are to:

- assemble a digital index of historical ecosystem data relevant to SEA
- establish an offline (tape) and low availability online (CDROM) database for historical data available in digital form
- select high priority data resources and complete necessary data processing to integrate these data into the SEA database and
- integrate relevant current data from sources other than the SEA data and satellite data

During FY94 a collaboration was commenced with Dr. Gary Drew of the National Biological Service (NBS) to address these historical and remote data goals. Work commenced by Dr. Drew in FY94 on compilation of pre-1994 climatological data, hydrological data, and AVHRR sea surface temperature data, as follows.

Climatic data up to 1991 has been purchased from the State Climatologist. Processing is ongoing to separate the records for Prince William Sound and the Copper River Basin. These records are in digital format and should be available through the SEA database in the near future. In addition, an account was opened with the SCS online Central DataBase System (CDBS) in Portland, OR. The CDBS provides both climatic and hyrdrologic data and data analysis tools. Lack of tools for downloading these digital datasets currently limits utility, but discussions with SCS are continuing on making these data more accessible. SCS has also provided their snow survey data to us in digital format.

The USGS Water Division has agreed to share their hydrologic records for streams in the study area. All stream-flow records of 5 years and longer have been identified from the USGS database. The number of records and format incompatibilities have slowed the process of integration with other data; however a test dataset was successfully imported. In addition, a prototype watershed model is under construction for the Copper River Basin. A single growing season of AVHRR data processed to yield a Normalized Difference Vegetation Index (NDVI) has yielded significant correlation with stream flow at the Copper River gaging station. The ability to predict stream inflow in a near-realtime manner could be important to ocean circulation models.

A collection of pre-1994 AVHRR images from a variety of sources was commenced in FY94. An important effort was completed to select a "standard" projection for SEA, to establish the boundaries of the region of interest in SEA, and to establish a common set of cloud and terrain masking algorithms. This work addressed differences in software and in convention between the oceanographers and terrestrial ecologists. The working choice for the projection is Albers equal area conic projection, with constraints at 55 and 65 degrees latitude and origin at -154 degrees longitude, 60 degrees latitude. During FY94, 40 images were purchased from the National Climatic Data Center (NCDC) operated by NOAA. These images were primarily selected from the period April-May, 1985-1990. It was found that two of the images, one from 1985 and one from 1986, were unretrievable from NOAA archives in Ashville, NC, apparently because the NOAA archive media is beginning to fail. Consequently, because of the potential to lose access to these earlier images, attention has since focused on this early data and an additional 40 images from the summers of 1985 and 1986 are on order. In-house processing capabilities were upgraded through purchase by NBS of a Terrascan site license. This substantial collaborative investment by NBS will provide direct compatibility with the current daily AVHRR image libraries being built at UAF and will also decrease processing turnaround time for the historical satellite sea surface temperature images.

To integrate these various data sources, a SQL relational database is currently under construction to index the resources compiled at NBS The primary index will be a year/julian day field. This will give SEA researchers immediate access to all data collected on a given day as well as point to data gaps in the time series. The collaboration between SEA and NBS is continuing in FY95.

## Near Realtime Field Data Communications

Inherent to the mission of SEA is the need for *coordinated* and *adaptive* field sampling, to maximize both the synopticity of data collected and the value of the information returned from each cruise. Additionally SEA is tasked with moving large quantities of data between remote collection sites and central computing facilities. To serve these needs, SEADATA has undertaken to establish a near realtime, two-way data link between field survey sites and online facilities at PWSSC. The FY94 objectives were to establish a prototype capability for near realtime data communications between a base station in Cordova and SEA survey vessels and fixed monitoring stations.

During FY94 the following was accomplished:

- An assessment of competing approaches was completed and a VHF/UHF packet radio design with land-based repeater selected;
- Agreements were reached with administering State and Federal agencies to allow placement of equipment at existing repeater sites sufficient for radio coverage of the SEA study area; and
- Equipment selection, installation, configuration and testing was completed and a working prototype communications capability achieved.

The following discussion summarizes FY94 realtime communications activity under categories of design, implementation and current capability.

*Design Considerations*

Design considerations for the data link included four requirements: (1) near real-time capability with a minimum of second party involvement; (2) two-way channel capable of high data rates for handling large graphics and time-series data files; (3) rugged, low power consumption hardware with a proven track record at remote, environmentally extreme sites; and (4) low cost.

To initiate the design effort, SEADATA undertook a review of existing technology options, summarized in the table below. The large volume of data to be handled by the system proved to be the driving factor in choosing a technology. Since the system is expected routinely to transfer data files on the order of a megabyte in size, high data rates are essential. A one megabyte file transfer at 9600 b/s requires approximately 15 minutes (not including overhead). The same file transferred at 1200 b/s would take over 2 hours of continuous data transmission. The slower rate is unacceptable not only from the standpoint of timeliness but also due to power limitations at remote sites. After a thorough review of these types of issues it was concluded that a VHF/UHF data radio link could best meet all four of the primary system requirements.

| Technology | Advantages | Disadvantages |
|---|---|---|
| HF Radio | No repeaters needed. Low Cost. | Maximum data rates < 1200 baud. Skywave propagation dead zones. High power consumption. |
| Satellite | No repeaters needed. Atmospheric degradation minimized. | Large amounts of data would require expensive dedicated channel. |
| Cellular | All aspects of link handled by common carrier. | Not available in PWS area. |
| VHF/UHF Radio | Capable of fast data rates. Two-way channel. Low power consumption. No second party involvement. Moderate cost. | Line-of-sight link requiring installation of repeater sites. |

Since VHF/UHF radio is line-of-sight based, installation of repeaters was required to provide adequate coverage of Prince William Sound. Contact was initiated with State and Federal agencies currently operating repeater sites for voice communications in the PWS area. Five sites came under consideration, two administered by the Alaska Department of Environmental Conservation (Heney Ridge, LaTouche Island) and three by the U.S. Forest Service

(Hinchinbrook Island, Naked Island, Ester Island). Coverage maps created using GIS terrain elevation data, together with reconnaissance flights to assess current configurations, indicated four sites would give adequate coverage of the FY94-5 SEA sampling area. Permission was requested for co-location of equipment at these existing repeater sites.

In tandem with the repeater negotiations, a review of available hardware was conducted. Suppliers for the two critical components in the system, the data radios and the RF modems, were reviewed. A short list of companies contacted for these components includes Campbell Scientific; Cylink; DataCom; Data Race; Data Radio; Handar; Kantronics; PacComm; Solid State Electronics; and Sutron. Several of these companies market systems for data collection at remote sites. However, a majority of these systems are designed to log data autonomously from analog or digital sensors and subsequently transfer the data to a base station via an RF link. The data loggers take sensor readings at relatively slow rates, with maximum sampling frequencies on the order of one sample per second. The remote ends of the RF link are designed to interface only with each company's data logger and the data link protocols are not standardized. There are no provisions in these systems for computer-to-computer communication links or file transfer at high data rates. Other companies listed above provide data and communication links primarily for urban applications. These companies make use of infrastructures already in place, such as repeater networks or cellular grids, and offer access to these links on a subscription basis. Still other companies manufacture RF modems for sale in the amateur radio market. These components generally to not meet commercial standards and are not ruggedized or field tested..

In summary, our findings indicated that the SEA requirements specified a state-of-the-art system in wireless data communications. A single company with the requisite experience in remote, ruggedized installations was able to offer radio modems for linking computers and operating in the 9600 baud range. This company, PacComm, manufactures RF modems and interfaces them with OEM radios, usually with minor modifications to the radios to obtain the high data rates. The data protocol used is referred to as Packet radio, or AX.25, which sends the data in short streams called packets each of which contains a destination address. An extended form of the AX.25 protocol, called NET/ROM, is used to control the modems at repeaters sites allowing for true store-and-forward repeating that greatly improves throughput over standard repeating. This improvement is realized by performing error checking at each node (repeater) rather that just at the terminal nodes. A sophisticated method of packet labeling combined with acknowledgement replies from the receiving stations allows for error free data transfer.

The final phase in the design effort was an analysis of power consumption for hardware to be installed at the remote sites. Of the proposed repeater sites, Heney Ridge is equipped with 120v line power and Naked Island has a large solar array already in place. Since power is not limiting at these sites, we opted to fit these repeaters with Motorola microprocessor-controlled 10 watt radios. The 10 watt Motorola radios have considerable power requirements in both transmit and standby mode making them unsuitable for strictly battery powered installations. At sites where power would be supplied by batteries, smaller crystal-controlled 2 watt radios with low standby current requirements were proposed. (Field testing during FY94 subsequently demonstrated 5 watt radios to have more satisfactory performance and the design plan was modified accordingly.) Power at these sites will be delivered by an array of AirCel alkaline batteries supplied by REVL Communications in Anchorage. Solar rechargeable systems were also evaluated and found to be cost competitive with alkaline systems, especially in the long-term analysis. However, since these systems represented greater initial costs and significantly higher risk of failure due to environmental factors, they were not considered a viable option for the initial installation. Options for the remaining components of the system including antennas, antenna towers, and enclosures for the electronics and batteries were reviewed extensively with durability and performance the driving considerations. Antennas were selected for durability under high winds and extreme icing conditions. The enclosures purchased meet NEMA 4X standards for resistance to environmental extremes.

*Implementation and Current Capability*

Field implementation was delayed relative to planned milestones due to delays in receipt of equipment from the manufacturer, equipment modifications required as a result of field testing, and protracted delays in obtaining USFS approval for use of the key repeater site on Naked Island. However, as of the date of this report, the subproject is on track and FY94 goals are satisfied. Specifically:

- SEA applied for and was granted FCC license for a dedicated, data only frequency of 464.425 MHz.
- Permission has now been granted by USFS and ADEC for co-location of SEA equipment at all needed repeater sites (Figure 13) and for the use of existing power sources, enclosures, and towers.
- The PWSSC Base Station equipment is operational.
- Repeaters have been installed at the Heney Ridge and Naked Island locations and successful data transmission has been achieved between locations in both Eastern and Western PWS and the Base Station. The coverage of the Western sound provided by the Naked Island repeater has exceeded expectations, reaching a range of at least 60 miles and extending coverage to the south end of Montague Straits as well as the "shadow" areas in the Eastern PWS. Consequently, installation of the Hinchinbrook Island site has been postponed and may prove unnecessary.
- Software protocols to facilitate unattended text and image transfer are currently undergoing final configuration for automation. The system uses ProComm Plus software running in HOST Mode to run a dialup BBS (bulletin board). This provides remote file transfer and email-messaging capabilities via the radio-modem repeater system while preserving network security.
- ASCII file transfers, Z-modem transfers, and image transfers of AVHRR images in the GIF format have been accomplished over the radio-modem repeater network. GIF images are translated into 6 bit ASCII using either the UNIX or DOS version of UUENCODE for ASCII transmission (default for the repeater network). The transmitted images can be viewed in the field, on a color or grayscale PC laptop using public domain software such as CSHOW or Graphic Workshop.

In addition to the above repeater network, equipment has been designed and purchased for one mobile station for a SEA survey vessel and for the shore station to transfer data from the SEAOCEAN tethered acoustic Doppler profiler which will monitor currents at Hinchinbrook entrance (HERO site). SEADATA has also provided consultation and communications support for design of a drifter buoy system to be deployed in Western PWS by the SEAOCEAN project in FY95.

## (2) NUMERICAL MODELLING

Numerical modelling tasks for SEA have been divided into 3 categories: ocean circulation (describing and predicting ocean current flow); physical-biological (coupling physical transport mechanisms, nutrient densities, and plankton dynamics); and nekton models (describing processes affecting fish distribution).

### Ocean Circulation Model

The objective for FY94 was to review contemporary capabilities for ocean circulation modelling and to select a suitable approach for PWS. During FY94, SEA was fortunate to establish a collaboration with Dr. Christopher Mooers, Rosentiel School of Marine and Atmospheric Sciences (RSMAS), University of Miami. Dr. Mooers has begun work on adaptation of the Mellor Ocean Circulation Model, also known as the Princeton Model, to Prince William Sound, in close collaboration with Dr. Vince Patrick and Dr. David Salmon. This is a continuously-running, 3-dimensional, wind-driven model achieving 2-3 day forecasting using NWS weather predictions. A working version for PWS is expected by August, 1995.

### Physical-Biological Model

This portion of the modelling effort was conducted by Dr. David Eslinger, UAF. His report is appended separately.

### Nekton Processes

The Nekton Modelling activity has been undertaken by Dr. Doran Mason and Dr. Vince Patrick, with numerical solutions by Dr. Ricardo Nochetto. A brief synopsis of progress in FY94 follows.

*Background*

The nonrandom spatial distribution of pelagic organisms and the heterogeneous physical environment are important considerations for understanding and predicting change in natural ecosystems (Steele 1978). Spatial patterns in the distribution of food resources, predators and competitors, and environmental conditions have direct implications for population demographies including differential rates of population growth and mortality (Haffaker 1958; Gliwicz and Rykowska 1992). Birth and mortality rates are directly dependent on successful foraging and avoiding predators; that is to survive and reproduce, individuals must acquire resources, avoid being eaten, and grow (Walters and Juanes 1994). However, the spatial distribution of food resources and predators are often patchy and vary over time. Furthermore, nutritional quality of food resources may vary across space and time (Willason et al. 1986). Similarly, environmental physical conditions affect population function in an ecosystem. Water temperature directly determines physiological rates in fishes which affect growth and activity (Fry 1971; Hewett and Johnson 1992). At the population and community level, water temperatures regulate the intensity and direction of population and community change by affecting spatial distribution and spatial overlap of predators and prey (Magnuson et al. 1979; Neill 1979; Williamson and Stoeckel 1990) and magnitude of interactions through direct effects on biological rates (e.g., Mason and Patrick 1993). Hydrological forces (tidal currents, circulation) operate directly as a transport mechanism of young fishes (Hjort 1914 ) and may facilitate mortality of young fish through aggregation and density dependent mechanisms (Dobrynina et al. 1989) and by increasing predator and prey overlap.

The SEA hypotheses explicitly acknowledge the role of biological and physical processes across space and time for understanding the growth and survival of salmon fry and young herring. Pink salmon growth and survival is believed to be coupled with the foraging behavior of walleye pollock and the presence of macrozooplankton (prey switching hypothesis). Walleye pollock are believed to feed primarily on macrozooplankton in the spring and summer when available. However, as macrozooplankton become less available, pollock will switch to salmon fry. The processes governing the interaction are complicated and occur over various spatial and temporal scales. At large spatial and temporal scales, the interannual timing and availability of macrozooplankton may be determined by interannual differences in circulation (lake-river hypothesis) and timing of the macrozooplankton descent to overwintering depths (bottom-up hypothesis). At finer scales, prey switching is also dependent on the local abundance of alternative prey (pollock fry, juvenile herring, etc) and tidal currents that may aggregate prey. Alternative prey may also act to provide a refuge for salmon fry (Gotceitas and Brown 1993). Salmon growth is also determined by food and water temperature. The spatial domain emphasizes spatial overlap of predator and prey and the physical environmental conditions. The temporal domain emphasizes the hourly, daily, seasonal, and annual changes in the distribution and abundance of food and predators and physical conditions.

Our modelling approach emphasizes process-based spatial and temporal models to understand and predict the distribution, growth and survival of pink salmon fry and young herring during their residence in Prince William Sound. Since species spatial distributions are often affected by the spatial distributions of predators, food, and physical conditions, knowledge of how these factors affect the movement and distribution of predators and food resources must be included in the spatial models. Previous studies suggest that pink salmon fry respond to predation risk (Abrahams and Healey 1993) and that predation risk may be partly responsible for determining salmon fry distribution and movement patterns (Werner and Gilliam 1984; Abrahams and Healey 1993). Furthermore, the level of hazard an individual fry is willing to risk may be proportional to the quantity of food in the stomach or recently past foraging success. Feeding rate and predation risk appear to be a reasonable starting point for modeling the spatial distribution, movement, and interactions with predators. Interactions between predator and prey occur only in regions where their spatial distributions overlap. The intensities of the interactions and individual performance (feeding rate and growth rate) are mediated by the physical environment. We therefore couple physical (circulation, temperature) and biological (predation, migration) processes in a heterogeneous environment.

*Identification of Subsystems*

Since FY94 was the first year for the integrated SEA program, data from the SEA surveys were not available for the initial identifications of trophic subsystems at the onset of the nekton modeling project. Trophic subsystems were therefore initially identified in the context of the SEA hypotheses and published literature. Potential predators of pink salmon fry ("plus 1" subsystem) were identified as adult Pacific herring (Clupea harengus), starry flounder (*Pleuronectes stellatus*), Dolly Varden trout (*Salvelinus malma*), walleye pollock, and adult salmon (Khorevin et al. 1981; Dobrynina et al. 1989). Although, pollock were not found to be potential predators from the literature review, preliminary field data supported the SEA hypothesis that the pollock are potentially an important source of pink fry mortality. Diets of pink salmon fry ("minus 1" subsystem) are generally dominated by calanoid copepods (*Neocalanus spp. Calanus spp., Pseudocalanus spp.*) (Godin 1981a, Cooney 1993; Parker and Massa 1994). However, fry may derive a significant component of their diet from pteropods, epibenthic prey (harpacticoids) and insects (Godin 1981b; Cooney 1993; Parker and Massa 1994). Preliminary field data of pink salmon fry diets are consistent with fry feeding upon calanoid copepod prey.

*Preliminary Model for Dispersion*

Our objective was to develop and test a behavioral-based 1-dimensional spatial model for predicting the spatial distribution and timing of predator and prey overlap in a well studied ecosystem; and, upon successful completion of the test case to adapt the 1-D model to Prince William Sound pink salmon fry.

Our one-dimensional spatial model is a system of coupled differential equations with a behavioral-based taxis term that determines swimming direction and swimming velocity as a function of food concentration, predation risk, and physical conditions. The single population model has the form:

$$\frac{\partial u_i}{\partial t} = \frac{\partial}{\partial x}\left(D\frac{\partial u_i}{\partial x} + \chi u_i \frac{\partial \lambda(u,e)}{\partial x}\right) \qquad (1)$$

where $u_i$ is population being modeled, t is time, D is the dispersion coefficient, $\chi$ is the taxis coefficient, $\lambda$ is a function that determines behaviorally directed fish movement, **u** is a vector that contains predator and prey populations, and **e** is a vector that contains all physical variables (temperature, salinity, light, hydrology) that affect the distribution of a fish populations. From eq. 1, the value of $-D\,\partial u/\partial x$ determines the random component of fish movement and $-\chi u\,\partial\lambda/\partial x$ determines the directional component of fish movement. The sum of the random and directional components of the model determines the number of fish crossing depth x per unit time. The equation describing the behaviorally based taxis function, $\lambda$, is:

$$\lambda = \phi(u,e) + \mu(u,e) + \theta(e) \qquad (2)$$

where $\varphi$ is feeding rate, $\mu$ is predation risk, and $\theta$ favorability of the physical environment. The taxis function acts on each individual in the population such that each individual perceives both biological (feeding opportunities and predation risk) and physical (temperature, salinity, currents) features of the environment. Direction of movement is assumed to be a result of searching for food, avoiding predators, and finding favorable physical conditions (e.g., optimal temperature for growth). The observed path should ideally lead to the site of greatest food density weighted by the willingness to accept some level of predation risk and environmental extremes. Thus, to move, the individual must continually evaluate the local environment using instantaneous local spatial and temporal cues (e.g., food density, predator density, water temperature). Direction is determined by crossing the contours of the taxis function (Fig.14).

*Test Site*: In order to begin preparation of a preliminary model immediately, without waiting for availability of FY94 SEA field data, we used the Laurentian Great Lakes and the alewife (*Alosa pseudoharengus*) as our test site and test species for the spatial model. The Great Lakes are an extensively studied large freshwater ecosystem that contains many of the species of fish found in Prince William Sound. Four species of Pacific salmon are stocked or self sustaining in the Great Lakes and include species found in PWS: chinook salmon, coho salmon, and pink salmon. The pelagic planktivore assemblage includes a clupeid species, the alewife.

*Preliminary Results*: The previous analytical solution (equilibrium case) for the 1-D model was limited to a single noninteracting population with no births or deaths and the assumption of equilibrium was rejected (Mason and Patrick 1993). Thus, to accommodate multiple interacting populations and birth and death terms, the solution for the space and time-dependence required a numerical solution of the partial differential equation (eq. 1). After several numerical methods were explored (finite difference and Method of Lines) without success, Dr. Ricardo Nochetto (University of Maryland) developed and completed a numerical solution for the one dimensional nonlinear model of nekton dispersion. Details of the solution are appended to this report. The algorithm is an adaptation of the exponential fitting method in finite element analysis. The algorithm was coded in C by Mr. Tongbiao Li (University of Maryland) and then debugged by Mr. Li and Dr. Doran Mason. Problems of conservation and numerical stability, found in previous attempted algorithms, appear to have been eliminated with the exponential fitting technique.

Presently, two numerical models for nekton dispersion in 1 spatial dimension have been developed. The first considers the dispersion of a single population in response to temperature, feeding opportunities, and risk of predation. The second model considers the dispersion of three interacting trophic levels (macrozooplankton, forage fish, and apex predator) with respect to one another and the physical environment. The case for one population interacting with the biological and physical environment has been applied to cases of known fish behavior for model validation by Dr. Mason. Animations of model results were presented at the October Workshop. The model of multiple interacting trophic levels is completed and being debugged.

The results of FY94 show that the modelling approach is well suited for capturing the spatial-temporal response of predators, forage fish, and macrozooplankton in response to environmental variables and trophic level interactions. The 1-D model for interacting populations (predators, salmon fry, and zooplankton) is presently being adapted for juvenile pink salmon in Prince William Sound.

<u>*Bioenergetics (Growth) Model*</u>

Traditional bioenergetics growth models (e.g., Hewett and Johnson 1992) consider feeding rate and growth rate for a daily time step. However, feeding rate occurs on the order of seconds to minutes and is governed by processes that may change in minutes. On the other hand, growth rate in fishes is the cumulation of feeding successes and occurs at a different temporal scale. It is thus problematic to model feeding rate and growth rate when the driving functions (food density) change on scales of less then a day. Feeding rate of juvenile pink salmon is proportional to the quantity of food in the stomach (Godin 1981). Furthermore, fish appear to modify their behavior in response to hunger level (satiation) and risk of predation (Dill 1983).

During FY94 we developed a preliminary foraging model and bioenergetic growth model for juvenile salmon. The model seeks to couple two processes that operate over different time scales, foraging rate (seconds to minutes) and growth rate (hours to days), through gut satiation and gut evacuation rates. It will make testable predictions of feeding rate, gut satiation, and growth rate given different environmental scenarios for juvenile salmon.

The general form of the feeding and growth rate model is:

$$\frac{da}{dt} = \phi(a,u,s) - \rho(T)a$$
$$\frac{ds}{dt} = \rho(T)a - \Lambda(a,s,T) \qquad (3)$$

where a is gut satiation (g), $\phi$ is feeding rate (g/t), u is prey density (number $m^{-3}$), s is weight of salmon fry (g), r is instantaneous gut evacuation rate ($t^{-1}$), T is temperature (°C), and $\Lambda$ are losses from standard and active metabolism, excretion, egestion, and specific dynamic action. The set of nonlinear equations is solved using the 4th Order Runga-Kutta method with adaptive step size.

*Preliminary Results*: Early results of the prelimimary model for predicting the feeding rate and growth rate of young pink salmon are encouraging. The model predicted a growth rate of 2-3% body weight per day at 10°C for a 1 gram fish (e.g., Figure 15a). Modeled growth rates are consistent with the growth rates of juvenile pink salmon fry, 1.8-5.5% body weight per day, reported from the literature (LeBrasseur and Parker 1964; Phillips and Barraclough 1978). More exciting, however, is the ability of the model to predict feeding rate as a function of stomach fullness, i.e., hunger level. Our model results independently duplicated the laboratory results of Godin (1981a). Godin (1981a) found that juvenile pink salmon with empty stomaches will rapidly fill their stomach by feeding at a rate of about 60 zooplankton per minute. Upon reaching satiation, feeding rate dropped dramaticly and was maintained at about 5-10 zooplankton per 10 minute. An equilibrium condition was reached where food evacuated from the gut was replaced through foraging. Our independent model result duplicated the feeding pattern and the equilibrium condition observed by Godin (1981a) (Figure 15b and c). Continued model development will consist of refining model parameters borrowed from related species (i.e., sockeye salmon) and adapting the model to pink salmon of Prince William sound.

## *Marcrozooplankton Model*

We presently have a 1-D vertical ascent model to predict the timing and relative abundance of Neocalanus eggs in the surface waters during the spring. We expect to have preliminary results from our expanded 3-D model for the oceanography and plankton cruise scheduled for mid-March.

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## DETAILS OF NUMERICAL SOLUTION

please see following attachment prepared by Dr. Ricardo Nochetto

## (3) NEW SAMPLING TECHNOLOGIES

In this subproject, SEADATA addresses the efficiency and cost of the SEA monitoring effort with respect to resolution and scale of sampling. Major technological advances in sampling and measurement technologies are occurring at an accelerating rate. Some of these have the ability to expand the density and scope of measurements attainable for a given cost or effort.

With regard to such advances, this subproject has two objectives:

a. To serve as the vehicle whereby new technological advances relevant to SEA can, on a selective and prioritized schedule, be introduced without impairing the ability of existing projects to fulfill immediate monitoring responsibilities; and
b. To provide a means whereby newly available advances or emerging technologies relevant to SEA can be reviewed and evaluated.

Efforts in FY94 focused on two technologies:

- Deployment of a towed platform equipped with optical plankton counter (OPC), CTD probe, fluorometer and flow meter, providing a programmable, depth-varying, undulating trajectory and suitable for unattended deployment on ships of opportunity: the Aquashuttle; and
- Preliminary examination of the application of acoustic tomography for unattended current monitoring.

### Aquashuttle/OPC

Integration of the Chelsea Aquashuttle and the FOCAL OPC was a cooperative effort using pooled resources from university, state agency and private industry sectors in three countries (US, Canada, UK). The design effort was headed by Mr. Edward Jin, University of Toronto. This system provides a pre-programmable vehicle capable of simultaneous real-time collection of continuous (i.e. along horizontal and vertical planes) physical (temperature, salinity, conductivity and depth) and biological data covering two trophic levels (algae and zooplankton) in the Prince William Sound food chain. Technical details of the integration have been published in Sea Technology, October 1994; Underwater, Winter 1995; Hydrographic Society Bulletin, October 1994; and World Water and Environmental Engineering, October 1994.

Two test cruises were conducted during July and September aboard the US Coastguard Cutter Sweetbrier. The shuttle system was deployed for a total of 14 continuous hours of data collection, covering the main part of the Sound and Orca Bay. The data collected revealed some interesting spatial patterns in the upper waters of the Sound. For example, a dense layer of plankton was found in the top 20 meters across the two upper west-east transects but was not evident in the lower one. An even higher density of plankton was found in Orca Bay which did not show such distinct layering as animals were uniformly distributed through the sampled water column. These patterns, together with data for other measured parameters (eg. temperature, chlorophyll, salinity), were presented at the October Workshop. Following the test cruises, the entire shuttle system was transferred to colleagues in the SEAOCEAN group for their survey cruise in September aboard the Bering Explorer. Figures 16 and 17 show physical data and OPC output from one transect of the July cruise.

Presently, plans are underway for modifications of the system for FY95. We have been working on details with Chelsea Instruments Ltd. (UK) to reduce the tow speed requirement of the shuttle to accommodate the simultaneous deployment of a current profiler and fish-acoustic transducers on a single vessel. In addition, a high frequency transducer (1 Megahertz) for detecting macrozooplankton (eg. euphausiids) is being sought that would fit into the payload of the shuttle. This additional sensor will allow the shuttle system to measure organisms from microns (eg.algae) to centimeters in size.

## Acoustic Tomography

It takes approximately 2 hours for the Aquashuttle to traverse a 15 kilometer transect. In addition, although these data are more dense and more cost effective than a series of vertical CTD drops, they are limited to a maximum depth of 100 meters. The cost of vessel time for a time series of such 2 hour transects made at Hinchinbrook entrance at a frequency of one every other day for one month would be over $30,000. Even at this frequency it is quite likely that the onset and maximum of any upwelling intrusion into Hinchinibrook would be missed. A moored ADCP will catch current changes along a single vertical line of the water column but cannot assess the spatial structure of the intrusion across the entrance. Since such events are pivotal to the tracking and nowcasting of processes associated with the river-lake hypothesis, a small project has been set up to determine the means by which acoustic methods can be used to obtain the same type of synoptic temperature and salinity data as the Aquashuttle provides, yet do so without the high cost of ship time.

The objective is to have a near realtime measurement of the sound speed field along a vertical plane across Hinchinbrook entrance, and have that data transmitted using the SEA packet-radio repeater network. The frequency of measurement would be on the order of one or more per hour. At that frequency and spatial coverage, episodic changes in the water mass due to inflow and outflow can be easily detected. The methods of acoustic tomography have the potential of providing such measurements and for realizing dramatic cost efficiency over existing solutions.

During FY94 a preliminary examination was conducted. A relatively new approach called Matched Field Processing (MFP) seems to offer some advantages for this application. The principle of this method is to adjust the sound speed field to maximize the correlation between the Fourier transform of the predicted and observed signals received by an array. This approach avoids having to distinguish the arrival peaks of different propagation modes, which are likely to be tightly clustered over the distances of the study region. It allows use of a narrow band, in fact even a single frequency, which can be chosen to optimize between resolution and attenuation (20 Hz or about 75 m wavelength has been chosen in previous studies). It is not clear whether the MFP method will be practical for determining currents, as is possible with time-based methods, although other techniques such as Doppler reflections from bubbles can be performed using the same equipment for this determination. Because the MFP method relies on a single frequency rather than a time-dependent pulse, it has the advantage of being able to use low peak power signals, which will allow minimal disturbance to the marine life in the region. New transducer hardware may shortly be available that would also enhance the attractiveness of this method.

The FY94 feasibility study was a two week effort led by Dr. Carlos Berenstein, University of Maryland. As a result of the SEA support Dr. Berenstein secured an addition three months of NSF support for a graduate student (D. Lindsay) which he applied to the SEA program. He and Mr. Lindsay established a collaboration with Dr. A. Tolstoy of the Naval Research Laboratory and completed an assessment of her frequency domain method as a candidate approach to the SEA program. Dr. Tolstoy is developer of the MFP approach and author of the book Matched Field Processing for Underwater Acoustics, World Scientific Publishing Co., NJ.

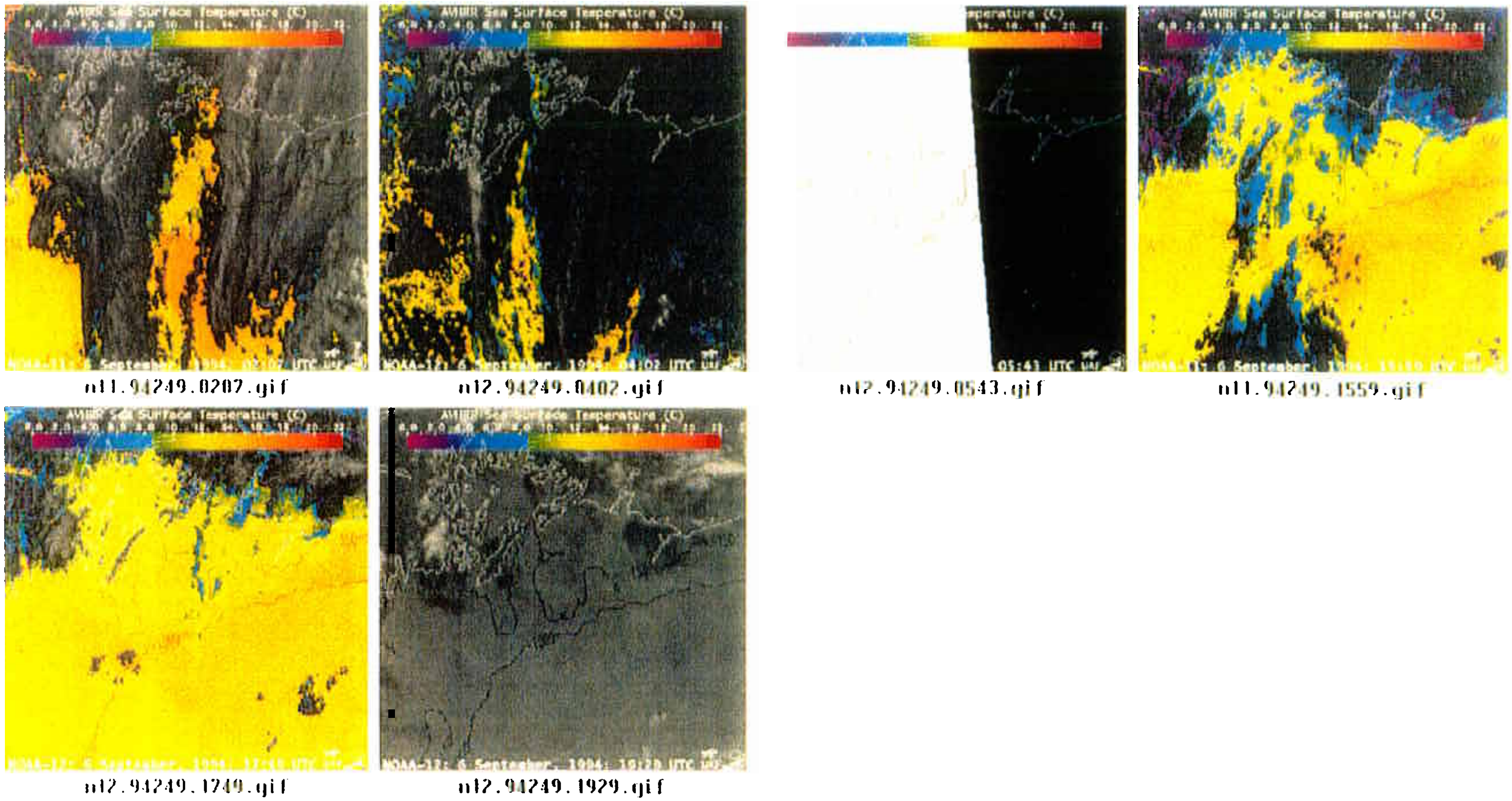



FIGURE 12: AVHRR satellite data (sea surface temperature) for September 8, 1994, displayed as panel of GIF images in the Mosaic browser

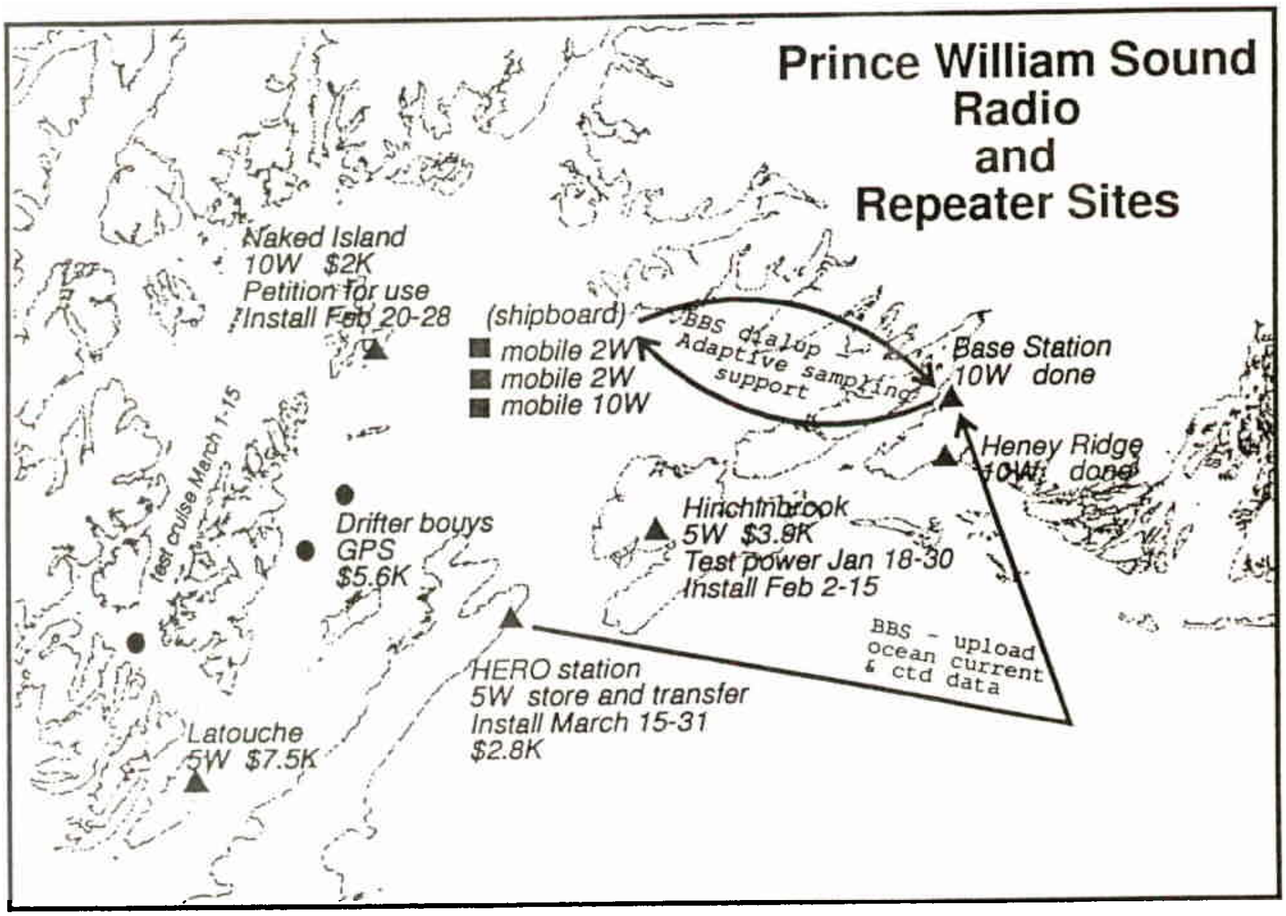
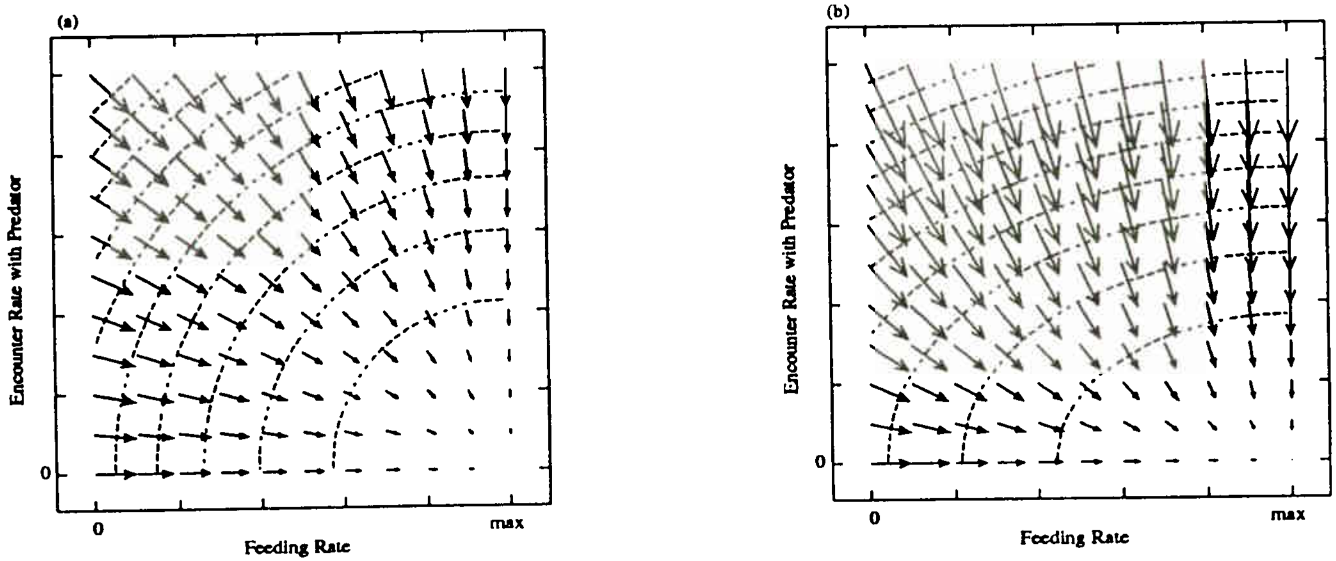



FIGURE 13: SEA Repeater Network. As of March 15, the base station, Heney Ridge and Naked Island sites are installed and operational. The Hinchinbrook Island site will possibly prove unecessary. The HERO station is due to come on-line before the April cruise.



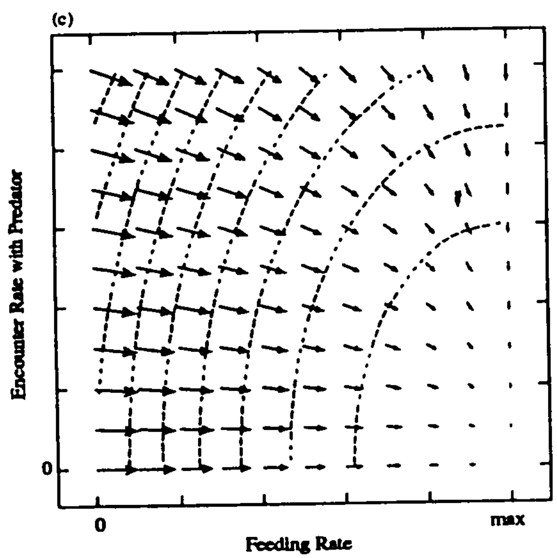




FIGURE 14: Contour graphs with vector field overlays generated by the taxis equation. The taxis equation was solved for 2 parameters: feeding rate and predation risk. Graphs show how a fish will move through parameter space to reduce predation risk and increase feeding rate. Contour lines define values of equal potential radiating outward with increasing value from the most favorable location. Vectors are perpendicular to the contour lines and are determined by taking the derivative of the taxis function with respect to feeding rate and with respect to predation risk. Vectors define direction and velocity of movement. Weighting can be applied to control the shape of the contours and direction and magnitude of the vector field. Thus, we can implicitly define the strategy for individual fish moving through space. An individual may (a) weight feeding and predation equally; (b) weight predation avoidance more highly than feeding rate; or (c) rate feeding rate preferentially over lower predation risk.

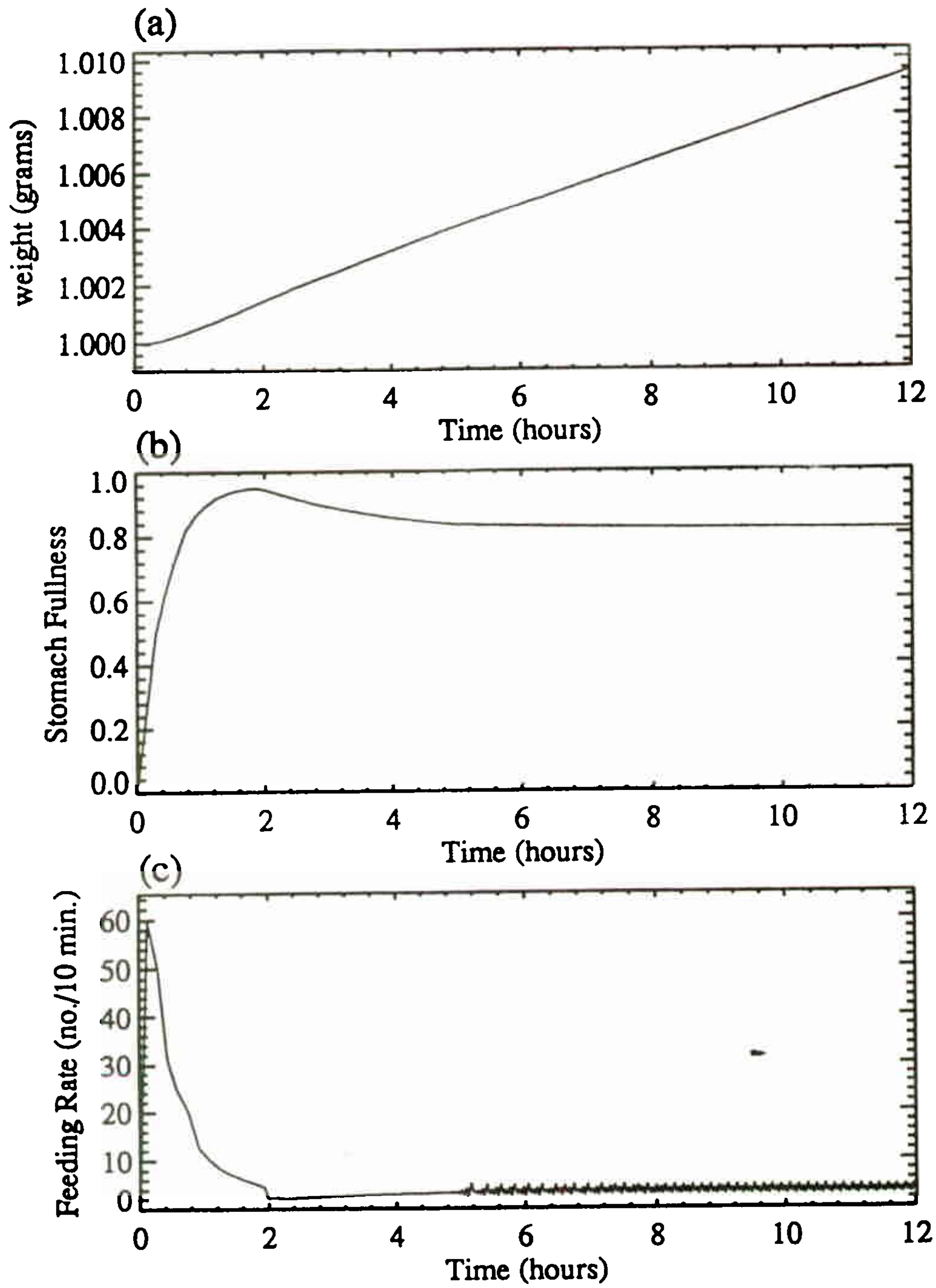



FIGURE 15: Size at age (a), stomach fullness (b) and feeding rate (c) of a 1 gram salmon at 10C as predicted by our preliminary feeding rate - growth model. Salmon stomach was assumed empty at time 0. The model prediction indpendently duplicates the laboratory observations of Godin (1981a) in juvenile pink salmon.

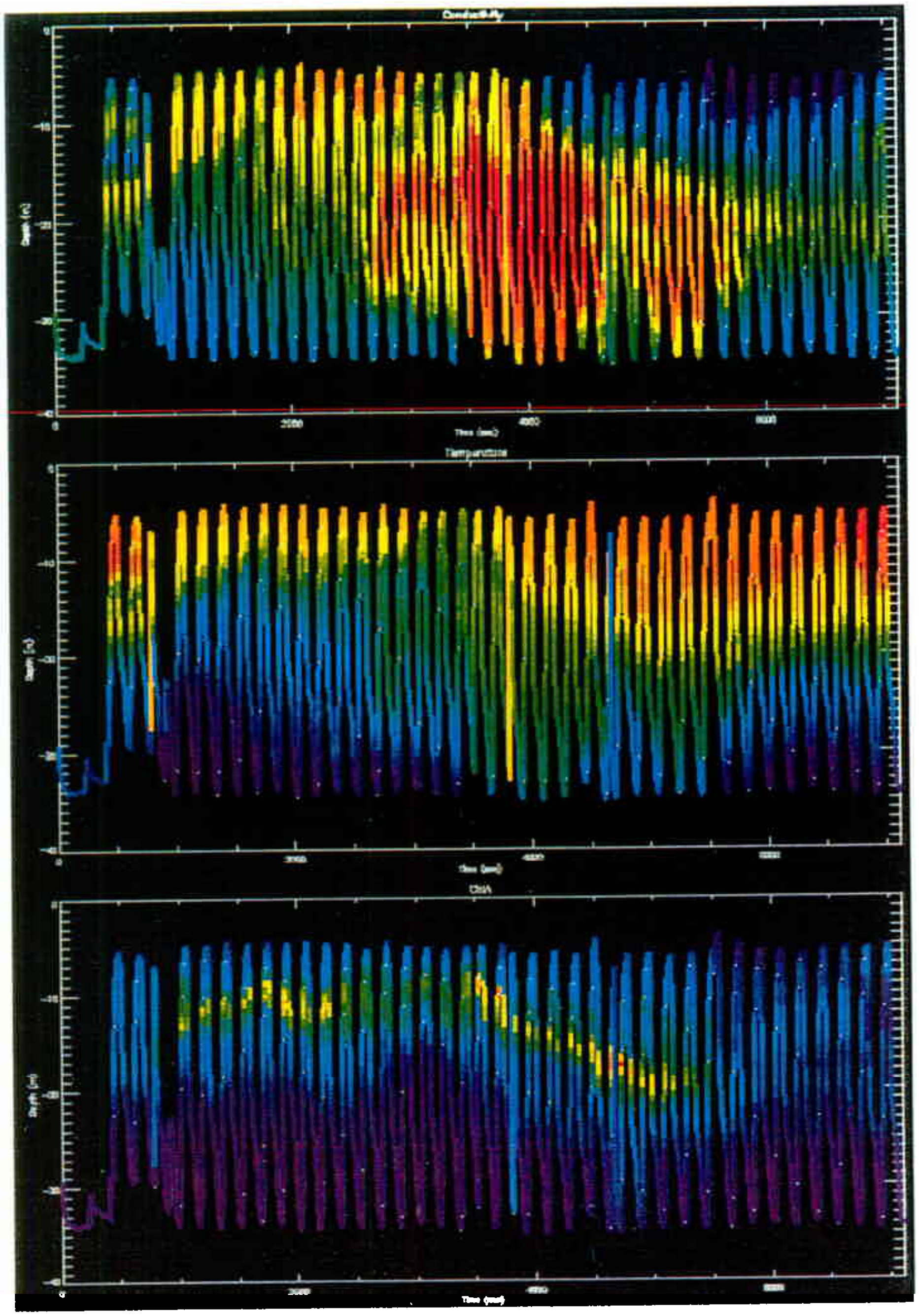



FIGURE [illegible] Aquashuttle CTD data from a NW (left side of figure) to SE (right side of figure) [illegible] between Nares Island and Hinchinbrook Island, September [illegible] 1994. [illegible] salinity. A region of high salinity (red) indicates strong subsurface flow [illegible] salinity surface water on top right indicates possible fresh water feed [illegible]. Middle panel: temperature. Thermal structure is evident with [illegible] at depth. The strong downward [illegible] of warmer water in [illegible] with the high salinity in the panel above. Lower panel: fluorometry [illegible] is evident at 8-20 m. Concentrated patches (red) of algea are visible [illegible]

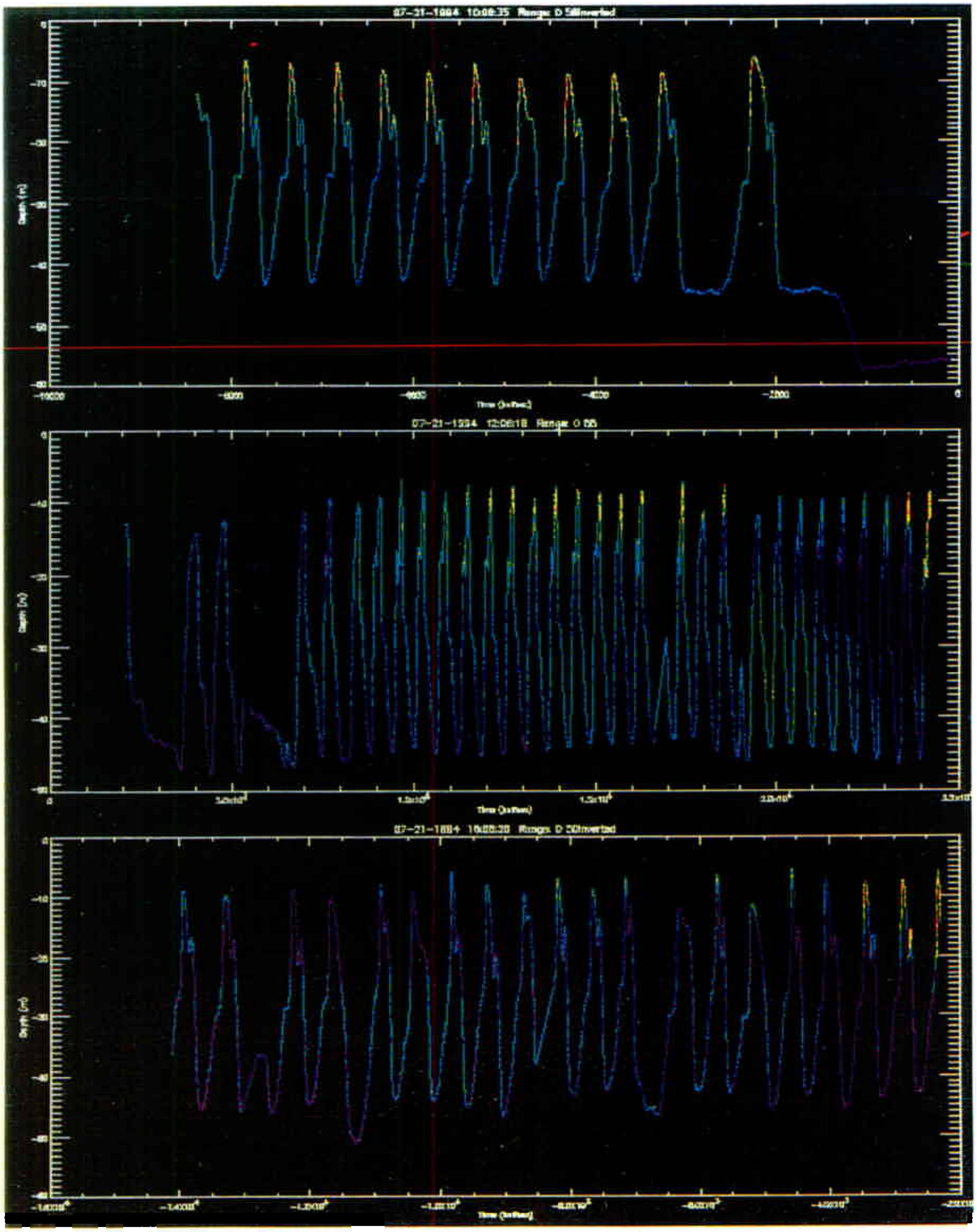



FIG. R[illegible] Aquashuttle OPC [illegible] from three transects across PWS in July 1994. [illegible] yellow [illegible] green [illegible] blue indicates high [illegible] liter [illegible] low [illegible] 4 liter counts [illegible] evident [illegible] with higher [illegible] counts found above 25m, which is approximately the depth of [illegible] Localized patchiness is also evident in the middle and lower panels.

**Physical Biological Modeling**

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The Physical Biological Modeling effort evaluated current methods in coupled phyical/biological model and developed and implimented a coupled biological–physical model of lower trophic level, i.e. phytoplankton and zooplankton, dynamics for the near-surface layers of Prince William Sound. This model is a one-dimensional, depth–time model, with a physically forced mixed layer. The biological components of the model are suitable for integration into larger three-dimensional models with appropriate vertical resolution. The physical parameters needed to force the model are wind speed and direction, air temperature and relative humidity, solar radiation, cloud cover, and precipitation. The effects of horizontal advection will not be included in this 1-D model. Vertical mixing will be modeled using the mixed layer model of Pollard *et al.* (1973). This bio-physical model is based on a model shown to be useful in simulation springtime phytoplankton dynamics in both the Bering Sea (Eslinger and Iverson, 1995) and the Mid-Atlantic Bight (Eslinger, 1990). The Prince William Sound model will be expanded biologically to include diatoms, flagellates and two zooplankton species, and temporally from a springtime model to an annual model.

*Brief Model Description*

The general equation governing a biological quantity, $X$, in the ocean is:

$$\frac{\partial X}{\partial t} = \nabla(K\nabla X) - \nabla(\vec{V}X) + biological\ dynamics, \qquad (1)$$

where the first term on the right side of the equality represents diffusion or, alternately, turbulence and the second term represents advection. In the present model advection and horizontal diffusion are assumed to be negligible. If $K$ is assumed to be constant, then the governing equation reduces to:

$$\frac{\partial X}{\partial t} = K\frac{\partial^2 X}{\partial z^2} + biological\ dynamics. \qquad (2)$$

The effects of vertical diffusion are assumed to be dominated in the spring by the effects of vertical mixing. In the present model, vertical mixing was not actually calculated from this equation, instead vertical mixing occurred according to a Froude number criterion (Thompson, 1976).

An equation describing the biological dynamics can be constructed for each biological component of the model. For the diatom component, for example, equation 2 becomes:

$$\frac{\partial P_1}{\partial t} = K\frac{\partial^2 P_1}{\partial z^2} + P_1(G - R_T - Rg - \Gamma_1 - \Gamma_2) + \frac{\partial(SP_1)}{\partial z}, \qquad (3)$$

where $P_1$ is diatom biomass, $K\partial^2 P_1/\partial z^2$ represents the effect of vertical mixing, determined from the PRT model, on $P_1$; $G$ is the light, temperature, and nutrient varying growth rate; $R_T$ is respiration rate; $Rg$ is heterotrophic remineralizaition rate; $\Gamma_1$ and $\Gamma_2$ are grazing losses to the two zooplankton components; and $S$ is a variable sinking rate.

Equations for the biological dynamics of the additional components are constructed similarly. A full description of the additional equations used in this preliminary model can be found in Eslinger (1990).

*FY–94 Results*

The initial FY–94 effort was directed at evaluating the potential of the Eslinger and Iverson type model to reproduce the spirng-bloom in Prince William Sound, and has been quite promising. The model was initially constructed for a simple diatom dominated community, with only low levels of zooplankton grazing. This is a suitable model for the spring bloom period in Prince William Sound. A comparison of model results with moored fluorometric chlorophyll concentrations from the CLAB buoy is shown in Figure 1. This initial model does an excellent job at simulating the timing and magnitude of the spring bloom. The biological dynamics for an annual run of the model remain to be included in the model. The physical portion of the model is presently being tested over annual time scales. Results are shown for two years in Figure 2. There is good agreement over most of the year in 1993, but poorer agreement in 1994. This is due to inadequate forcing data in 1994. We are presently exploring additional data sets to provide the needed data.

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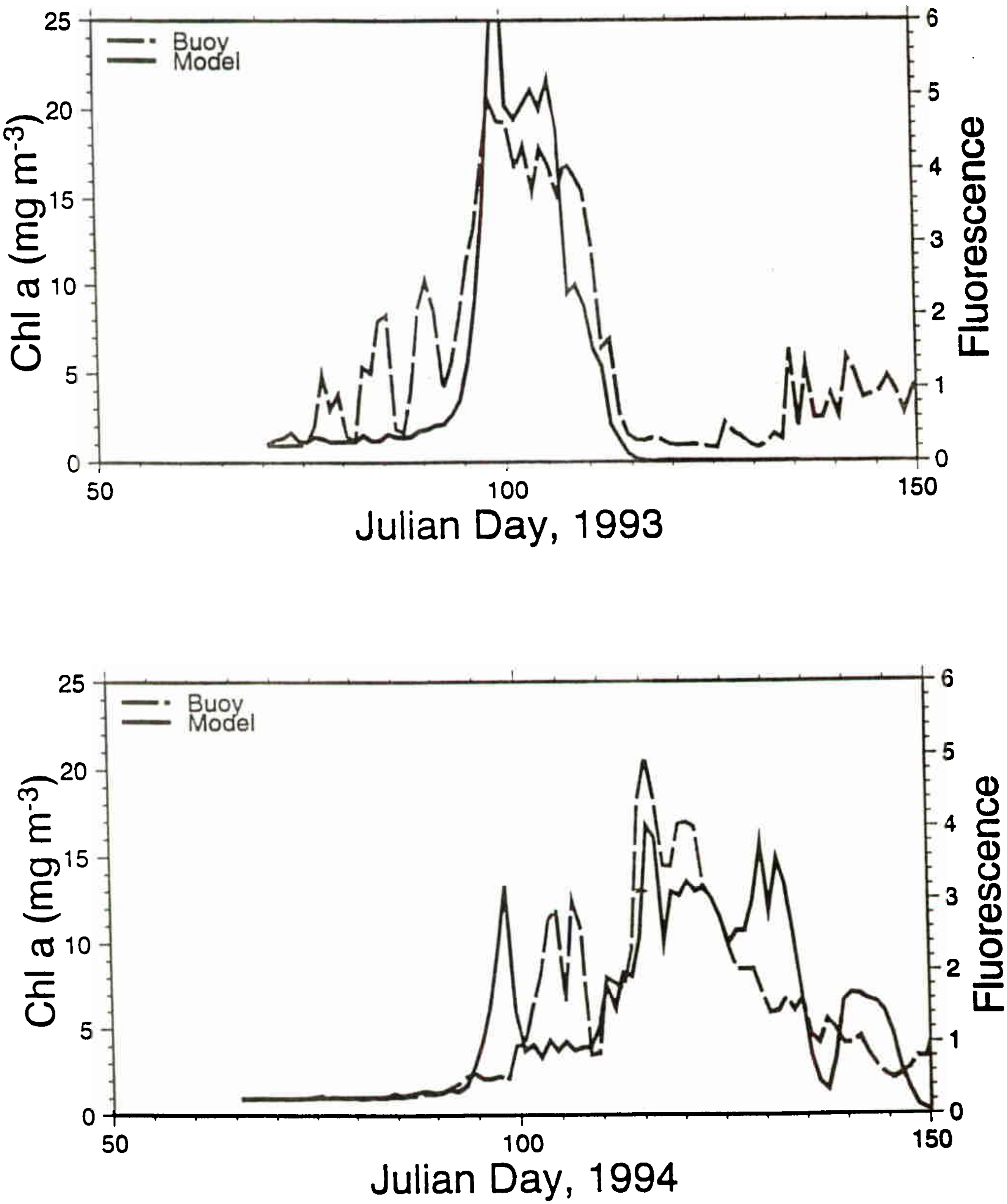


Figure 1. Bio-physical chlorophyll model results for the spring bloom compared with CLAB buoy fluorescence for 1993 and 1994.

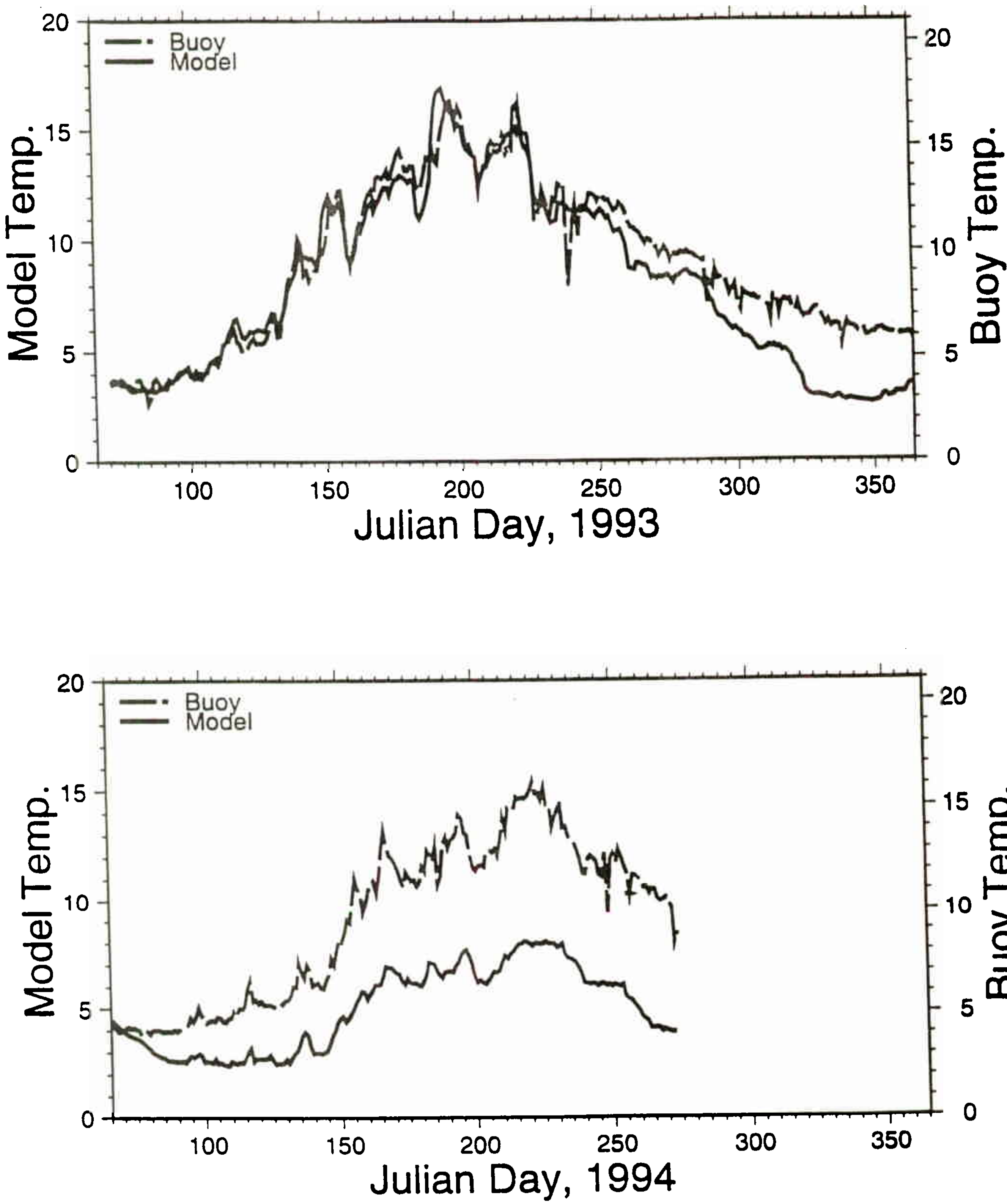


Figure 2. Bio-physical model temperature results compared with CLAB buoy temperatures for 1993 and 1994. Differences between years are do to lack of accurate forcing data in 1994.