Exxon Valdez Oil Spill
Restoration Project Annual Report

Information Systems and Model Development

Restoration Project 96320-J (SEADATA)
Annual Report

This annual report has been prepared for peer review as part of the *Exxon Valdez* Oil Spill Trustee Council restoration program for the purpose of assessing project progress. Peer review comments have not been addressed in this annual report.

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Study History: The Sound Ecosystem Assessment (SEA) Program is based upon the *Sound Ecosystem Assessment Initial Science Plan and Monitoring Program,* Rpt No. 1, Nov. 24, 1993. It began April 1994 (Restoration Project 94320) and has continued through FY96 (Projects 95- and 96320). The Information Systems and Model Development Project (SEADATA) is a Restoration Project (9x320-J) within the SEA Program. Prior progress is described in the SEA Annual Reports to EVOS for FY94 (Ch6) and FY95 (Ch7). During this reporting period the journal *Continental Shelf Research* accepted for publication the manuscript "On the Development of a Three-Dimensional Circulation Model for Prince William Sound, Alaska" by C. N. K. Mooers and Jia Wang.

Abstract: The four main development efforts of SEADATA are reviewed: SEA database, SEA Intranet, PWS circulation model, and the nekton models for pink salmon fry and juvenile herring. During FY96 each effort was at the middle of its planned five year development period and each faced critical milestones for feasibility and for realizability of proposed end-points. The milestones were achieved. The SEA database progressed from prototype to full implementation for a subset of the archive. This demonstrates the final functional configuration and confirms the feasibility of completion within projected time and cost schedules. The SEA Intranet faced rapidly emerging technologies wherein described function very often meant software development goals. Through in-house development and collaborative agreements for pre-release software, the SEA Intranet is delivering a full set of scientific collaboration resources. The circulation modelling effort began this period with the problems of limited data for PWS. It has, in collaboration with the observational oceanography project (S. Vaughan, 96320-M), developed the needed historical climatologies and is completing the phase of model development and validation that utilizes the climatological datasets. The nekton model effort had first to implement the combined diffusion-taxis and foraging-bioenergetics model, and second to demonstrate the efficacy of that model through simulations of seasonal fry mortality for quasi-realistic outmigration scenarios. Both tasks were accomplished. A further result for the year was the realization of the first low-cost, near-realtime monitoring system for SEA: the repeater-network and the Applegate Rock meteorology station are now providing near-realtime sea surface wind and weather data. This was a year of difficult technical and operational challenges. Although all concerns described in the FY95 Annual Report were resolved, they were accomplished over a somewhat "extended" year. The project has slipped on some of its anticipated schedules by up to three months. It is possible some or all of this slippage will be recovered during FY97.

Key Words: bioenergetics, circulation model, collaborative software, database, diffusion-taxis, dispersion, *Exxon Valdez,* Mellor-Blumberg, Pacific herring, packet-radio, physical-biological model, pink salmon, Prince William Sound, Princeton Model, SEA, Sound Ecosystem Assessment, visualization, World Wide Web

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EXECUTIVE SUMMARY

The four main development efforts of SEADATA are reviewed: SEA database, SEA Intranet, PWS circulation model, and the nekton models for pink salmon fry and juvenile herring. During FY96 each effort was at the middle of its planned five year development period and each faced critical milestones for feasibility and for realizability of proposed end-points. The milestones were achieved. The SEA database progressed from prototype to full implementation for a subset of the archive. This demonstrates the final functional configuration and confirms the feasibility of completion within projected time and cost schedules. The SEA Intranet faced rapidly emerging technologies wherein described function very often meant software development goals. Through in-house development and collaborative agreements for pre-release software, the SEA Intranet is delivering a full set of scientific collaboration resources. The circulation modelling effort began this period with the problems of limited data for PWS. It has, in collaboration with the observational oceanography project (S. Vaughan, 96320-M), developed the needed historical climatologies and is concluding model development and validation using seasonal climatological cycles. The nekton model effort had first to implement the combined diffusion-taxis and foraging-bioenergetics model, and second to demonstrate the efficacy of that model through simulations of seasonal fry mortality for quasi-realistic outmigration scenarios. Both tasks were accomplished. There was a further highlight. The report last year of completion for the PWS repeater-net was premature. The repeater-net and the Applegate Rock meteorology station now provide near-realtime sea surface wind and weather data. They are the first of the SEA long term, low cost monitoring implementations. This year was a period of difficult technical and operational challenges. Although concerns described in the previous report were resolved, it was achieved during an "extended" year. The project schedule has slipped approximately three months. It is possible some or all of this will be recovered during FY97.

INTRODUCTION

The Information Systems and Model Development Project (SEADATA) is one of the original projects in SEA. SEADATA was organized to deliver to the Program numerical models, a database, computing resources and networks, data visualization, computer- and network-based resources for remote collaborations and interactions, and selected sensor technologies that were judged to be sufficiently mature to have immediate impact on the cost-effectiveness of the final SEA products for long-term monitoring.

The project history and highlights are described in the FY96DPD. This and other information is available at the SEA Web site at URL

`http://www.pwssc.gen.ak.us/sea/sea.html`

This Annual Report for FY96 will follow the same format as the Annual Report (AR) for FY95. During the second quarter of FY96, due to a change of contracting agency, this project was required to prepare a Detailed Project Description (FY96 DPD) for the period of FY96 through FY98. This DPD has somewhat greater detail than the SEA Integrated DPD for FY96. Therefore this FY96 DPD will be used for assessments of the project with respect to schedules.

Throughout FY96 the tasks that were held to be the most critical were those that had been spelled out explicitly in the FY95 AR. Indeed, these issues were explicitly identified in the abstract of that report:

> **Abstract:** The four main development areas of SEADATA are reviewed: database, Internet and Web based collaboration tools, circulation model, and the fish model. Each of these has reached important milestones, but each is at midstage and facing ahead tasks that will be equally critical. For the database, the technically demanding tasks of the initial architecture have been resolved. The task ahead is to make everything fit within the available resources. The Web tools that were implemented were a significant accelerator for SEA. But more is required and the technology has now expanded unbelievably. The next steps will be all new terrain. The circulation model has been successfully implemented in a remarkably short time. The task ahead of validation and refinement will become increasingly difficult as the limitations of the available data for Prince William Sound become clearer. The fish model now has an efficient scripting code, a new algorithm, and the major parts of its foraging-bioenergetics model. It now must put these together to get the desired mortality estimates. The one message that came consistently from all quarters in this report is the need for more and better communication and coordination.

Each of the issues were pivotal. That is, each would either be successfully accomplished or that component of the project failed. Hence these were very much the focus for the year. They were all successfully addressed during this reporting period. These successes are the primary topics of this report.

The aforementioned FY96 DPD had been prepared during the month preceding the analysis and review carried out for the Annual Report. Consequently the project schedule of the FY96 DPD is more optimistic. Although each of the critical tasks was completed, some progressed more slowly than had been scheduled. This report will review what slipped and the extent of any delays. With the planned adjustments and refinements the slip of the schedule looks to be at most three months.

From the perspective of the project and its ability to achieve the project objectives, the slippage is of significantly less consequence than the successful resolution of all four of the issues in the FY95 abstract. The resolution of these four are the highlights for the year. In addition there were two further results of substantial consequence. The first is the commencement of daily transfer of data from the SEA Applegate Rock meteorological station using the SEA packet radio repeater-modem network. The time interval between of transmissions is solely a function of battery capacity at the remote site. The second is a much improved specification for the SEA modelling endpoints, and substantial progress in establishing a working dialogue with ADF&G for the identification of issues and problems for which one or more of the various development efforts of SEA, in whole and in part, has relevance.

OBJECTIVES

The purpose of SEADATA is to deliver to SEA

1. numerical models for circulation and for juvenile fish, specifically for pink salmon and Pacific herring;
2. database, computing and network resources, and Intranet functions;
3. *cost efficient measurement technologies* that address SEA's requirements for low-cost, long-term monitoring and model maintenance.
4. (newly requested.) development and implementation of methods whereby the *(reportedly) long* time interval between research result and the applications of that result in resource management is substantially reduced.

METHODS

Multidisciplinary research

The review for FY96, as in FY95, had some unexpected findings. One of these has to do with the multidisciplinary collaborations in SEA. Although finding the methods to make the collaboration more effective is a significant part of this project, a totally separate aspect emerges this year. That aspect is the unique choices, selections, and optimizations that are used by differing disciplines as the project nears completion and discrepancies between objectives, options, and resources come into focus.

Two areas in this report are good examples. A review of the database work during FY95 and during this year will show a continuing refining and evolution of the design as experience is gained with the diversity of data types, the model applications, and the quantity of data to be addressed through both the exploratory and then the monitoring stages of the work. This flexibility to move around within an extended range of database and computer science is due to the multidisciplinary structure. Such flexibility would not be possible for one attempting this task who did not have database design and development experience. There have been significant adjustments as well as a few major changes. These are all documented in the annual reports. Despite these, the database is progressing well and approaching roughly its half-way mark.

Such adjustments and corrections are increasing as the end is clearer and nearer. One such choice that is made in the nekton modelling effort is to suspend efforts on the 2D and 3D versions of the model, at least until late in this year. It was not possible to support the necessary programmer, Mr. S. Rao, after the fall of 1996. A very attractive business offer became available to him in the fall. It was the proper decision for him to take it. The model scope will meet the requirements, simply not as comprehensively. The search for ways to revive the effort will continue, for the effort is only suspended. But such effort in FY96 did not succeed.

The design of the monitoring effort to maintain the models will require the multidisciplinary insights that SEA has assembled. It was unexpected to see how the insights of the different disciplines are used to make the difficult feasible. One reason that such things are more apparent is the increased exchange between projects and investigators, a process that has been significantly enhanced with the advances of the SEA Intranet.

SEA Intranet: the development path

There are two simultaneous issues behind the concern expressed in the abstract of the FY95 AR: 1) what methods will produce quantum changes in the SEA collaborative exchanges, and 2) what software can be used to most effectively implement those methods for WWW.

There was the clear need for methods whereby the collaborative exchanges would be significantly increased and facilitated. Despite the clear need, the methods that would in fact result in an increased exchange or prove to enhance efficiency are not well understood at all. This is one of the issues of the manuscript of J. R. Allen, et al, in Appendix 2. The manuscript is being prepared for submission to the *International Journal of Human Computer Interactions, Special Issue on Innovative Applications of the World Wide Web.*

Along with the ambiguity over collaborative method is the ambiguity over software resources due to the rapidly evolving technology and industry. The task was to assess as much as possible of this highly dynamic technology, expecting that nearly everything was likely to be incomplete and inadequately specified. This was to be evaluated in the context of a problem that too was poorly specified. Throughout all of this there is the pressure of time due to the present need for solutions that will make a difference in the outcome of SEA.

The SEA Intranet is described in Appendix 2. The manuscript describes the technology that was selected for implementation now, technology that is emerging, and the technology that is expected to require considerable time to realize its potential.

Project Plan for the SEA numerical models

The overall plan for the SEA model is shown graphically in Figure 1. The detailed discussion of the chart is in the Methods section of the FY95 Annual Report, and will not be restated here.

RESULTS

The SEA Database

Status

A status report on the development of the database is provided in Appendix 1.

The progress of the database, both in content and in concept, is shown in part by the comparison of Figures 2 and 3.

SEA Intranet

Status

A status report, description, and technology background are presented in the manuscript in Appendix 2.

The Ocean Circulation Model for Prince William Sound

Publications

During FY96 Dr. Christopher N. K. Mooers and Dr. Jia Wang, along with Mr. San Jin, have completed the second year of development of the three-dimensional, primitive equation circulation model for Prince William Sound. (This effort began in FY95.) A manuscript describing the progress of this work at the early part of this reporting period was submitted by Drs. Mooers and Wang to *Continental Shelf Research* in December 1996. The manuscript, titled "On the Development of a Three-Dimensional Circulation Model for Prince William Sound, Alaska," has been accepted for publication. Elsevier Science, Ltd., the publisher of *Continental Shelf Research*, has kindly granted permission to include the manuscript in the FY96 Annual Report. The manuscript appears in Appendix 3 of this report. The letter of permission also appears in Appendix 3. The letter grants permission to reproduce as part of this report; the letter excludes distribution in electronic form.

Status

The following summarizes progress relative to the project plan of Figure 1 and the FY96 DPD. The plan of the FY96 DPD is included below in italics; status and remarks follow each item.

Certain background issues will reappear in the status remarks; these are briefly referenced here. Additional discussion of these appear elsewhere in this report. Through the beginning of FY96 three factors slowed this work:

1a) final confirmation of funding delayed through April due to transition to new contracting agency;

2a) execution of project plan partially constrained until resolution of project funding plans at March SEA meeting;

3a) although data acquisition continued without interruption, some delay in analysis with changes in the scientific staff in the Oceanography project.

Regardless, during this period Mooers and Wang completed the construction of the climatologies needed to continue. By late summer of 1996 the foregoing issues were resolved:

1b) new procedures instituted by EVOS eliminated between-year problems and funding uncertainties at the end of 1996 and beginning of 1997; momentum was maintained;

2b) funding schedule revisions provided means to proceed with project plan; however, confirmation of the revisions would not be available until August;

3b) Dr. S. Vaughan established an extremely well run observational project; throughout the second half of this period and the beginning of 1997 data gaps that were of concern in the FY95 AR were fully resolved; as noted below all open issues are resolved and an excellent coordination was established between the circulation modelling and the observation effort.

During CY96 the first two task below are of equal priority and will be addressed in parallel.

1 <u>Model refinement:</u> The first task is the completion of the 1996 version of the model. [Fig 1: "model config 96"] The model features to be added during CY96 are

1 <u>tides:</u> in addition to M_2 tidal forcing, include K_1, O_1, and S_2 tidal forcing; incorporate realistic amplitude and phase values from tidal data analyses and/or larger scale tidal models.

Tidal forcing extended to six dominant modes. Second half of the task underway. Progress at the end of the period is such (see 3b above) that open items will be resolved in 1997.

2 <u>winds:</u> apply idealized atmospheric storms to develop scenarios for the response of PWS to storm passages in order to estimate the nature and (space-time) pattern of the PWS circulation response.

Completed. [See "simulations of lake & river", Fig. 1] See manuscript in Appendix 3. The results of a simulation study are described in section 4.3 (pages 12-14, Figures 8 and 9a, b, c, and d).

3 <u>resolution:</u> add more sigma levels to resolve better the surface and bottom boundary layers.

Completed: increased from 11 to 15 sigma levels, with increased resolution in upper mixed layer.

4 *inflow: improve the specification of temperature and salinity fields on the inflow based on SEADATA observations.*

Completed. Throughout the latter half of the period the data available for boundary conditions has been continually expanding. [See "simulaltions" and "scenarios" in Fig. 1]

5 *fresh water runoff: by the end of CY96 establish the data resources and models to incorporate realistic values for freshwater runoff for the PWS watershed.*

Completed. During the early part of FY96 Mr. Harper Simmons worked with the SEA Oceanography project. His work was a freshwater runoff model, the subject of his Mater's research under Dr. R. F. Carlson, Dept. of Civil Engineering, UAF. Mr. Harper Simmons has made available to SEA the final form of his hydrology model and continues to provide support for its application to the circulation model. ("Estimation of freshwater runoff into Prince William Sound using a digital elevation model") In the 96DPD and 95 AR is was not resolved how this component would be addressed within existing schedule constraints. This issue has tentatively now been resolved.

2 *Model validation: The second task is the validation of the 1996 version of the model using the data resources assembled by SEA. [Fig 1: "review ocean data"] along with new oceanographic measurements. [Fig 1: "drifter studies" and "tide gauge stations"]*

Climatologies completed. Tests and validation with climatologies underway. As noted above the processing of datasets for instrumentation newly deployed for FY96 has made great strides and the latter components of this task are in progress.

3 *Space-time analyses of surface winds: This third task is an effort that will be conducted in collaboration with SEAOCEAN, the database effort in SEADATA, the and Trophodynamics Project. During CY96 a priority task for these four projects is the completion of the oceanic and atmospheric database.*

The databases for surface meteorological information are largely completed. This is described in some detail in Appendix 1, Appendix 2 and Appendix 4 of this report. The analysis is underway during early 1997. This data archive, both historical and near-realtim, is accessible through the SEA web site. The question of additional meteorological stations [see "addit'nl met stations" in Fig. 1] has largely been resolved with the successful completion of the Applegate station and near-realtime data system described in Appendix 4.

4a *Model coupling and ecosystem processes: This task draws upon tasks #1, #2 and #3 to establish a collection of meteorological and oceanological scenarios and corresponding* *seasonal and annual circulation histories for PWS. The purpose is to identify physical features associated with "river" and "lake" annual variations of PWS circulation. The principle result for CY96 is a collection or catalog of model output simulations and an initial set of quantitative descriptors whereby the physical and the biological classifications of "river year" and "lake year" are made more complete and precise.*

4b The second part of this task is to collaborate with the Trophodynamics Project and develop the coupled plankton-ocean model within which the catalog of circulation scenarios and simulations is used to produce a corresponding catalog of seasonal macrozooplankton production and distribution.

This component of the FY96 plan is not fully addressed during this period. [See "collection of lake & river one yr scenarios & simulations" in Fig. 1] A partial set of simulations is described in the manuscript in Appendix 3 (Section 4, Simulation Results). This component is slipped to 1997. In part this is a result of the constraints described at the outset. However, it is also due to a rescheduling whereby the collection of scenarios and substantial simulations with circulation forcing will follow a more complete set of validation studies. Hence, more of the validation work, especially with the climatological datasets, has been conducted during this period than is indicated in Figure 1. Conversely, less of the scenario construction work has scheduled for this period.

On the other hand, certain topics scheduled for 1997 in Figure 1 were addressed during the past period. Most notable is the herring larval drift work. Preliminary trials were run during this period and the results are described in Appendix 3 (section 4.4, page 14).

The Nekton Model for pink salmon and Pacific herring

This report on the nekton modelling effort will be in several parts:

1) ***Status*** of the project relative to the project plan of Figure 1 and the FY96 DPD;
2) ***Chronology*** for the reporting period;
3) a ***Summary*** of the results from the simulations for estimates of fry mortality during spring outmigration.

Status

The format of the foregoing section is followed here: the plan of the FY96 DPD is included below in italics; status and remarks follow each item. Figure references are to the project PERT chart in Figure 1.

One of the background issues discussed above applies here as well: items 2a and 2b were factors for the first and second halves of the reporting period, respectively.

1 *<u>Remaining foraging/Bioenergetics models:</u> During CY96 remaining foraging/bioenergetics models will be completed. These include models for age 1 and age 2 walleye pollock and age0+ through age 2 Pacific herring.*

Partially completed. Most of the components for the models were assembled during the period but they were not fully implemented in the format of the SEA foraging-bioenergetics model. For the simulations of fry mortality it sufficed for initial runs to work with the adult pollock model and the pink salmon fry models. These two had been fully implemented during FY95 and are described in the FY95 AR. During FY96 priority was given to combining the foraging-bioenergetics model with the dispersion model and to obtaining the first simulation-based estimates for fry mortality. There was further work on the juvenile herring bioenergetics model during the last part of the period to as part of the herring overwintering work.

During the early part of FY97 further work is scheduled for a second level of refinement and validation of the foraging-bioenergetics models in conjunction with the next series of fry mortality test simulations.

2 *<u>The combined dispersion-foraging/bioenergetics model:</u> The most important task for CY96 is the development of the complete nekton model incorporating both the Version 4 dispersion model and the foraging/bioenergetics models. This combination of the two models is an non-trivial task and it is fully expected that several versions of the combined model will be developed during CY96 through CY98. For CY96 the most simple form of the combined model will be implemented.*

Completed. During this period version 1.0, 1.1, and 1.2 of the Combined model were developed. See chronology for FY96 below.

3 *<u>Simulations of fry mortality using hypothetical scenarios:</u> During CY96 initial estimates of fry mortality during outmigration will be computed from combined model simulations for a variety of hypothetical scenarios for spatially and temporally varying physical conditions, macrozooplankton distribution, predator distributions and population structures, fry distribution, and outmigration timing and duration.*

Completed. During the last part of the period simulations for fry mortality were run. The results were presented at the EVOS January 1997 reviews. See the simulation "walk-through" below.

4 *<u>Preview version of the long term monitoring-modelling facility:</u> At the end of CY96 a preliminary version of the final SEA long-term monitoring and modelling plan will be prepared using currently available knowledge from both the field measurements and the model simulations. This preview version will provide an first estimate of the how the monitoring-modelling facility scheduled for delivery in CY98 will function. A block diagram for the facility is shown in the 1998 panel of Figure 1.*

Initial monitoring plans were formulated. A subset of these was presented to EVOS in the proposal for FY98 submitted by G. L. Thomas and E. V. Patrick (representing the SEA collaboration) for a pilot monitoring effort.

5 *Version 5: The next version (Version 5) will replace the one spatial dimension of Version 4 with 2-dimensional and then a 3-dimensional code. Version 5 will be developed during the end of CY96 and the beginning of CY97.*

Significant first steps toward the 2D and 3D versions of the model were initiated. See chronology below.

Chronology

The status of the effort at the beginning of this reporting period is described in FY95 AR: a mixed method finite element solution (*Aw version 4*) for the diffusion-taxis model had been implemented, and a foraging-bioenergetics model for pink salmon fry and adult pollock (*gut version 2*) had been completed. Simulations from each had been run.

The foraging-bioenergetics model *gut v2* had successfully captured both the foraging (sub-hour time scale) **and** growth (time scale of days) processes of fry as described by Godin (1981, 1981a, 1984). It had also successfully reproduced feeding sessions (or episodic or "glut" feeding) that has been suggested as a candidate feeding pattern for adult pollock. The diffusion-taxis model requires feeding patterns and responses as factors to drive distribution changes. Hence, the combining of these two is an essential step, and certainly required for estimates of fry survival.

A second priority in the model development is the migration of the model from the present one-dimensional form to two- and three-dimensional models.

Winter and spring, 1996. During this period R. H. Nochetto and S. Rao conducted an in depth review of available options for the migration of the nekton model code to 2- and 3-dimensions. In this effort they evaluated numerous mesh generation codes and combined finite element solvers (typically for elliptical pdes) and mesh generators. In selected cases codes were installed and tests were conducted with the nekton model. In particular, work was begun on the task of coding the equations in multiple dimensions.

A progress report for their work for this period is contained in Appendix 4. A summary list of the items accomplished for the 2D effort up to July 1996 was prepared by S. Rao.

1. Model Formulation
    a. Hybrid solver implemented
        o This method is now being implemented
          due to its desirable properties for our

case.

b. Mixed solver used for comparison

2. Exponential fitting issues.
    - o Redo exponential fitting with 2d elements in mind.
    - o Implement an exponential scaling using a two dimensional approach.
3. Adaption and refinement schemes.
    - o Recursive approaches studied.
    - o Recursion allows for a transportable approach to mesh solving and can hence be applied to multiple domains and problems.
4. Iterative Solving.
    - o Studied the GMRES solver (Generalized Minimal RESidual).
    - o Offers a good solution to a non-symmetric problem such as ours.
5. Review of FEM packages.
    - a. KASKADE
        - o C++ based and somewhat slow.
    - b. MGGHAT
        - o FORTRAN based and fast, but offers little flexibility as far as migration to 3D.
    - c. Baensch
        - o FORTRAN based but offers great deal of flexibility.
        - o Collaborations with the author of the code and methods used there-in offer an advantage in development with regards to our problem.
6. Review of numerical packages.
    - a. LASPACK
        - o C based but somewhat slow.
    - b. LAPACK
        - o FORTRAN based and could suit our needs.
    - d. Doerfler
        - o FORTRAN based and offers an advantage in that it is used by Baensch.
7. Coding of 2D solvers.
    - a. Implementation of Baensch code with our formulation.
        - o Linking FORTRAN with C routines to allow for eventual migration to an Alewife scheme.
        - o Testing new 2D solver with our formulation.

Summer 1996, Part 1. Much of the above effort was in anticipation of the visit during July of Dr. Eberhard Baensch of the University of Freiburg, Germany. He had developed mesh generation code that was formulated for both 2D and 3D. As noted in the above list, although there were a variety of options for mesh generators, the better ones typically were written only for 2D, and there was no clean way to extend to 3D. However, the work of Baensch already had been developed for 3D. It would enable us to do initial development in 2D and have at hand the tools to extend to 3D.

It was and interesting and productive two week session. Dr. Baensch is interested in two aspects of this work: a) the ecological application, and b) the exponential fitting methods employed by Nochetto for this class of pde models. He will return for a second visit in October 1997. The visit was moved back until the coming fall for reasons to be discussed below.

Prior to the visit, the 2D studies led to the realization that the hybrid form of the finite element solution was significantly simpler than the mixed method form. Consequently, the code for *Aw v4* was rewritten with the simpler model. This simplification has been of considerable significance in the last half of the period.

During the visit the model code in hybrid form and with 2D formulation was merged with the code that Baensch brought for the visit. Some initial tests were made conducted.

To illustrate his algorithms and to begin to set up a test simulation for the 2D nekton model, Baensch generated the mesh in Figure 4 for a generic vertical "water column" 2D domain typical of Prince William Sound.

Summer 1996, Part 2. In addition to the work on 2D and 3D codes, the visit of Baensch led to useful test questions regarding the stability of the nekton model for various extremes of population densities and various taxis-diffusivity ratios. A first analysis was carried out during the second half of the summer of 1996.

The major work of this period was the implementation of the combined code. The diffusion taxis code had been developed in C. The code for the foraging-bioenergetics had be written in IDL. One of the two had to be selected for the first combined code. The C language had been used for portability, and this was certainly advantageous when merging codes with prior work of Baensch. On the other hand, prototyping could be done more quickly in IDL. It was further preferred to have the prototype code generate graphical output during the simulation rather than having to wait for the completion of the run. This enabled both debugging and model analysis to proceed more quickly. Finally, the simplicity of the new hybrid code made the transfer of the diffusion-taxis solver to IDL significantly simpler than converting the foraging-bioenergetics code to C.

The results from the first combined code were presented at the SEA Seward meeting in September, 1996.

Fall, 1996. During the fall of 1996 further analysis was completed for model stability. Following a review of model functioning by M. Willette in October, the combined model was further developed by

1) a comprehensive set of graphical representations of the various states of the model during a simulation were implemented;
2) a submodel for fry schooling was added;
3) a submodel for two distinct feeding modes by adult pollock was added:
    a. particulate feeding, and
    b. suspension or filter feeding.

and during any feeding period the fish chooses whichever method provides the greater consumption in terms of mass per unit time.

The implementation of these additional modules constitute version 1.2 of the Combined model. This version was used for the fry mortality simulations described below.

Summary

The following is a brief and partial description of the manner in which the nekton model captures the simultaneous processes described by the various SEA hypotheses in the determination of fry mortality. It was found to be very helpful to use time animation in such a description, and that was done for the EVOS January review. An animation server is planned for the nekton model during 1997. This report will only overview selected functions. The full function can only be described by the model equations, and technical manuscripts are in preparation. The next best resource will be an on-line animation server.

There is considerable additional detail regarding model features in the FY95 Annual Report. This is a 1-dimension implementation, and for fry-adult pollock interactions the model is used to capture in-shore to off-shore population distribution changes in time, due both the predation and to movement. A typical domain of one spatial dimension would be the cross-passage domain shown in Figure 5. Along this "line" observations have determined the relative distribution of the various zooplankton species from off-shore to nearshore.

Simulations were conducted using simplified forcing and with no coupling between the zooplankton and nekton populations. That is, zooplankton densities were assumed to be given, and for these tests they were assumed constant throughout the simulation. Similarly, physical variables such as temperature were assumed constant. The processes that the nekton model captures for these simulations are the feeding of the fry and the adult pollock and changes in spatial distribution in response to feeding, predation, and any other factors affecting distribution. Here only feeding and predation are included in the taxis responses. Throughout these tests the total pollock population "in the domain" is assumed constant, though free to redistribute along the domain. That is, total predator abundance is not changed. Similarly, except for one case, the initial fry distribution is the same for all simulations. Zero mortality for adult pollock is assumed.

With these assumptions and configuration the following mortalities were obtained for four simulations.

zooplankton density (max density #/m^3	timing of feeding	fry survival
pseudocal: 150 neocal C4: 200	day and dawn	10da: 88% 25da: 60% 65da: 40%
pseudocal: 100 neocal C4: 100	0-10da: day & dawn 10-30da: day & dawn	10da: 97% 25da: 60% 65da: 40%
pseudocal: 150 neocal C4: 450 neocal C5: 350	mixed	10da: 99.5% 25da: 97% 65da: 95%
pseudocal: 250	n/a	10da: 50% 25da: 2%

The larger values for zooplankton density persist only for one to two weeks at most, so the assumption of constant density is solely to examine the interaction of the model components.

The last entry is a baseline case. There are now alternative prey for the adult pollock; the fry are the only prey item. The fry have the one prey zooplankton pseudocalanus. For the calibration used in version 1.2 of the model for the parameters regulating the mobility and feeding rates of pollock, the pollock consume available fry within a month.

The first two cases show were selected in anticipation that the second, with fewer zooplankton, would surely have higher fry mortality (lower survival). Instead it resulted in the opposite. This is due to the interaction between assumptions regarding the feeding mode for pollock and the schooling behavior of fry. Because of the substantial impact of this interaction it will a first issue addressed in 1997.

The third scenario is represents the upper end of zooplankton density. Here their role as alternative prey and the switching of pollock between particle and suspension feeding is a factor.

A complete presentation of the model behavior will be documented during 1997; it will be necessary to first implement suitable formats for presention.

Monitoring and Model maintenaance

Achieving near-realtime data from remote stations has been a goal of this project since the beginning. The first continuously running installation realizing that objective came alive during this reporting period. It was through the tenacity of Mr. Steve Bodnar, the patient and persistent engineering of Mr. Roy Murray, and the assisted software leap to the world wide web provided by J. R. Allen that this long sought objective is now daily delivering information about the western sound. The story and how to access it via the web is told in Appendix 5.

DISCUSSION

Design and development selections

From this review a different theme emerges. For the FY95 Annual Report there were concerns regrading the resolution of pivotal technical issues. Those critical issues were resolved in FY96. In assessing the outcome for the year that is definitely good news.

With that progress the outcome for the effort is becoming clearer. With that it is also clearer where choices must now be made. There are aspects of the original plan that at this time do not have solutions regarding resources for full implementation. Considerable effort during the past year went into finding cost-sharing projects that would help sustain, for example, programming help to continue the 2D/3D implementation. That did not develop and that aspect of the work is on hold. The scope of the models will be adequate for the task at hand. It is a function range that has been adjusted to match the resources.

Prudent design and development decisions are seen in all aspects of the project. They indicate proper attention to the final objectives on the part of all of the investigators in SEADATA.

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FIGURES

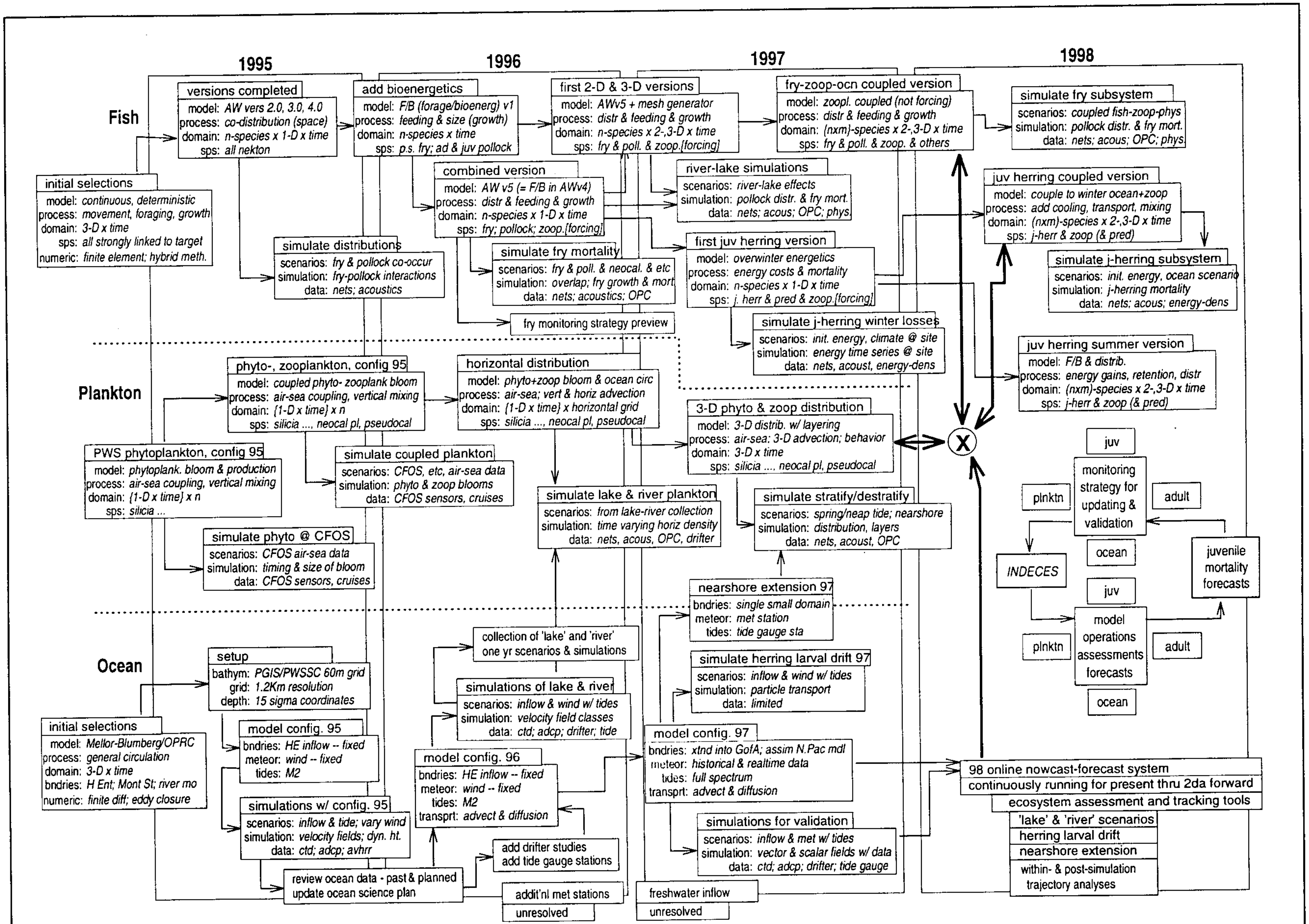

Figure 1. The SEA models: status, development plan, dependencies, and endpoints.

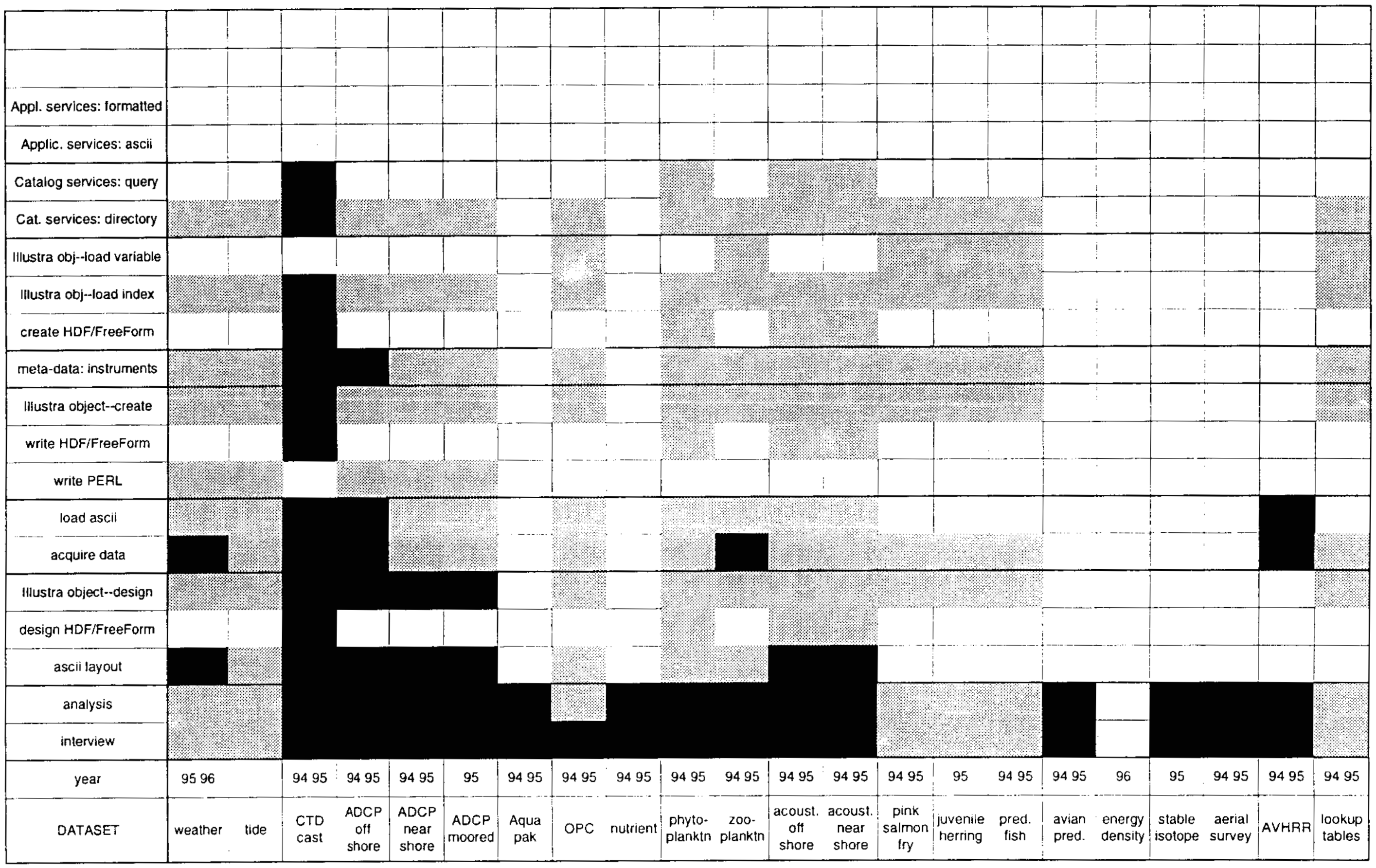

Figure 2. The SEA Datasets and the SEA Database; status for Oct. 95 (black), expected status for Oct. 96 (gray).

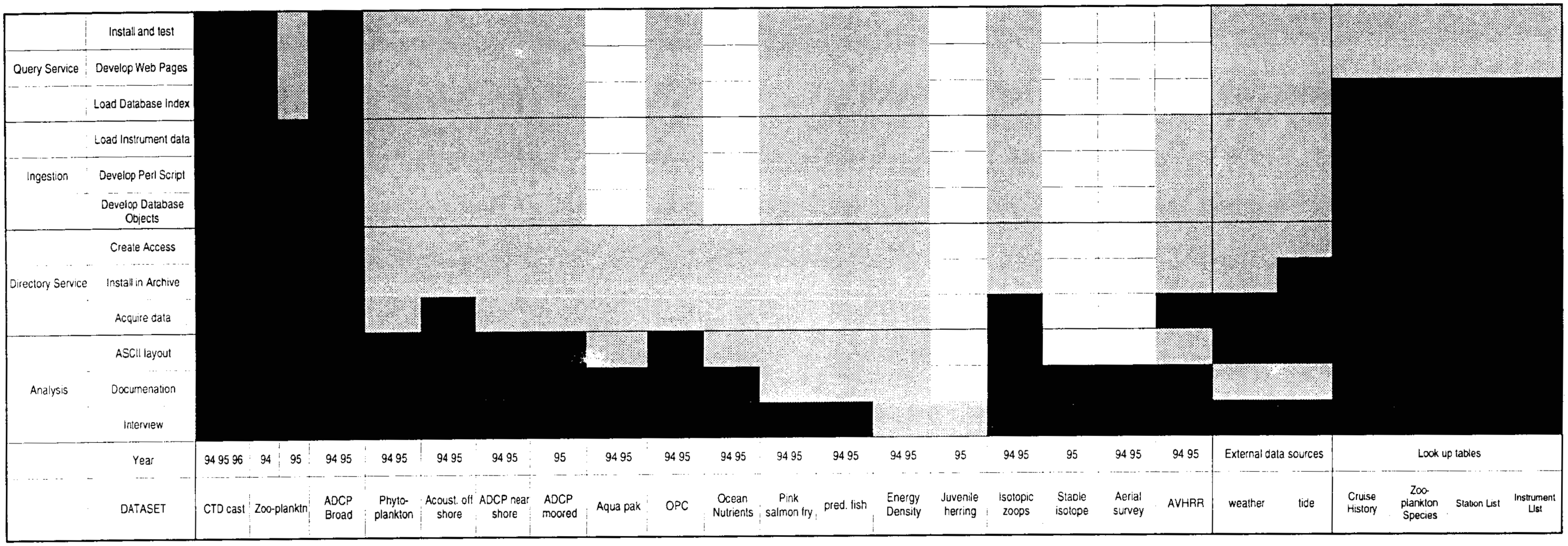

Figure 3. The SEA Datasets and the SEA Database: status at the conclusion of 1996 (black), expected status for 1997 (gray).

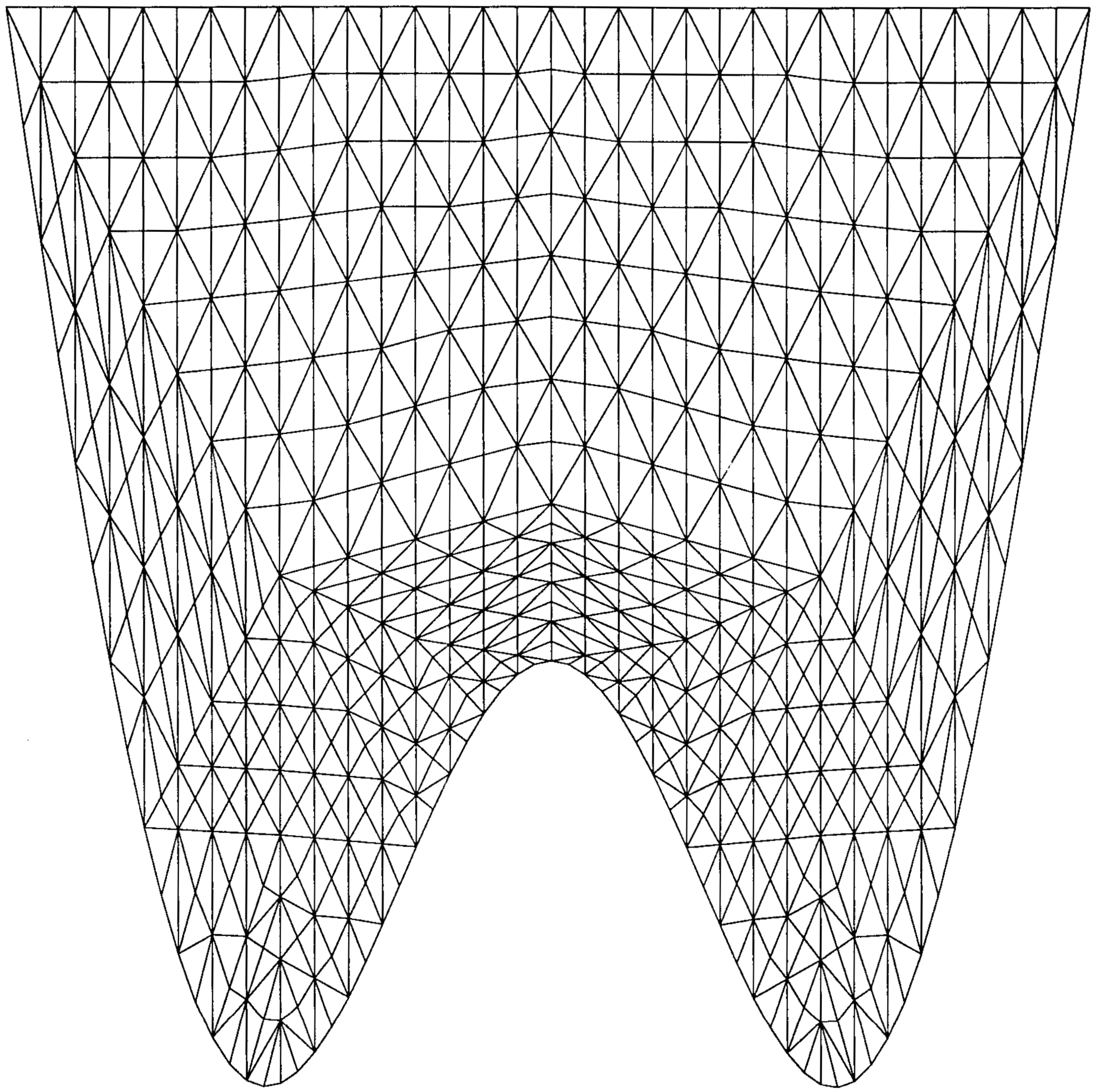

Figure 4. Test mesh for simulated 2D vertical domain in PWS. Generated by E. Baensch, Univ. of Freiburg, during visit to explore development of 2D and 3D codes for SEA nekton model, July 1996.

Figure 5. Cross-passage direction and upper layer of water column in neighborhood of maximum zooplankton abundance: modelled as a one-dimensional domain.

Appendix 1

Report on the Development of the SEA Database during FY96

Report on the Development of the SEA Database during FY96

Charles Falkenberg

Summary

While the focus of the FY95 database work was design and prototyping, the FY96 effort has concentrated on implementation. As a result, the SEA database has been brought online through the SEA DataWeb intra-net. This Netscape application unifies the access to SEA datasets and provides for the retrieval and processing of the data needed for integrated analysis of the ecosystem of Prince William Sound. The implementation milestones for FY96 include:

Purchasing and installing the Illustra software at 3 of the SEA sites.
Training a SEA collaborator at each site on Illustra.
Developing and installing the SEA DataWeb.
Collecting and ingesting the meta-data needed to index SEA datasets.
Ingesting several datasets from the 94, 95 and 96 field seasons.
Initial use of the database with the SEA models.

With the establishment of the DataWeb, SEA researchers can use the Netscape browser, or other advanced WWW browsers, to select from multiple SEA datasets using a wide variety of meta-data. The resulting list can be viewed or displayed on an interactive map of Prince William Sound. The map shows the positions of all selected datasets and can display a list of datasets at each location. The datasets can then be downloaded, in a single step, to any of the SEA hardware platforms. Allowing multiple types of datasets to be selected using the same criteria unifies the process of analyzing these datasets together. This level of data integration is required by the ecosystem models developed by SEA. Although more datasets need to be brought online in FY97, the current availability of many of the higher demand datasets and the establishment of the SEA DataWeb is a major milestone for the SEA database.

In addition to the creation of the DataWeb, the database development effort had several other significant accomplishments in FY96. These include:

Establish public data access and visualization of PWS weather data. (Allen & Bodnar)
Mirroring the DataWeb and archive to provide fault tolerance.
Compiling a description of all SEA datasets for the EVOS CD.
Begin retrieving and cataloging tide data from NOAA.
Upgrading the cruise planner for the 97 field season.

As part of the SEA effort we are collecting and analyzing weather data from around Prince William Sound. SEA is making these data, and the visualization of these data, available to the public over the World Wide Web. Jenny Allen and Steve Bodnar have created a set of web pages for selecting and graphing a wide range of weather data for Prince William Sound.

The data archive and the DataWeb tools are being mirrored to allow faster access for a wider number of researchers and provide some fault tolerance if any site is experiencing problems. Finally, we produced a unified document for the upcoming CD which is being put out by the Alaska Department of Natural Resources for EVOS. This document met the specifications of Carol Fries at ADNR and describes all of the datasets being collected by SEA in a concise manner.

The main effort in FY97 will be to bring several new dataset types online, and to add data from recent field seasons to the datasets currently online. Support for the modeling effort will also increase and provide input to the SEA models as well as an archive for the output from the models. Finally, the DataWeb will be expanded to include datasets which are derived from external data including tides, stream runoff and weather.

Using the DataWeb

The DataWeb provides three levels of data access; a directory service, a query service, and a modeling service. Directory service is the initial level, allowing files to be retrieved by dataset and year. Although these are limited selection options, this directory service provides immediate availability to the datasets in the SEA archive. It acts as shared data directory for SEA. Individual SEA projects can make their data quickly available to other members as the initial analysis is under way.

Query service provides access to multiple types of SEA datasets through a database query. Here, datasets can be selected using a wide range of meta-data which has been extracted from the dataset and used as an index. These meta-data include geographic location, collection date, cruise and instrument ids, and value ranges from the data variables. A researcher using the query service enters one or more of these attributes through the browser and a list of all datasets meeting the criteria is displayed.

The selected datasets can then be displayed on an interactive map of Prince William Sound. The scale of the map can be changed and if one of the locations is selected with the mouse, a list of datasets at that point will be shown. This list includes the type of dataset, the station or transect name, the date and time of collection, and any relevant notes associated with that dataset.

All of the files associated with the selected datasets can also be listed and downloaded. Individual files can be browsed or downloaded or they can be retrieved together in a single ZIP file. Each researcher can then work from a local computer on any of the SEA datasets which meet the specific criteria of a project. With the use of Netscape and ZIP, the DataWeb becomes accessible to all researchers in SEA, regardless of the computer platform.

The Modeling service provides the most advanced set of database functions. Using the Netscape browser, a query which is tailored to a particular modeling requirement, results in a set files which contain reformatted data from several different datasets. The query is a proximity query which returns datasets throughout the region and time period being monitored or modeled. Specific variables are extracted from these datasets an mapped into the space described by the model.

Although it is still in it formative stages, the modeling service provides the foundation for integrated modeling and long term monitoring. The database will store both the data needed as input by the models and the data output by the models. Data supplied by the database will provide three initial functions. Boundary conditions for the model, such as ocean currents or temperatures, will place the model in a spatial and temporal context. Data may be assimilated into the model as it runs. And Finally, data may be used to validate the model results. These results will then be placed back in the database and possibly used as input to a subsequent modeling effort

Under the Hood of the DataWeb

The DataWeb uses the Illustra Database Management System (DBMS) to store and search the dataset indexes. Illustra is the leading object-relational DBMS and was, as a result, purchased by Informix which is incorporating the Illustra model into its own DBMS product. Illustra (and soon Informix) supports spatial indexing, allowing an index of datasets to be created using the latitude and longitude of the sample files. Illustra was originally used to support the Sequoia 2000 project which, like SEA, has integrated environmental data from a wide number of sources.

Informix is one of the top 3 DBMS vendors. With the adoption of an object-relational approach Informix presents a formidable challenge to the other major DBMS vendors, Oracle and Sybase. NASA is considering switching from Sybase to Informix for it large EOS project and Oracle is now pursuing the object-relational approach as well.

The DataWeb tools are also based on some emerging technologies for database access through the web. Illustra's Web Datablade provides server side interpretation of HTML pages and allows the results of SQL statements to be embedded in the pages before they are returned to the Netscape browser. This product became available in December of 1996 and was used as an integral part of the initial DataWeb pages.

In addition to the Web Datablade, Perl was used extensively to generate the pages needed in DataWeb. An API is available for Perl which allows access to Illustra. This Perl library is being used to select datasets for the SEA models as well as to create the ZIP file which is used to download the datasets.

In order to support JavaScript, and the HTML forms needed by DataWeb, the latest web server and the Netscape browser were installed in the summer of 1996. JavaScript is used heavily to validate the input needed by the DataWeb. Fields such as year, month, day, latitude, longitude all require extensive validation to insure that they can be used in a database query. In addition, JavaScript is used to create a list of dataset files at the browser and reduce the overhead of a second database query.

One of the other advanced features of the Illustra system is the ability to create functions that are executed by the Illustra server during the processing of an SQL statement. The DataWeb includes several of these server side function which tailor the output of query to meet the needs of the application. One of these functions is used by the modeling service to project the lat/lon of the dataset polygons into an albers projection. This is required in order to provide accurate proximity queries for the SEA models.

The DataWeb tools and the SEA data archive are being mirrored in Cordova and at the Advanced Visualization Lab in Maryland. This provides high speed, fault tolerant access to a wider range of SEA researchers. The Maryland site provides collaborators in Fairbanks and in the lower 48 to have access to the SEA datasets with the speed of a terrestrial data link. A development environment has also been established in Maryland and in Cordova. This allows the development and testing of new DataWeb modules to be done without interfering with the use of the production version of DataWeb.

Status of Development

The database effort can be broken down into two categories: software development and dataset ingestion. The software development work includes the design, programming, testing and installation of the DataWeb tools as well as the cruise planner and several productivity aids. The major thrust of the FY96 effort was the installation of the DataWeb tools. These tools, described above, provide the foundation for retrieving all of the SEA datasets. These tools will be refined and expanded as time goes on but the largest part of the development is now complete.

In addition to the DataWeb development several datasets were ingested in FY96 and made available through the DataWeb tools. The ingestion effort includes four general phases which are shown in Figure 3 from bottom to top. First, the analysis of the dataset includes interviews and documentation. Next, the data are acquired and made available with a simple directory based lookup. The third step, is the largest part of the overall ingestion and includes the creation of the programs which build the database objects and indexes. Finally, several dataset specific web pages are added to the DataWeb Tools.

The focus of FY96 dataset work was on four datasets: the CTD, Zooplankton and ADCP datasets and the meta-data needed to index these. The columns of figure 1 represent the datasets and these 4 are now available through the Query Service portion of the DataWeb. The first three of these datasets include data samples which were collected by SEA. The meta-data tables, or lookup data, includes the cruise history, ship and instrument inventories, SEA station lists, and zooplankton species list. These meta-data tables are used to validate the datasets during ingestion and as selection criteria in the DataWeb tools.

As an example, each dataset has a SEA cruise number which can be used to select the datasets for a single cruise. A meta-data table containing all cruise numbers is used during the ingestion processes to validate the cruise number in each of the datasets. This table is also used by the DataWeb to present a list of possible cruise numbers. Once one or more cruises have been selected from the list, the cruise index is used to quickly locate all datasets for those cruises. The cruise meta-data table, therefore, insures consistancy within the database and greatly simplifies the entry of the selection criteria.

The current inventory of datasets available through query services includes the CTD dataset from 94 through 96, the ADCP dataset from 94 and 95 and the Zooplankton dataset from 94. The Zooplankton data will be brought current in the spring of 97 and additional ADCP dataset may be available in summer 97. The main goal of FY97 is to bring several new datasets into the archive and make them available through the DataWeb.

The database effort received about 6 months of funding in FY96 and about 22% of that was devoted to EVOS related projects. These included the EVOS meetings, the EVOS CD and year end reporting. About 40% of the FY96 database effort was devoted to installing software and creating the various parts of the DataWeb tools. Finally, about 38% of the effort went into populating the archive with meta-data tables and the initial datasets. The three main datasets required about 4 to 5 weeks a piece to ingest and some of this was done in FY95. It should be noted that the individual projects which submitted the datasets were actively involved and devoted a fair amount of time to the ingestion effort as well. It is anticipated that the other datasets will require about the same amount of effort. Some are more complex than others, however, and will require additional time. As with FY96, the future database effort will be divided between adding datasets to the archive and enhancing the DataWeb tools. In addition, as the modeling effort matures a great deal of work will be needed to supply the data in the model specific formats.

Shared Data and Interdisciplinary Research

As a large scale interdisciplinary research project, SEA faces many unique data sharing challenges. In many regards the SEA approach to sharing data is closer to a corporate model than to the traditional scientific model. Scientific analysis of sample data has traditionally been done in relatively closed environments. A small number of researchers, who have exclusive access to their data, can set their own data standards and establish their own data management scheme. Larger research projects must face the difficulties of sharing the management of data and large multidisciplinary projects must create shared standards across disparate disciplines. SEA has embraced both of these challenges as part of its interdisciplinary character.

A significant part of the SEA program has been to collect field data on a wide range of physical and biologic parameters. As a result, 15 or 20 datasets will be created, consisting of some 200 thousand sample files. From the beginning SEA has recognized the importance of cataloging these data and making them available within SEA during the proprietary phase and, following that, to the public at large. The SEA DataWeb is the cornerstone of this effort.

This data sharing strategy is closer in many ways to an enterprise which maintains a common database and provides a consistent view of those data to all departments. Therefore, the SEA DataWeb utilizes many of the emerging technologies found in corporate intra-nets. The DataWeb has a client-server architecture using a secured sub-net of the World Wide Web. The datasets are indexed using a transaction oriented, object-relational, Database Management System which supports spatial indexing. The current version of JavaScript is used to validate the query input and the results are displayed on web pages which are dynamically generated at the server.

The goal of the DataWeb, however, is to support science and not an enterprise. This makes it much harder to anticipate the types of synthesis and integration that will done with the SEA data. Science is discovery, and that requires unplanned synthesis. The DataWeb provides 3 levels of access in order to support this uncertainty. Data can be submitted to the archive and made available through the directory service while it is being processed and indexed. An integrated view is then available through the query service. Once the modeling requirements are established the same indexes can be used to select the cross section of the data needed by the model.

As inter-disciplinary research becomes more common and the gains are realized, data sharing strategies like those used by SEA will no longer be rare. The process of establishing shared standards and conducting integrated data analysis may itself change the way in which data are collected and cataloged. For instance the sampling strategies employed for long term monitoring will be effected, at least in part, by the demands of integrated classification and analysis.

Appendix 2

The SEA Intranet

with 10 figures

The SEA Intranet:

Scientific collaboration in a shared information space by a multidisciplinary, geographically-dispersed research team

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RUNNING TITLE: The SEA Intranet
KEYWORDS: Intranet, world wide web, computer support for collaborative work, ecosystem, Prince William Sound Alaska

ABSTRACT

The term *Intranet* refers to the use of Internet and world wide web protocols for internal communication within an organization. The web-based approach to cooperative work includes both functions mediated directly by the HTTP protocol and those where the browser as universal client serves as a hypermedia interface to other protocols or applications. This paper describes a working Intranet that has been used since September 1995 as part of the Sound Ecosystem Assessment (SEA) program in Prince William Sound, Alaska. SEA is a multidisciplinary, ecosystem-level study comprised of more than a dozen integrated projects with research teams distributed over eight institutions from Fairbanks, Alaska, to Miami, Florida. Coordination, data sharing and joint synthesis are essential to accomplishing the program's mission. The SEA Intranet provides mechanisms for user-driven, problem-oriented group interaction and information sharing via a single seamless web interface. Key components include a dynamic results archive; a threaded discussion server featuring user identification, notification, and multimedia attachments; and a fully interactive project-oriented papers collaboration work area incorporating file upload and retrieval. Strengths and limitations of an HTTP based collaborative technology are discussed. Findings from the first 18 months of use indicate that a web-based approach is ideally suited to a circumscribed set of coordination and communication functions in distributed research groups, and that obstacles to be overcome are as much social as technical. Achieving a critical mass of users was essential to establishing Intranet utility and depended on optimizing a cost-benefit balance. To the degree that a scientific project is truly cooperative, collaborative tools offer tangible benefits. However, successful introduction of cooperative tools requires sensitivity to the social and political concerns that characterize joint scientific work.

INTRODUCTION

Collaboration and communication are central to scientific research. Large scale cooperative research programs involving pooled resources and shared information are increasingly required to address complex scientific problems. Although the computing revolution has brought obvious benefits to science, the impact of technology on the scientific collaborative process itself has been insignificant when compared with expectations for the near future (Kouzes, 1996). The spectrum of applications ranges from in-house repositories of hyperlinked data to interactive virtual collaboration environments on the global information network.

The term *Intranet* refers to the use of Internet and world wide web protocols for internal communication within an organization. At its simplest, an Intranet uses a hypertext transfer protocol (HTTP) based internal web server, with a web browser as universal client, to share multimedia files within organizations (Bednarcyk, 1994). The concept, rapidly embraced in the corporate world, has been described as a new paradigm that is predicted to replace client-server architecture as the dominant construct of distributed computing (Gallant and Naik, 1996). An Intranet is a cross-platform solution that avoids problems of heterogenous networks, operating systems, devices and formats; it exploits low-cost, easy to use browser software already ubiquitously deployed; and it is based on open standards and protocols which allow organizations to leverage innovation from the whole industry rather than committing to a single vendor. Over the past two years, corporations have discovered that Intranets provide a powerful mechanism for organizing and accessing internal information using search engines, forms-based queries and web interfaces to legacy databases. Standardized application programmable interfaces (APIs) supporting the Java language offer the spectre of a platform-independent launching vehicle for entire software applications. Netscape Navigator's incorporation of email and chat/whiteboard features portends the beginning of a seamless web browser interface to asynchronous and synchronous communications tools. As of March, 1996 at least 22% of Fortune 500 companies were using web technology for internal information transfer, and another 40% were considering or preparing to do so (Bruno, 1996). Currently about 70% of all new web server sales are estimated to be for Intranet applications (Gallant and Naik, 1996). Intranets are reported to enhance internal communications, improve efficiency, and promote teamwork (Cline, 1996).

Despite this strong endorsement from the commercial sector, application of Intranet technology to scientific collaboration has lagged behind its adoption in the corporate sphere. For the last fifteen years, collaborative use of the Internet by scientists has largely been confined to e-mail, FTP and Gopher protocols. However, the very genesis of the world wide web, which dates to 1989 and the invention of HTML and the first Mosaic browser, was inspired not by commercial objectives but by the need for collaborative data access by physicists at the European Particle

Physics Laboratory (CERN). An internal web today remains ideally suited to sharing of results and information among cooperating scientists, and it offers unparalleled potential as a vehicle for coordinated work among geographically separated researchers. Federal initiatives are increasingly stimulating research on technology to support Internet-based scientific collaboration tools (Cerf, 1993; Weymouth, 1994; Kouzes, 1996). This paper describes a working Intranet that has been used since September 1995 to coordinate and integrate a multidisciplinary, multi-institution, ecosystem-level research project in Prince William Sound (PWS), Alaska.

BACKGROUND AND OBJECTIVES

The Sound Ecosystem Assessment (SEA) Program is a five year study designed to investigate several ecosystem-level hypotheses regarding recovery of pink salmon and Pacific herring populations in PWS following the *Exxon Valdez* oil spill. SEA is an integrated study comprised of more than a dozen individual research projects. Its research teams are scattered over eight institutions from Fairbanks, Alaska, to Miami, Florida, including academic, government and private organizations.[1] The observational studies covered by the individual projects include oceanography; remote sensing; abundance and distribution of nutrients, phytoplankton and zooplankton; abundance, distribution, habitat, diet composition and energetics of the fish species, their prey and predators, including seabirds; and foodweb assessment by stable isotope analysis. The program's three numerical modelling teams are creating (1) a continuously running four-dimensional general circulation model of PWS; which will be used to drive (2) a trophodynamic model linking physical parameters to biological production rates; which in turn will serve as one of the forcing inputs to (3) a coupled multispecies diffusion-taxis model predicting juvenile fish survival. Each of the dozen program components is a complete project in its own right. However, these individual projects were all conceived, designed and developed in a single integrated SEA plan. Their fieldwork is coordinated, uses shared resources and conducts cooperative synoptic measurements at several spatial scales. Each project's data is gathered into a central SEA database, from where it is available to the group and is used both for model validation and for collective refinement of the group's understanding of the system. The deliverables from the program include the set of working coupled models plus a synthesized evaluation of the underlying ecosystem-level processes.

The ultimate success of this program depends critically on solving coordination problem across distance and disciplines. In addition to the basics of scheduling and data sharing, the day to day

[1] Participating institutions include the University of Alaska, Fairbanks; the UAF Seward Marine Center in Seward, AK; the Prince William Sound Science Center and the Alaska Department of Fish and Game, both in Cordova, AK; the University of Miami; the University of Maryland; the University of Wisconsin and the University of Toronto, Canada.

tasks include joint assessment and assimilation of large volumes of data across disciplinary boundaries; preparation of joint presentations, reports and manuscripts; and timely reassessments and revisions to plans for joint work based on accumulating information and insight. A major challenge is maintaining convergence of the field and modelling efforts through model validation and tightly coupled dialog between the mathematical modellers and the field researchers. The ongoing quest is to integrate the observations, expertise and knowledge of each investigator into a joint system-wide synthesis, with translation into management and monitoring applications.

Clearly, interaction and exchange of ideas between all SEA components is essential to accomplishing these tasks. In the second year of the program, SEA coalesced organizationally into three hypothesis-based workgroups. However, the quality and frequency of interactions within and between groups was hindered by geographic dispersion, a demanding timetable and habituation to conventional more solitary approaches to data analysis and reporting. Because of the remoteness of the Alaskan study site and the wide separation of research teams around the country, face to face meetings of the whole program team were feasible at most a couple of times a year. Intervening teleconferences did not occur often, and were often regarded as inefficient. The SEA Intranet was developed to supplement and augment conventional meetings and to catalyze and facilitate the collaborative interactions critical to SEA's mission.

The approximately 45 SEA researchers all have Internet access. With the exception of the Seward site, all connections are digital links at 256 kbs^{-1} or better; the Seward center has dialup access only. The SEA team members have varying levels of computer expertise and operate from a range of platforms including networked Macintosh, DOS, and Windows 3.1 / 95 / NT machines as well as a variety of DEC Alpha, SGI and Sun Solaris Unix workstation environments. The overriding objective in design of the SEA Intranet was to create a uniform, integrated, seamless collaborative environment which would be equally accessible regardless of platform and computer skills and that would be *used.* Achievement of these goals presented both social and technical challenges.

The following requirements were imposed as design constraints. The solution should:

1. Be platform independent; provide core functions compatible with the lowest common denominator of access technology; be comprised of modular components and compatible subsystems; provide adequate security.
2. Be user-driven, that is, empower users through a system that is not "administered" but rather facilitated; be easy to use; minimize for researchers as far as possible the additional overhead (time, effort) required to participate.
3. Be rapidly implementable with existing technology; but nevertheless allow for expansion and increased sophistication to occur while in use.

The core capabilities needed by the SEA researchers included the following:

* Ability to **locate** and **browse** project documents, calendars or news quickly and easily.
* Ability to **post** (make available to others) new results, quickly and easily; and ability to **view** (see and have access to) new results of others, quickly, with context and interpretation.
* Ability to **brainstorm** over results with others, from multiple locations, while interactively viewing a common display of data products.
* Ability to **exchange** (upload and retrieve) draft copies of joint documents in progress, transparently, regardless of platform.
* Ability to **annotate** objects; and ability to carry on **sustained dialogs** in an open group forum, from multiple locations, without being limited by schedule conflicts and meeting costs.
* Ability to **stay connected** (keep current and involved) with the activities of others and the evolution of group thinking.

COMPONENTS OF THE SEA INTRANET

The SEA Intranet uses an NCSA httpd server, version 1.5, running under Solaris 2.5 on a Sun Sparc20 workstation located at the Prince William Sound Science Center (PWSSC) in Cordova, Alaska. At 2,500 residents, the township of Cordova on the eastern shore of PWS is a remote fishing community accessible only by air and water; nevertheless, dedicated frame relay Internet connectivity allows the 9-workstation PWSSC local area network in Cordova to serve as the hub of communications for the SEA program. The HTTP/1.0-compatible NCSA httpd is a small, efficient server which provides built-in support for directory indexes, user directories, imagemaps, server side includes and user authentication. Access to the Intranet is restricted to SEA personnel by means of group and password files maintained in an ASCII flat file format.

The layout of the SEA Intranet is diagrammed in Figure 1. To facilitate orientation and navigation, a clickable menu bar, incorporating a graphical indicator of current location, appears on each page (Figures 2). The key web site components include (1) a dynamic results archive, (2) a threaded discussion server, and (3) a fully interactive papers collaboration work area. These are discussed in more detail below. In addition, the site offers hierarchically arranged informational documents including calendars, maps, cruise plans, cruise reports (Figure 3), and announcements. There are also links to SEA web documents in the public domain, as well as to the internal web interface for the SEA database. To minimize browsing time, a What's New section directs a user's attention to specific updates since the last visit.

Dynamic Results Archive

The dynamic results archive was the first SEA Intranet component implemented, by virtue of being the most urgently needed. It is designed to disseminate awareness of emergent SEA data products rapidly across all SEA researchers. A distinction here is made between *data* and *data products*: the former denotes large files of raw or relatively unprocessed alphanumeric values; the latter refers to summarized and interpreted results including annotated tables, figures and animations.

Mechanisms for shared access to SEA's archived raw data are being addressed in a multi-year database design project which has been previously described (Falkenberg and Kulkarni, 1995). The SEA database architecture exploits the spatial indexing capabilities of the object-relational *Illustra*™ database management system, enabling selection of datasets within an arbitrary region defined by a bounding space-time polygon in addition to standard metadata-based queries. These features are essential to full utilization of the synoptic sampling design inherent in the SEA program. *Illustra's* built-in web application interface ("web datablade") mediates web forms-based queries on standardized selection criteria across all SEA data sets. Query results consist of a list of datasets which meet the search criteria; the web interface then allows retrieval of the selected data sets from the HDF and/or ASCII archive in which they reside (Falkenberg, 1995).

By contrast, the SEA Intranet's Results section does not provide retrieval of raw data but instead gives rapid access to interpreted summaries of current results, usually in the form of tables and figures, for discussion, integration and preliminary model validation purposes. The actual and intended use of this area has been primarily in rapid sharing of new observations for discussion and synthesis. The area is used extensively in both asynchronous viewing and simultaneous conferencing modes, particularly in preparation of joint presentations. A secondary use which has emerged is that of an organized catalog of results and figures: providing a convenient, centralized reference repository. Within the Results area, data products are organized by project and displayed with most recent findings first. Postings more than 3 months old are moved off the "current" page but are archived and accessible retrospectively by project, subject and date. Figure 4 shows an example of the New Results archive for the SEA Oceanography project, where data products are in the form of two-dimensional contour profiles through the water column. Figure 5 shows two examples of the use of GIF animations to display complex data: a three dimensional rendering of current vectors spatially oriented within the PWS bathymetry, animated over tide stages; and output from the nekton model showing evolution over time of spatially dependent model variables.

The mechanisms by which researchers contribute their data products into the Results area vary according to researcher ability and preference, with concomitantly varying degrees of involvement by the Intranet Administrator (IA). The spectrum ranges from (a) a fully user-maintained web site on a separate server, in one case; through (b) user-managed project-based results trees in user directories provided by the SEA Intranet server, with links and maintenance overseen by the IA; (c) user-driven file upload via custom utilities (see below) into designated directories, with layout and links managed by the IA; to (d) user-initiated emailing of pointers to desired graphics files, with format conversion and posting performed by the IA. It was found advantageous to maintain a range of mechanism choices for this procedure, in order to minimize the net cost to researchers of participating in the system. In fact, it was necessary, since even within this relatively small group no single method existed which was optimal for every member. It was recognized to be as much a hardship for programming-literate members to relinquish control of their results layout as it was for others to be forced into unfamiliar procedures of format conversion and linking; and it was apparent that attempts to impose a middleground solution would meet dissatisfaction from both ends. It was, however, possible to find a mechanism suiting any individual from the range above. Under this system, users have as much or as little direct involvement as they wish in creating and maintaining their "results web", and the only requirement to be a team player is to make current images available. The IA's task then becomes to manage postings to ensure a seamless top level look and feel. The web structure lends itself well to this approach, since below the single IA-constructed interface the resource locations pointed at are transparent to the user.

Threaded Discussion Server

Numerous web-based discussion software options, including *HyperNews*, were evaluated for use in SEA, and three (*WebThreads*, *Netscape's News Server*, *InterBoard*) were installed for trial periods. Of these, *InterBoard* (The Forge Foundation, Woburn, MA) was selected as the most full featured and best suited to the needs of a scientific Intranet. In fact, this was the only software found which satisfied all of SEA's key requirements of multilevel threaded organization, searchable archive, seamless web browser interface, and capacity for attachments. The attachment feature was added ahead of schedule by The Forge in response to the needs of the SEA group.

InterBoard runs as a separate server on its own port, thus providing improved performance over CGI-based alternatives plus intrinsic access authentication. A customizable interface allows transparent integration of the software into an existing Intranet, including for example the ability to incorporate the standard SEA clickable menu and locator bar into the Discussion area display. Discussion contents are organized into forums and threads or topics within forums (Figure 6). Forums are created by the administrator. Users are free to initiate new threads, which can be nested without limit, and to reply to messages in existing threads. A useful set of administrator tools includes prune-and-graft utilities, which allow a portion of a thread that has deviated from the original topic to be transplanted to the start of a new thread. A number of access options are provided, including the useful ability to make forums invisible to users for whom they are not relevant; for example an "Executive Committee" forum might appear on the opening menu of that committee's members only.

The server keeps track of messages read by each user, notifies users of new messages on each visit, and automatically selects only unread messages for display. The message display screen includes a navigatable diagrammatic outline of context, in which both history and replies to the message are shown in a clickable tree diagram (Figure 7). By means of a typical web browser button-type interface, a user can sort messages by subject, author or date; restrict messages for display by date range; expand the display to show all messages and replies or collapse it to list just main topics; and perform boolean text searches on subject, author and content. New messages and replies are posted via an intuitive forms interface. Postings remain editable at any time by the author, can be written in plain text or any valid HTML, and automatically translate valid URL's into hyperlinks. Attachments can be included on messages via a point-and-click browse selection dialog box. These can be in any format and will be handled appropriately by the message viewer according to MIME type. For example .ps or .dvi files attached to messages will be viewable by users with appropriate helper applications (ghostview or xdvi respectively) installed for their browser; .gif or .txt attachments will be directly viewable; and unrecognized formats such as spreadsheet files will initiate a download prompt in response to an access request.
Together these features provide a powerful user-driven collaborative tool. The SEA Discussion area provides a vehicle for sustained, threaded, asynchronous group dialog which is almost entirely directed by the users. The advantages of communication in this form extend well beyond those of the email alternative, in that: (a) the dialog is open to all and not restricted to people who the original correspondents may have guessed would be interested, thus maximizing the chances of serendipitous sparking of ideas; (b) attachments allow easy uploads and rapid contribution of "what do you think of this?" type messages regardless of computer literacy; and (c) the discussion files plus attachments provide an organized, searchable, centrally located archive of the brainstorming and commentary processes, in essence a multimedia group electronic notebook. However, care is required in definition of the forums. It was found that having too few forums can lead to lack of focus and unconnected rambling threads; while having too many presents an impediment to regular message browsing by busy researchers.

Papers Collaboration Work Area.

As SEA entered its third year, there emerged a preeminent need for mechanisms to facilitate joint writing and joint communication of findings to the rest of the scientific community. SEA's multiple collaborating teams of authors work under conditions of geographic separation and highly compressed time schedules. Their specific needs include mechanisms to stay in touch with what others are writing; to circulate manuscripts efficiently for internal review; and to exchange drafts within the author group. These requirements go beyond simple annotation tools provided by contemporary group-writing software packages, since, in contrast to many cases where papers are written by a senior author and then circulated for minor edits by coauthors, most collaborative papers in SEA are truly multi-disciplinary and therefore true multi-author constructions.

The Papers Collaboration Work Area (PCWA) was designed to address these needs by providing a single central repository and work area for papers in progress. SEA researchers contribute updates on their work in progress into this area for two reasons: (1) As a courtesy to their SEA colleagues, the simplest way to keep the larger group informed; and (2) To enhance the efficiency of their writing process. Although the area's name and this discussion refers mainly to preparation of manuscripts, it applies equally to group presentations and has been used by the whole of SEA to prepare a single collective presentation series for peer review.

Within the PCWA, there are two top level arrangements. The first is by discipline: papers are filed according to the discipline of the lead author, with extensive hypertext-mediated cross-referencing to all other areas involved (Figure 8). The second is by hypothesis or ecosystem-level issue: synthesis papers are filed according to the fundamental SEA issue addressed, again with extensive cross-referencing back to the areas of the contributing disciplines. Summary tables show work in progress listed by investigator, giving an at-a-glance summary of contributions underway and commitments made by each team member. The hypertext nature of web-based storage and retrieval lends itself ideally to this multidimensional web-like filing system where a single resource is accessible transparently from many different request perspectives.

Each paper registered with the PCWA is allocated a directory area and a workspace. The PCWA interface for an individual paper is shown in Figure 9. The left hand column allows a user to browse the abstract, outline and figures for the paper. The central column provides access to file upload utilities for posting new drafts of the paper onto the website. Draft manuscripts can be uploaded in any format, including plain text, Postscript, or any word processing binary format. The interface to the file upload utility is shown in Figure 10. The user specifies the file to be uploaded via a browse button, which invokes a platform-appropriate widget for selecting files from the user's local disk. File type is not inferred but is specified on the upload form by the user from four radio button choices. The default type is application/octet-stream i.e. unspecified filetypes are treated as binary files. A storage name for the uploaded file is requested since this will often be different in information content from the storage name on the local machine. Optionally, unlimited notes on the draft can be typed or pasted into the comments box; these are uploaded as a companion file with the same name as the draft plus the extension ".notes". File upload is achieved using the FILE option of the TYPE attribute for the INPUT tag, and specifying ENCTYPE="multipart/form-data" in the HTML form (RFC1867). On activation of the SUBMIT tag, all parts of the form's data, including the contents of the selected file, are sent by the browser in the order specified, as a multipart stream separated by a unique boundary string. A simple CGI script locates the boundary string, parses the stream and writes the draft and accompanying notes file, if any, to the designated directory for the paper.

The right hand column of the PCWA interface for each paper (Figure 9) provides two key tools. The first is a direct link to a discussion forum dedicated to the paper, via which comments can be posted and online dialog can proceed. The second link accesses an index listing of the drafts directory for the paper. This allows the user to scan the directory of uploaded drafts, including filenames, sizes, upload dates, plus the optional accompanying notes files, and then to either view (text) or download (binary) draft files. Setting the double period (..) as a non-displayable directory entry in the httpd server configuration provides a simple way of allowing the convenience of directory listing while restricting the listing to the designated directory. Together the file upload and directory index features provide a simple document exchange loop: a push-button send/retrieve mechanism that is totally independent of platform and circumvents frustrations of formats, mailer incompatibilities and uuencoding. In these small dynamic authoring groups, complex annotations and version tracking are less important than efficiency of document exchange and communication of ideas. The PCWA provides a task-oriented electronic work space offering net gains in efficiency of joint authoring. It also serves as a focus for exchange of ideas and a catalyst for discussion relating to evolving ecosystem concepts.

Synchronous Communications

SEA has installed several applications for synchronous communication, including *ShowMe*, *Collage* and *CoolTalk*. These each provide realtime conferencing with a chat text text window, audio link, and shared whiteboard. *ShowMe* also has shared application capability, by which software running on a host machine is displayed simultaneously to one or more other terminals. All three function as standalone applications, although *CoolTalk* is now bundled with *Netscape Navigator*. The upcoming *Netscape Communicator* promises a more integrated interface as well as multicasting capability. In a recent discussion, Kouzes (1996) drew attention to the immaturity of the synchronous protocols, high bandwidth costs and poor quality connections, concluding that "The perceived benefit of videoconferencing is not sufficient to overcome the problems of using available systems. Cross platform whiteboards and shared screens use less bandwidth than video but remain in an early state of development. Synchronous collaboratory tools need several more years of research until they will be mature enough to be acceptable to end users." This is in accord with the experience in SEA, where bandwidth limitations are such that realtime computer conferencing has not yet replaced teleconferencing. Use of *CoolTalk* audio and whiteboard between two parties is now routine, but group conferencing is still undertaken by telephone. However, a web extension to teleconferencing that has become common in SEA is synchronized viewing of web-posted results. Two or more team members post results they wish to review with colleagues, then access them simultaneously while conversing on the telephone. This marriage of technologies draws the best from both modalities and has been one of the most valued uses of the dynamic results archive. A useful extension is offered by innovative software enabling linked group web tours, such as *Virtual Places* by

Ubique Inc., and this type of "similtour" capacity is the next planned addition for the SEA Intranet.

DISCUSSION

At the national level, efforts are underway to deploy technology that will enable scientific researchers from any geographic location to interact with colleagues, access instrumentation, share data and computational resources, and retrieve information from digital libraries. Prototype efforts to implement such electronic "collaboratories" include the Upper Atmospheric Research Center (UARC) Collaboratory at the University of Michigan, funded by CISE and NSF, which focuses on shared access to solar wind observation instruments, and the DOE Distributed Collaboratory Experiment Environments Program, underway at the Argonne, Lawrence Livermore and Pacific Northwest National Laboratories. The DOE initiative seeks to create a web-based virtual environment encompassing the resources of the National Laboratory system that will allow scientists from around the world to participate in solving national research questions. The vision behind these endeavors is based on technology that already exists (email, world wide web and other Internet protocols), technology that is still maturing (audio and video conferencing), and technology that is still being created (such as telepresence) (Kouzes, 1996). The present report is concerned with implementation of existing web technology for synthesis and coordination within a single project: a cooperative study of a remote site by an integrated but geographically-distributed research team. Findings from the first 18 months of use indicate that a web-based approach is ideally suited to a circumscribed set of coordination and communication functions; and that obstacles to be overcome are as much social as technical in nature.

HTTP (Berners-Lee, 1996) is a stateless, file-based, object-oriented protocol developed for static file delivery, to which a degree of interactivity can be added by means of the common gateway interface. Its advantages include global accessibility, platform independence, scalability, replication through cacheing, and security. From the group work perspective HTTP also presents distinct limitations: firstly, it cannot accommodate some traditional groupware functionality such as notification, access control, and transaction management; and, secondly, it has no provision for synchronous communications. The first limitations have been addressed by developers through server side enhancements (for example, Bentley et al., 1996) or client side helper applications. However in scientific collaborations these particular limitations tend to be less an impediment than they may be in business applications. In interdisciplinary scientific groups, concurrency issues and version tracking, for example, are far less a priority than support for discussion of concepts, efficient exchange of documents, and access to interpreted summaries and analyses. The second deficiency of HTTP, lack of synchronous communications ability, is an inherent feature of the protocol. "Web-based" collaboration systems that incorporate chat and other synchronous features are of course not using web transport for those features. However, from its inception the web browser was designed as a convenient resource access tool that could point to diverse information sources via gateways to FTP, Gopher, SMTP, NNTP and WAIS protocols. In this sense even though the web protocol is inadequate for synchronous services it can usefully function as a transparent access mechanism pointing to those services, as discussed by Dix (1996). The "web-based approach" to cooperative work therefore includes both functions mediated directly by the HTTP protocol and those in which the universal client paradigm extends browser functionality to that of a hypermedia interface to other protocols or applications.

It has been shown that in problem-solving teams where each member possesses only partial information, the process of interaction itself, not just the exchange of information per se, is an important part of the problem-solving process (ref). Experience in SEA with twice yearly face-to-face gatherings of the entire group has demonstrated this phenomenon clearly. A principal objective of SEA Intranet development was to attempt to duplicate this high productivity environment during the extended intervals between meetings, by providing opportunity and mechanisms for user-driven, problem-oriented online interaction and information sharing.

The result has been an implementation of a single seamless interface to joint information access and retrieval, interactive asynchronous discussion, and dynamic document exchange for authoring. The strengths of a hypertext approach are invaluable in this context where the same piece of information is often needed by many different people for a number of different purposes. Hypertext linking via an image map is also the basis of the navigation menu bar consistently present through the discussion/results/papers areas; which allows users to move easily back and forth between an object (result or paper) and the discussion relating to it, or to display them concurrently in adjacent windows. This contributes useful deictic reference ability and alleviates a frequent problem in groupware, namely the inability to reference the work domain from the conversation domain (Dix, 1996). The new capability for multimedia attachments to discussion postings is similarly important, as many quanta of scientific dialog relate to a finding that can be illustrated in an attached one-page image. A particularly useful web ability has been the capacity to post animations illustrating the space-time evolution of either field observations or model output. Use of the browser to load and run multiple animated GIFs simultaneously in tiled windows allows visual comparisons of complex, concentrated information that is not easily presented or absorbed via other modalities. In addition, results created and normally only viewable with specialized software can be shared interactively with all colleagues, the only display requirement being a web browser.

A system to enhance cooperative work is only useful to the extent that it is used. For this reason a principal obstacle to the success of a new technology is obtaining a critical mass of users (Grudin, 1988). In a cost-benefit analysis of a cooperative system, the costs to a given user are relatively constant but the benefits increase dependent on the number of other users. At some number of participants a critical crossover point is reached; and only then can mainstream users be predicted to stay with the system. Conversely, below the critical mass, any sensible user judging solely on an objective basis will abandon the system (Dix, 1996). Successful establishment of the SEA Intranet was therefore critically dependent on adoption by an initial core group of enthusiastic participants who could see the potential offered by the system. These people were key to getting the Intranet off the ground, as predicted by Grudin and as reported by others in early experiences with web applications (Bednarcyk and Bond, 1994). The concept of critical mass was in the forefront of consideration during implementation of the SEA Intranet and was addressed both by attempts to minimize costs and attempts to maximize early paybacks. In practice, it proved easier to accomplish the former than the latter, because of the ultimate dependency of benefits upon adoption and participation by the whole group. The remainder of this discussion considers the nature of the costs, benefits, and measures taken to try to optimize the balance between them.

Malone (1994) lists one (among about a dozen) definition of coordination as "the additional information processing performed when multiple connected actors pursue goals that a single actor pursuing the same goals would not perform"; in other words: costs are inevitable and collaborating is more work than working alone. The issue of major interest is what factors influence the balance point in the cost-benefit tradeoff.

A report by Cole (1994) provides interesting insight into features of workgroup structure that influence adoption of computer conferencing (his term for threaded discussion forums) and is particularly relevant to the SEA experience. Cole's study evaluated the first year of use of computer discussion forums by three separate workgroups within a company: a research team, a senior management team, and a product development team. In all three cases, the team leader announced the goal of implementing the technology and instructed team members to use it. At the end of a year, despite an initial effort, use of the discussion system had dwindled to perfunctory in two of the three workgroups (research and management) and it was non-contributory to the work of those two groups. Reasons given for this by the research team members centered around feeling little social pressure to contribute to the forum when others were not, feeling that if something were important it would come by email, and objecting to having two different systems to check. Comments from the management team additionally referred to low value of the material posted: managers were required to post reports, but they were of interest only to the vice-president and none of the other managers ever read them. By contrast, in the product development team, the discussion forum became a central focus of the workgroup's activities. Discussions involved most of the team members in generating ideas or giving feedback. Day to day questions or issues that arose would frequently be addressed by opening a topic in the discussion forum. The team leader participated in the conference and actively encouraged people to use it, and most members reported a daily habit of reading the forums first thing in the morning over coffee. Use was consistent throughout a project but was most intensive close to deadline. Analysis by Cole identified four factors contributing to these differences among the workgroups: leadership, task fit, process fit, and group learning. Acceptance of the tool was strongly influenced by the degree to which the leader integrated the technology, established expectations for its use, provided incentives and or consequences for its use, and, most importantly, reinforced and modelled its value through his own use. Acceptance was also affected by the degree to which the tool provided tangible assistance in performing tasks of value; and the degree to which the technology accommodated the normal culture of the group. Of the three groups studied, the product development team was engaged in high energy, project and deadline oriented, critically inter-dependent cooperative work which required both coordination and collective problem-solving. Work in the research group was more individually independent. Work in the management group was more isolated due to mistrust and competition.

These observations by Cole suggest reason for some optimism concerning the usability of computer technology in scientific collaborations, but also point to potential pitfalls. To the degree that a scientific project is truly cooperative, such as an ecosystem study where each person's contribution is one piece of the final picture, then collaborative tools offer tangible benefits to the process. However, professional competition, isolationism, lack of perceived rewards, and ambiguous leadership are potentially jeopardizing influences. Any introduction of cooperative tools must be sensitive to the to the issues of autonomy and trust and must pay vigilant attention to the social and political concerns that characterize joint scientific work, including authorship, acknowledgement, and individual recognition for joint results and products.

Within SEA, reservations and resistance to using the Intranet system centered around the time cost and inconvenience of having to remember to check the web, having to make time to interact, and doubts that the new way offered any advantages over existing tools of telephone, email and fax machine. A technology often exists without being used because it is perceived as adding little or no value (Kouzes 1996) and this was initially the case with many SEA researchers. About three months after implementation, however, the Intranet attained active use by more than half the program members. This occurred during preparation for a major program review, where synthesis and synchronization were urgent and imperative. The Intranet tools, which focused largely on the dynamic results archive at that time, offered advantages of speed, access, and utility in planning and exchange of information that was not available by other means within the operative time constraints. In other words, critical mass was attained during a time of intense need marked by a confluence of the tasks at hand with the capabilities of the technology, as predicted by Cole (1994). Today SEA remains in a period of active synthesis in its final active year, and the same type of need, perhaps magnified, obtains. The central role of the Intranet through the remaining phases of the project therefore seems assured.

The SEA researchers are a closeknit team who work in a shared information space of data, images, concepts, discussion arguments, and the papers being written to describe them. The attributes of this team include a strong common sense of purpose, commitment to the joint research product, strong leadership, and personal and professional compatibility among team members. Their activities are goal oriented and highly interdependent. In many ways the SEA team is most like the product development group in Cole's study. In the context of these natural advantages, a number of design aspects of the SEA Intranet may have assisted it in gaining acceptance. Design was approached from a service-oriented basis rather than attempting to create impressive technology for technology's sake. Costs to researchers were greatly reduced by the choice of the web approach, since the already familiar browser software guaranteed a minimal learning curve on the client end and removed frustrations of platform incompatibilities. On the content creation side, individual comfort levels were accommodated by providing a range of possible involvement levels while still defining minimum thresholds for good citizenship. On the content browsing and interaction side, the inherent passivity of the web presented a problem: initiative for awareness of change resides with the user. Several SEA mechanisms address this. The discussion system automatically flags new messages and by default displays to each user only the postings unread by that user. The "what's new" page is kept current and serves to cut down browsing effort. One measure of the utility of this page is that it is set by some researchers to be the default opening page on startup of their browser. These two, still passive, mechanisms are augmented by active notification via email. This procedure was instigated at the request of several researchers and involves emailing essentially a copy of the what's new page to a distribution list, at varying time increments depending on web activity level. Dix (1996) has commented that, in collaborative systems, pace (how often one interacts) is usually more important than bandwidth (how much one communicates); and that, provided it is not so frequent as to constitute interruptions (as for example automatic email every time any post is added), explicit notification may be desirable to reduce the initiative required and hence increase the pace in web systems. This has been found beneficial in the SEA system and requires little additional work on the part of the IA. The decision to organize a major work area around manuscripts, rather than more loosely around hypotheses, problems or other tasks, was made intentionally in attempt to maximize the paybacks for participation. A number of other arrangements could potentially have stimulated the same discussion of concepts and review of joint findings. Successful interaction in the papers collaboration work area culminates, however, in a paper, which constitutes tangible reward in the currency of the scientific system.

Most of the SEA researchers have contributed to development of their Intranet through feedback in various forms. Although much of the system's current functionality was developed in response to user requests and suggestions, there is a continuing need for its developers and administrator to stay attuned to the needs of the user group and to anticipate their evolution. Both technical and human obstacles still remain and present challenges to keeping the Intranet growing and useful. Nevertheless, the SEA experience has demonstrated that simple web-based tools can provide a productivity enhancing contribution to the joint work of a collaborative scientific research team.

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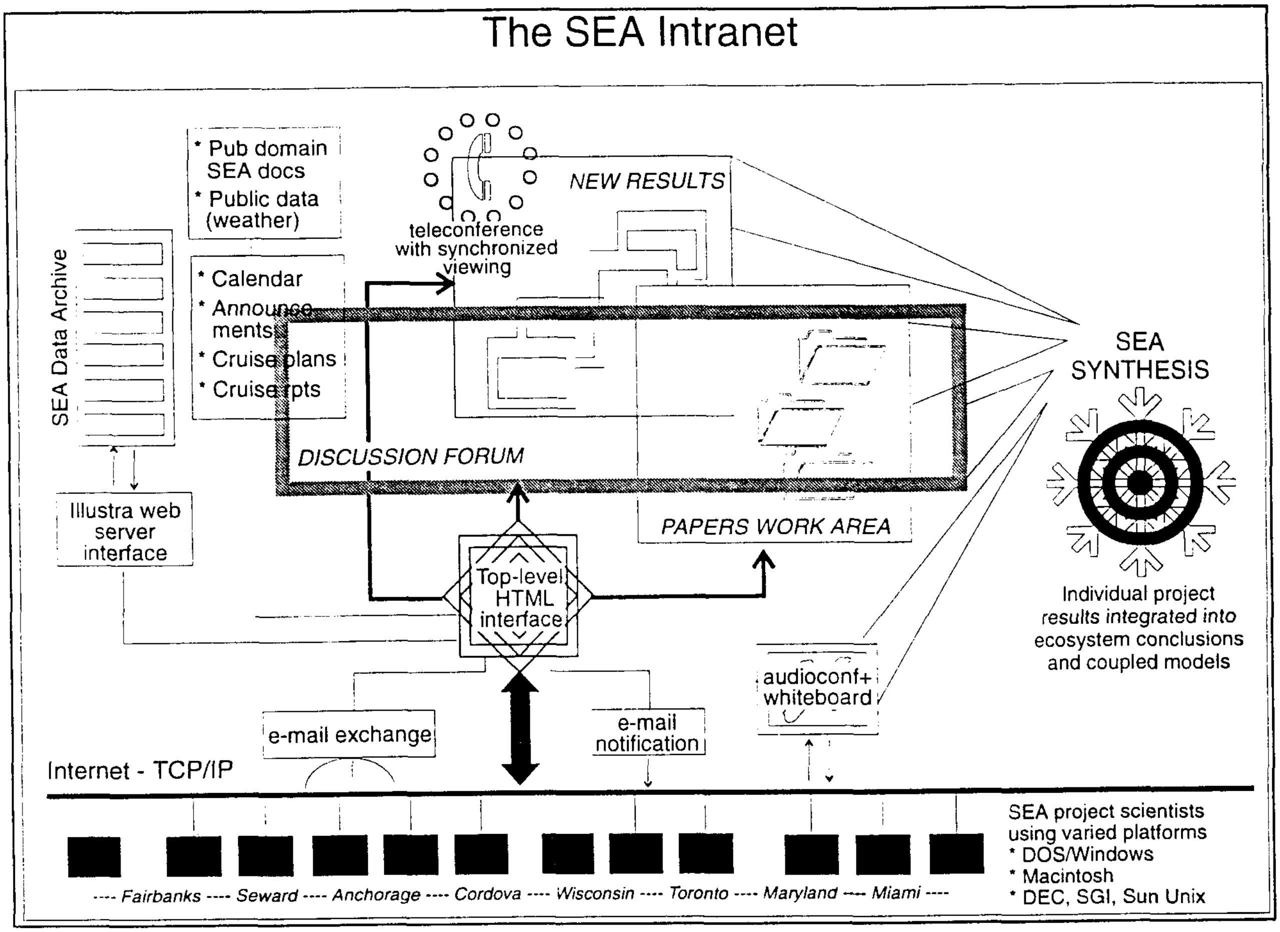


Figure 1: Components of the SEA Intranet

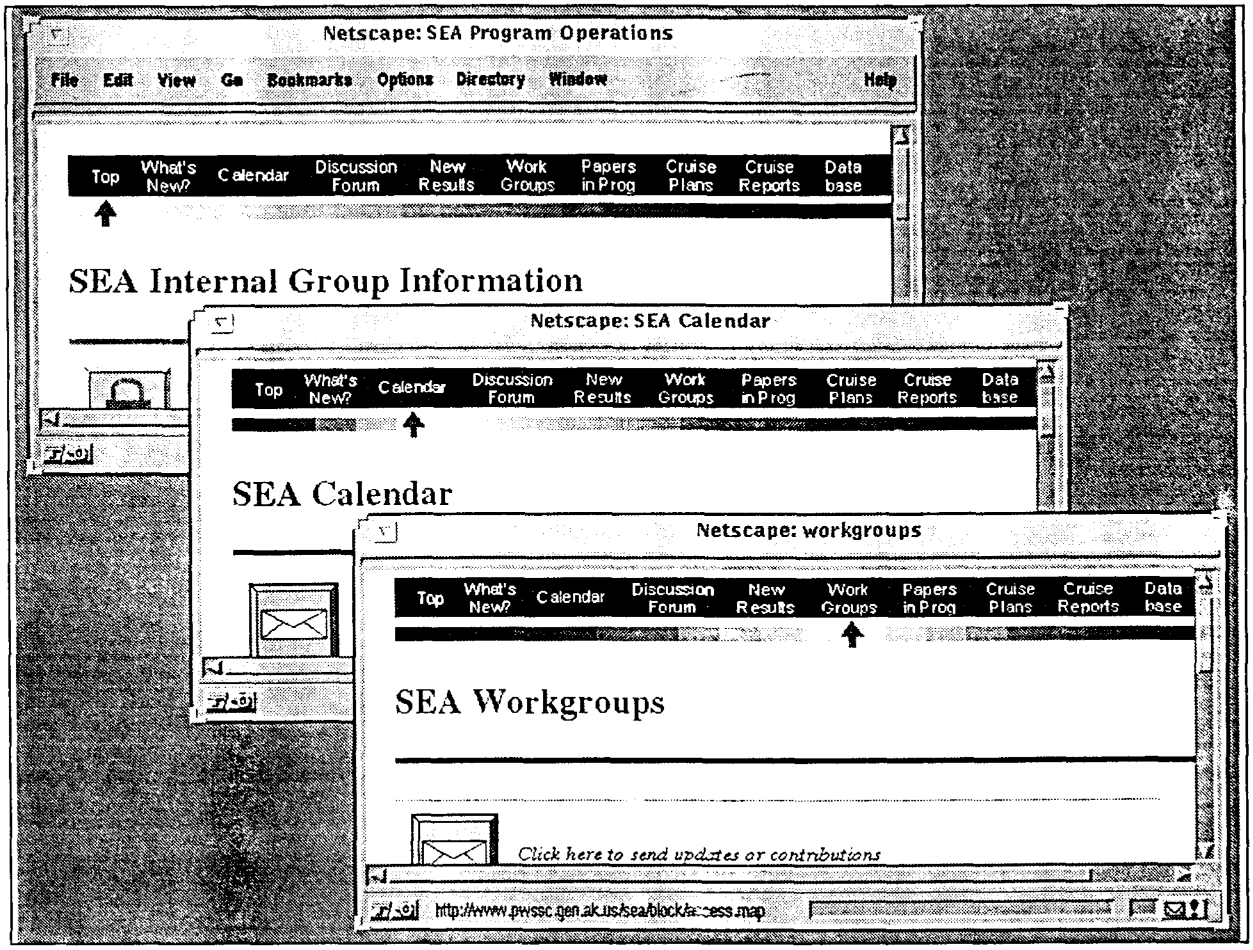


Figure 2: A consistent imagemap-based menu bar with location indicator is present throughout the SEA internal web site, providing a means of rapid navigation around the web tree.

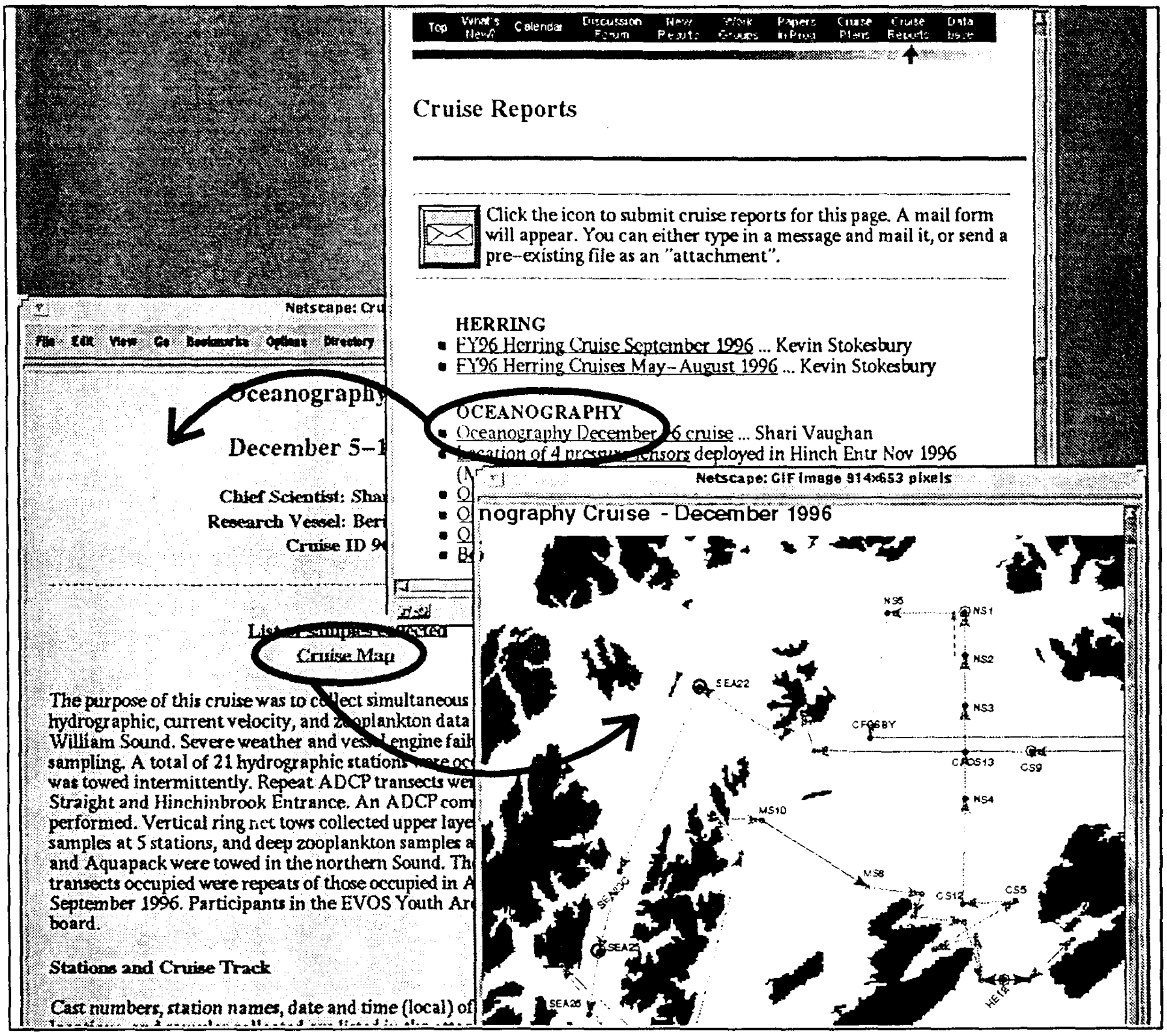


Figure 3: An example of a cruise report posted in one of the coordination/information areas of the Intranet. Hypertext links facilitate natural hierarchical arrangements of documents, lists and maps.

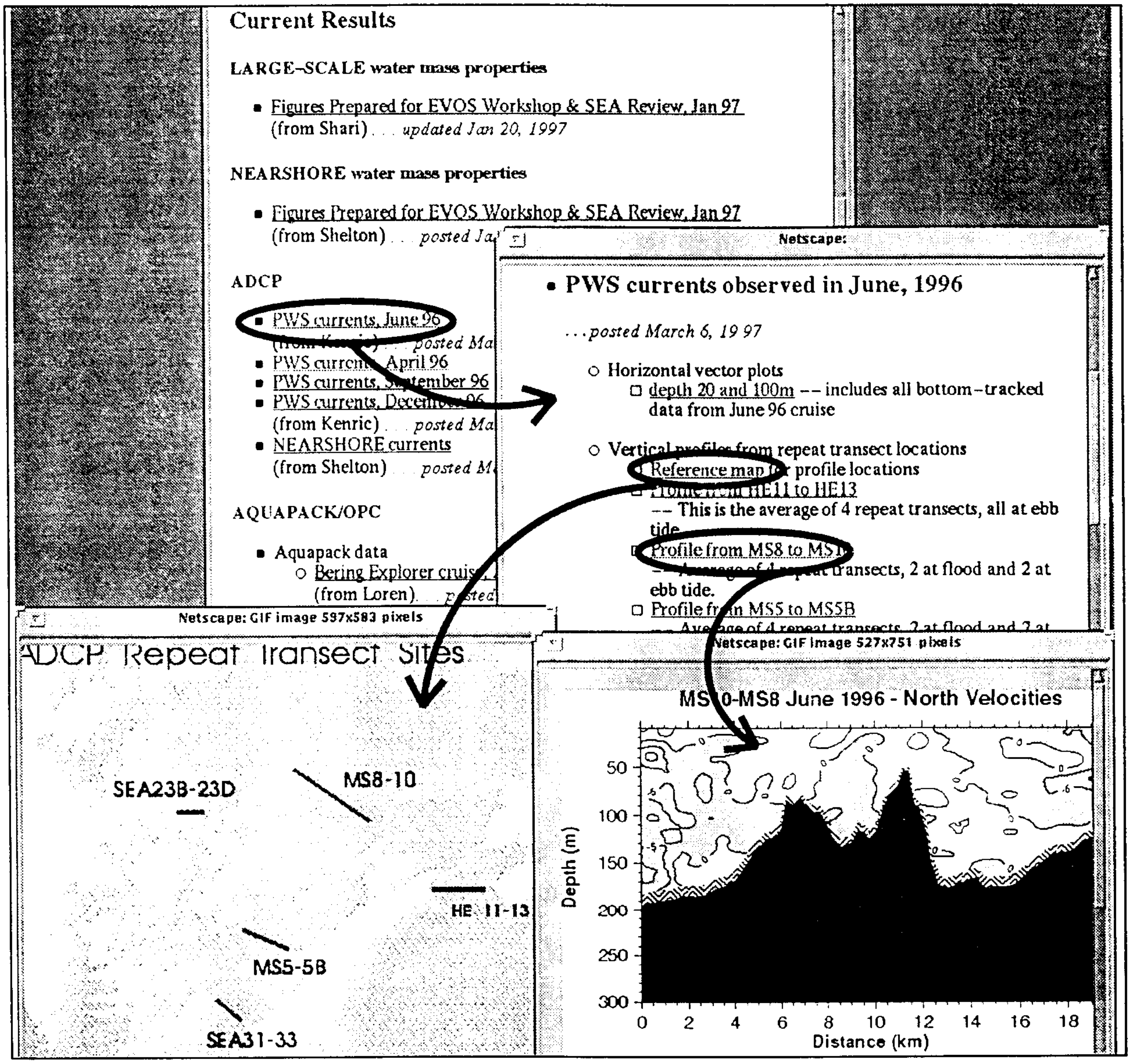


Figure 4: Example of results layout by the Oceanography group in the Dynamic Results Archive. Data products for this group are often in the format of 2-dimensional contour plots showing horizontal profiles at a certain depth or vertical profiles through the water column (seen here).

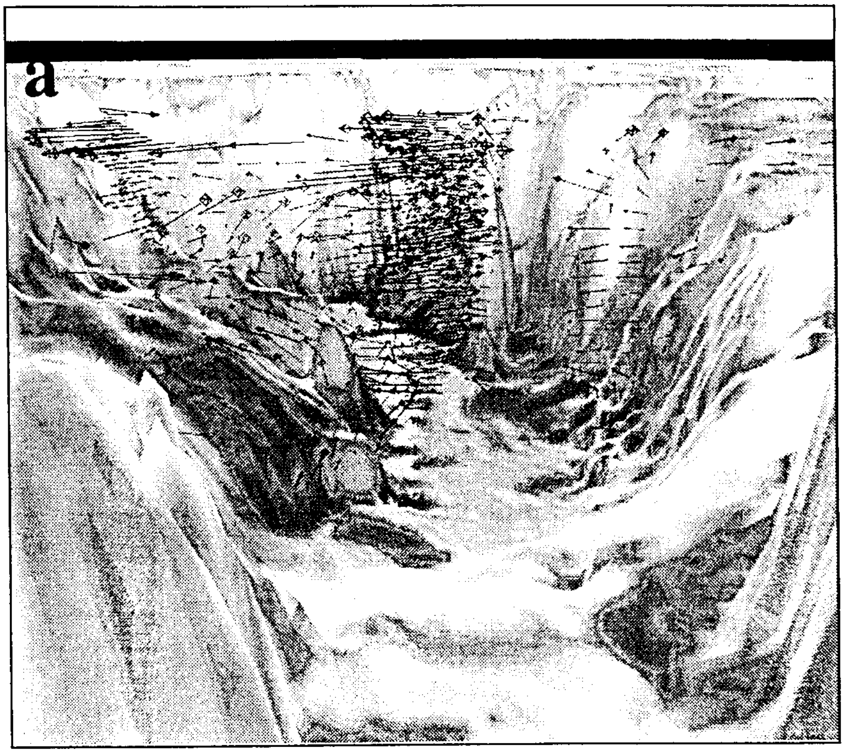
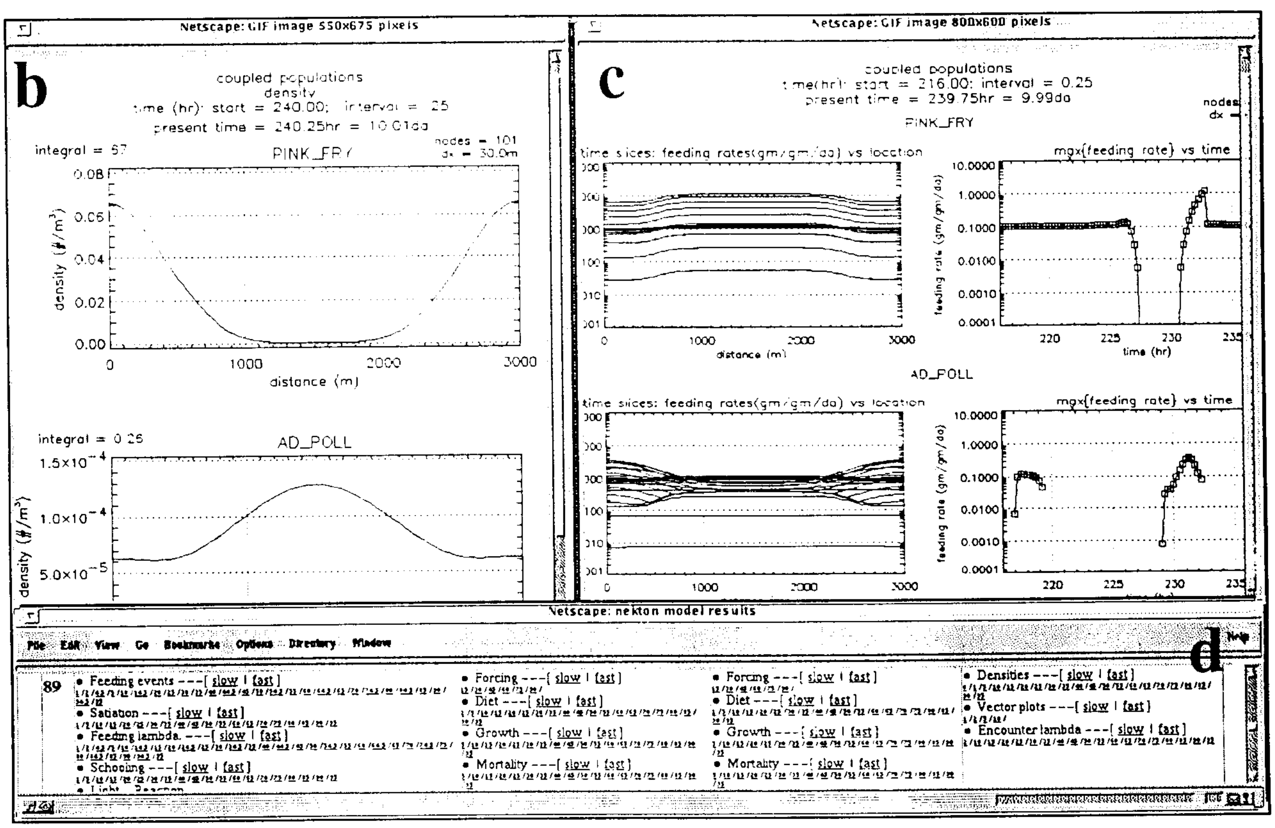


Figure 5: Examples of results displays that use GIF animations. **a:** Three-dimensional current flow observations. The arrows indicate current direction and speed. ***Below:*** Multi-panel display of nekton model output, showing spatial and time evolution components. **b:** Density changes in populations of pink salmon fry and walley pollock, a major predator, animated over 90 days on a transect across the migration pathway channel. **c:** Feeding event patterns of salmon fry and walleye pollock. **d:** Control panel for running the model output animations.



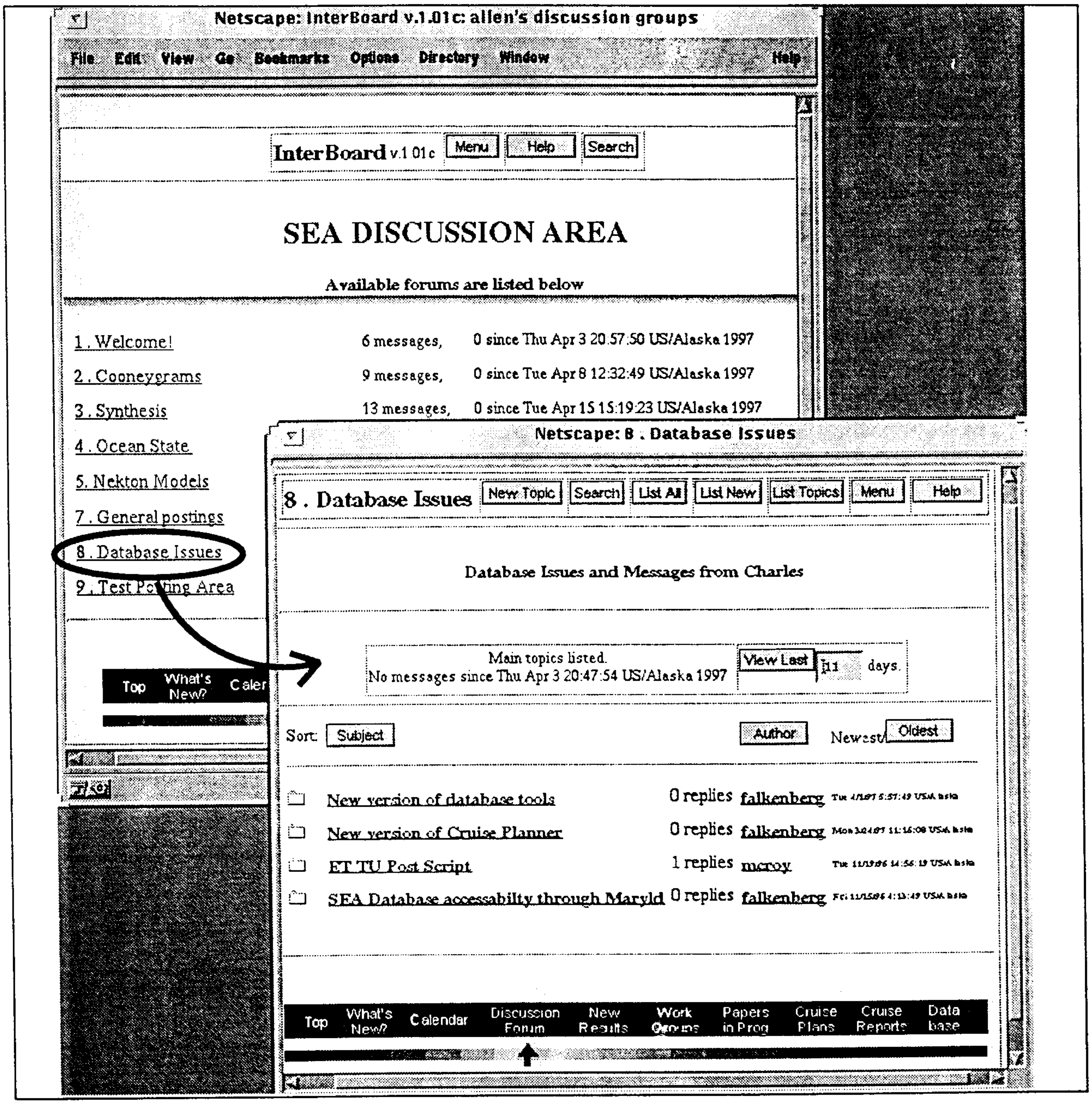


Figure 6: The SEA Discussion Area. The opening menu lists available forums and indicates the number of messages posted since this user's last visit. Entering any forum brings up a display of messages within the forum. Messages can be sorted by subject, author or date and are searchable on subject, author, and content.

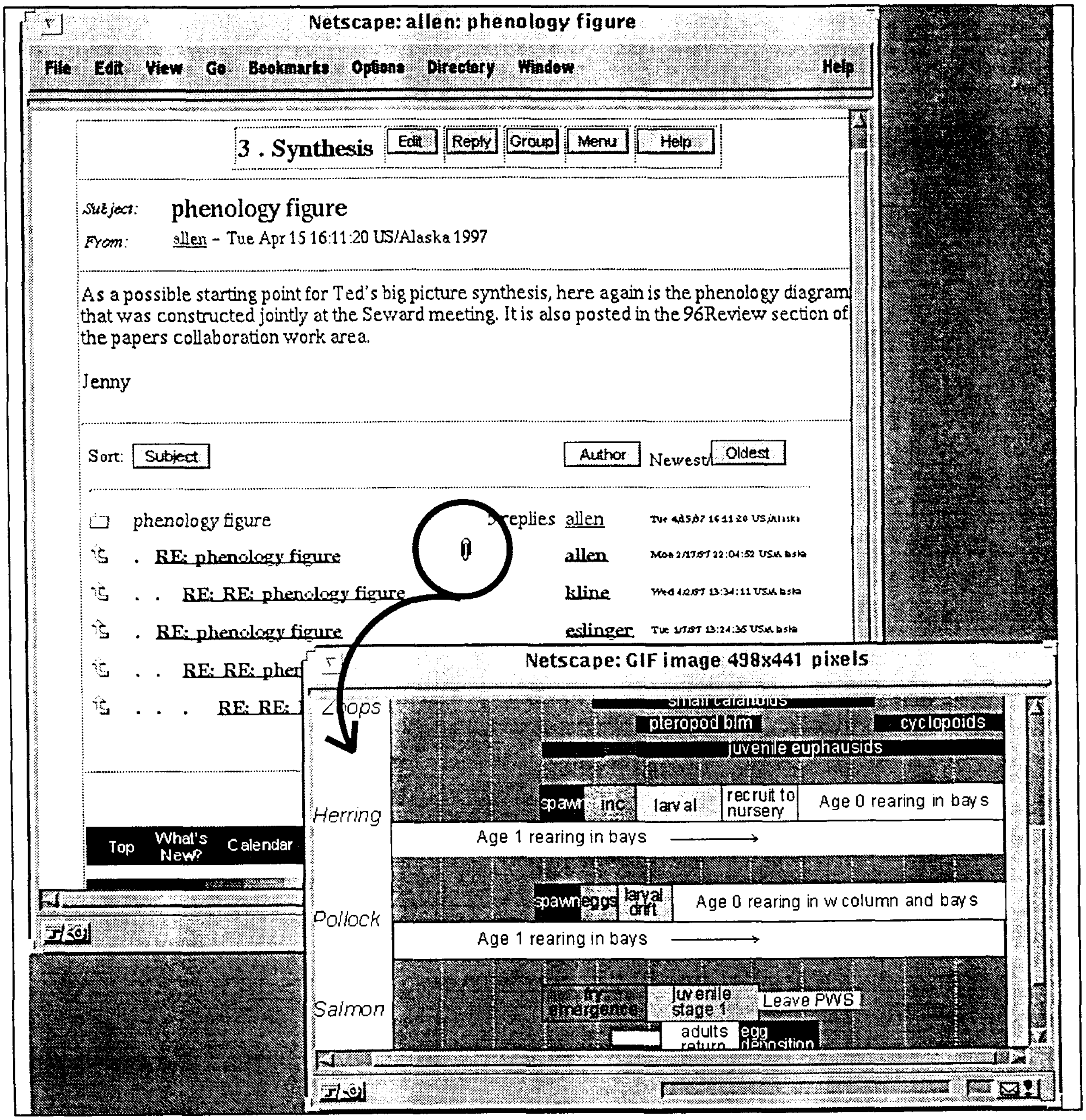


Figure 7: Example of an individual message posted to the discussion area. Below the header and message text is a clickable tree layout indicating the context of this message and its replies. The (clickable) paperclip symbol indicates an attachment to the message, in this case a figure (lower panel) which is the subject of the discussion thread. Buttons at the top of this screen allow the author of the message to edit it, and other users to post replies.

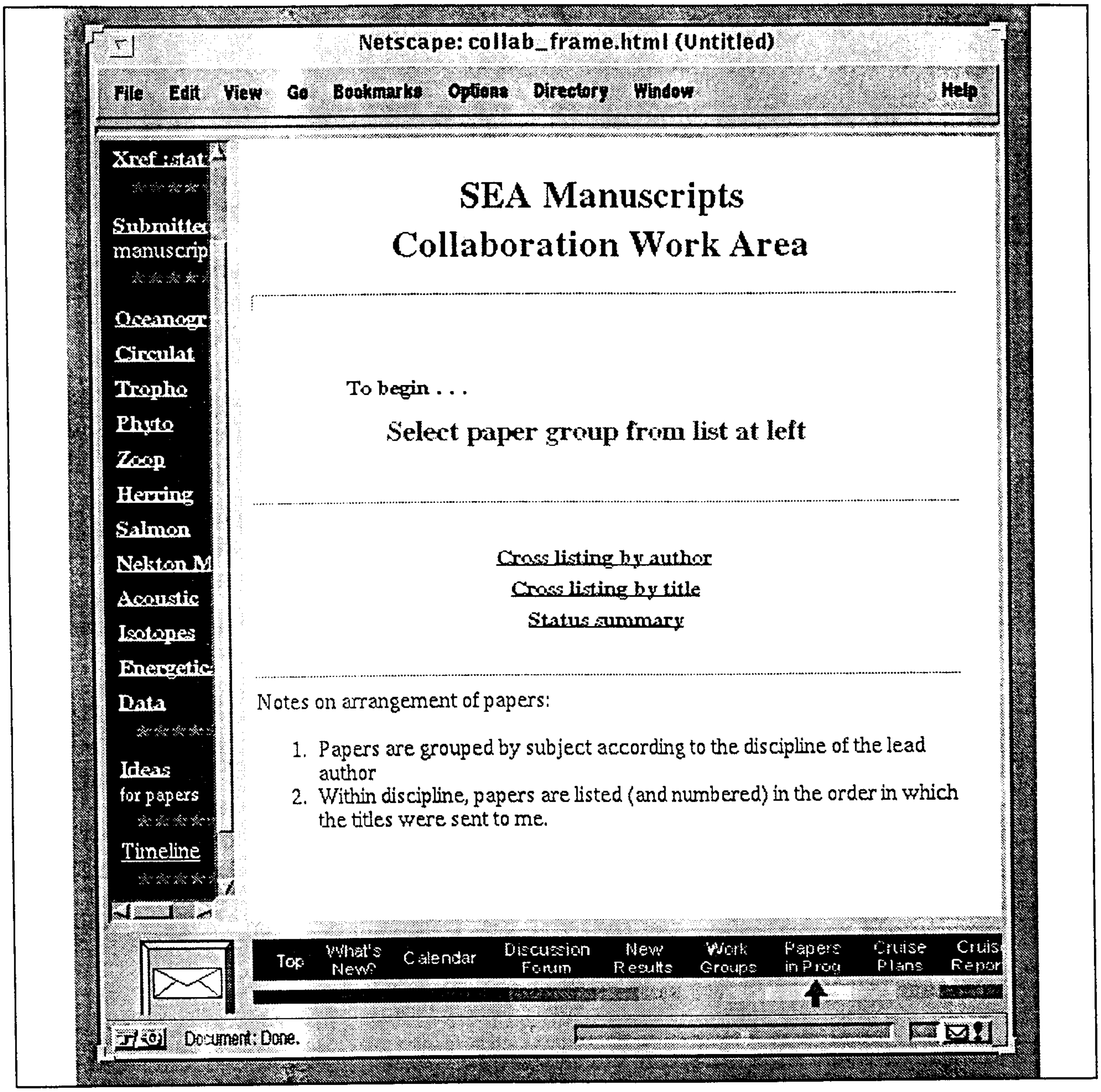


Figure 8. The opening page of the SEA Papers Collaboration Work Area. The left hand frame serves as a subject index and allows rapid navigation between subject groups.

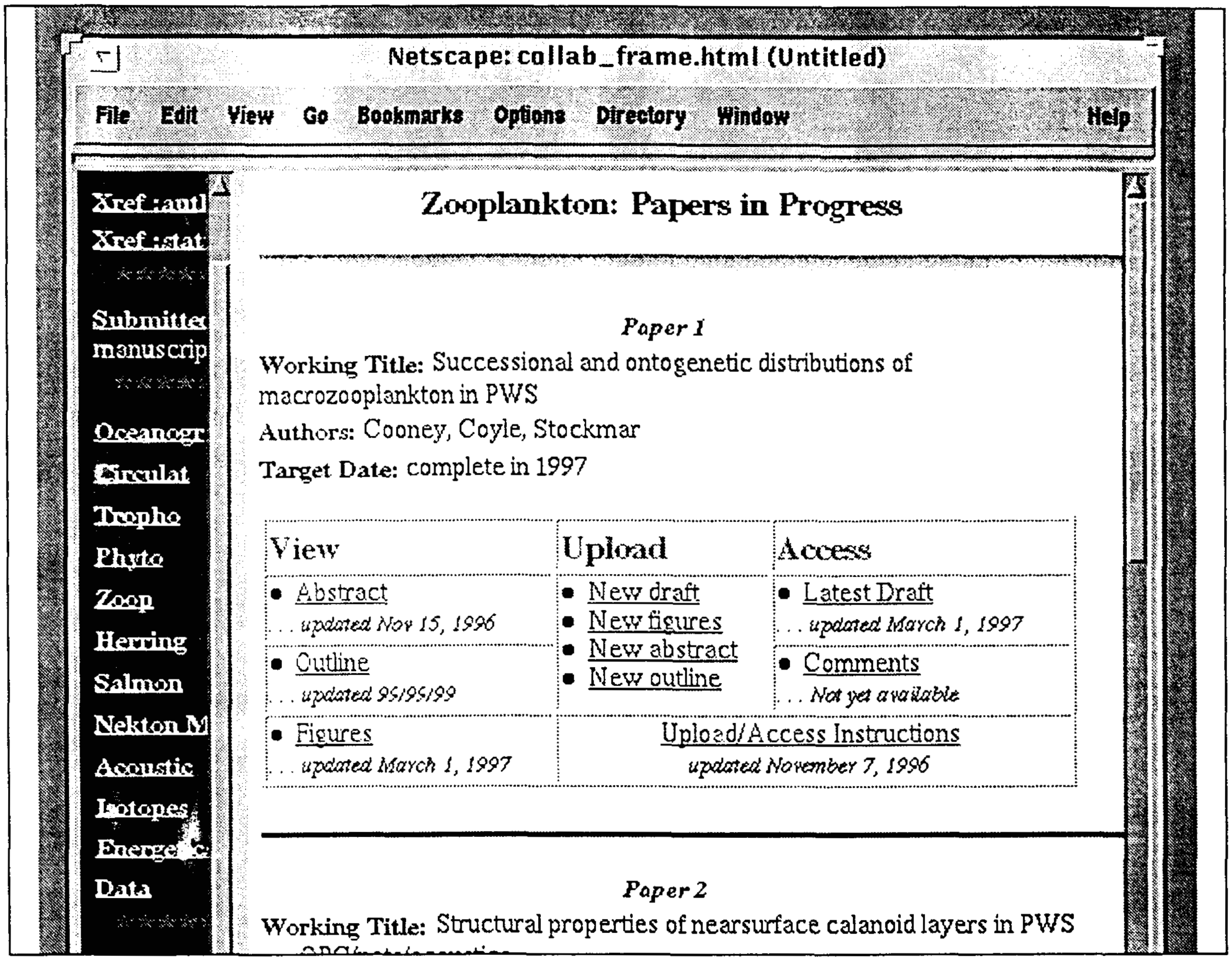


Figure 9: The individual panel of tools set up for each paper in the papers collaboration work area. Choices here allow the user to view the paper's abstract, outline or figures; upload new versions of the manuscript in any format; view and/or retrieve previously uploaded versions; and access discussion dialog relating to the paper.

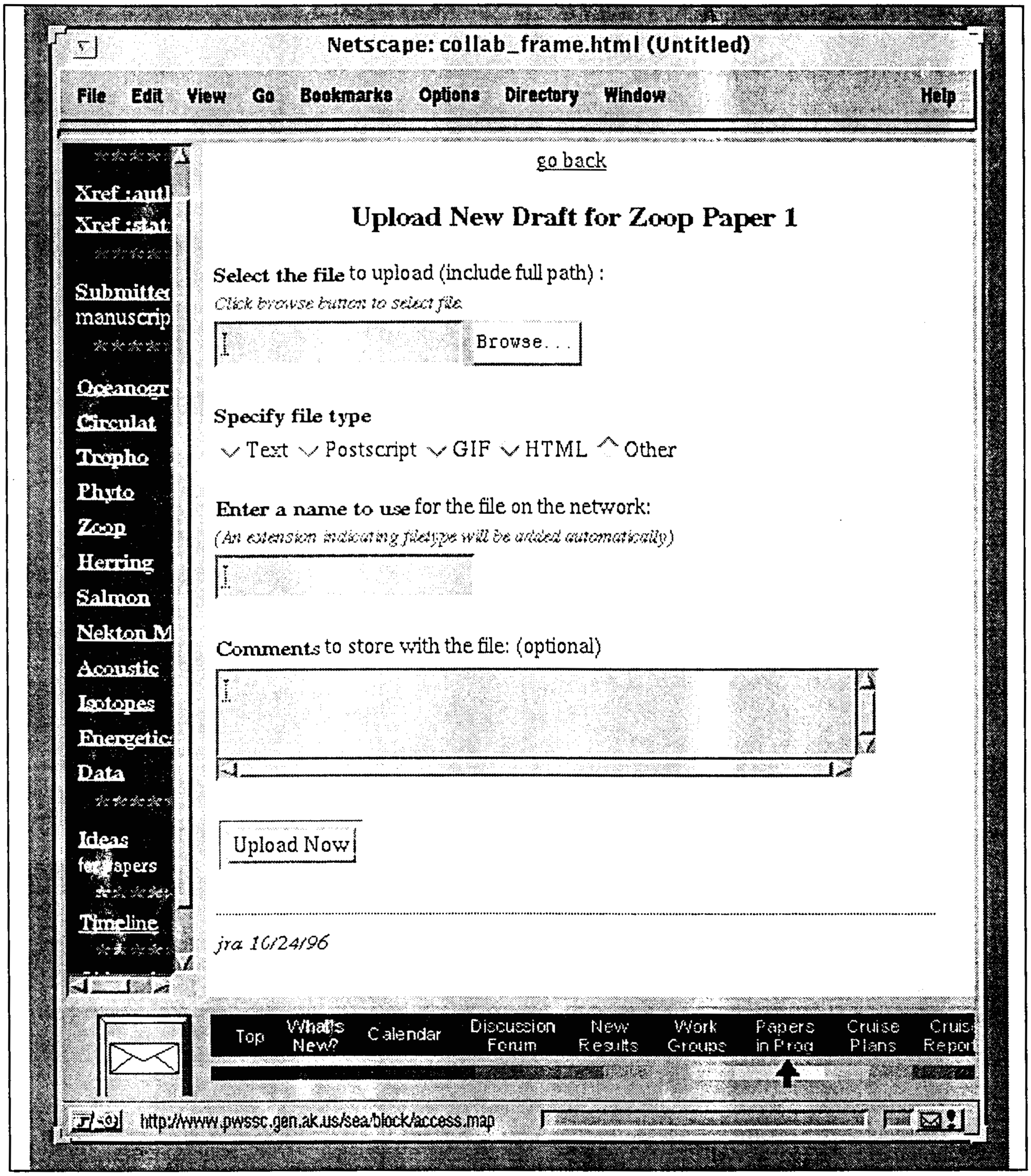


Figure 10: Interface to the file upload utility. The browse button activates a platform-appropriate file selection widget. Additional notes typed or pasted into the comments box are saved as a companion file, allowing any meta-information desired by the user to accompany the uploaded file.

Appendix 3

On the Development of a Three-Dimensional Circulation Model for Prince William Sound, Alaska

to appear in

Continental Shelf Research

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On the Development of a Three-dimensional Circulation Model
for Prince William Sound, Alaska

which is to appear in

Continental Shelf Research

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On the Implementation of A Three-Dimensional Circulation Model for Prince William Sound, Alaska

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(Submitted to **Continental Shelf Research**, December 1996; Revised May 1997)

Abstract

The POM (Princeton Ocean Model), a three-dimensional, primitive equation ocean circulation model, is applied to Prince William Sound (the Sound or PWS), Alaska. A 3-D concentration equation for passive tracers is added to POM to explore transport pathways and rates. The 3-D structures of the current, temperature, salinity, density, and concentration are examined for realistic bottom topography, typical Alaskan coastal water inflow/outflow, and wind forcing. Based on the observational evidence and ecological concerns, the "lake/river hypothesis" (i.e., the effect of weak versus strong throughflow) is explored to determine the importance of its influence on the circulation and transport patterns. Strong inflow through Hinchinbrook Entrance (river-like case) is crucial to the vigorous cyclonic circulation in the Sound, while with a weak inflow (lake-like case), the circulation in the Sound is much weaker and decoupled from offshore influences. Mesoscale eddies are induced in the deep basins that have not yet been studied observationally. The anomalous advection of buoyant (relatively warm and fresh) water and high concentration coastal water into the Sound significantly influences the circulation pattern and environmental conditions inside the Sound. Typical winter and summer wind forcing generate characteristic surface circulation patterns and are important to the transport of passive tracers.

1. Introduction

Prince William Sound (the Sound or PWS) is a combination of multiple basins, fjords, channels, islands, inlets and estuaries along the coast of Alaska (Fig. 1). Its area, including estuaries and arms, is approximately 120x120 km (about 70% covered by water) with an average depth of about 190m.

The observational studies conducted before 1989 are described below. Because North America's largest oil spill by T/V Exxon Valdez on 24 March 1989 seriously impacted the ecosystem in the Sound and the adjacent downstream waters, extensive observational programs have been carried out since then. The SEA (Sound Ecosystem Assessment) Program is one of these major efforts. This multidisciplinary project started in 1994 with major focus on salmon, halibut, herring, plankton ecology, and physical oceanography. The physical oceanography component consists of a field program and the numerical model to be described here. This paper presents numerical simulations of PWS circulation to help understand the dynamical mechanisms, to depict typical flow regimes, and to set the stage for simulations with more comprehensive (e.g., seasonal heating/cooling and runoff) and realistic (seasonal and synoptic) wind forcing.

The water exchange between the Sound and the coastal Gulf of Alaska (GOA) strongly influences the circulation pattern and biomass distribution. The exchange of the waters inside and outside the Sound through Hinchinbrook Entrance and Montague Strait is an important factor influencing the PWS circulation and water properties (T, S, and other variables) (Schmidt, 1977). The water exchange depends on synoptic scale atmospheric forcing and the seasonal variation and interannual variability of the large-scale Aleutian sea-level pressure (Royer, 1988). There is low (high) pressure center during the winter (summer), indicating that westward (eastward) winds prevail in the winter (summer) season. The autumn and spring seasons are transitional. During winter, onshore surface Ekman transport dominates, producing coastal downwelling along the Alaskan coast offshore of PWS, while during summer, offshore surface Ekman transport dominates, producing coastal upwelling. The coastal upwelling and downwelling influence the water exchange between GOA and PWS. However, the local winds must also be important in driving the circulation of the Sound and their influence will be examined here.

The spatial scale of the Sound is barely large enough for a recirculation to develop because the baroclinic Rossby radius of deformation is about 5km (50km) in the winter (summer) season (Niebauer et al., 1994). Based on data from two moored current meters (one located in Hinchinbrook Entrance and the other in Montague Strait, Fig. 1) and from an ADCP (acoustic Doppler current profiler), Niebauer et al. (1994) examined the transport through the two openings and the baroclinic current. (Their observed transport will be used for the boundary condition in our model). Because the barotropic component was removed by a differencing between the upper and lower level velocity values, the resultant cyclonic circulation pattern obtained by Niebauer et al. (1994) only reflected the baroclinic current. Thus, it is necessary to understand the general circulation (both baroclinic and barotropic components) pattern in the Sound using a 3-D model to interpret the on-going field studies.

PWS is very rich in the production of salmon, halibut, herring, and other fish species. Its economic potential strongly depends on how well the fishcatch can be managed and how well the pollution can be minimized in the presence of a major oil tanker route. Naturally, understanding of the circulation patterns is essential to understanding PWS ecology and environmental risks (Royer et al., 1990). Thus, this study will offer, for the first time, a 3-D view of the PWS circulation, as well as the advective mechanisms for dispersal of passive tracers.

Based on the subsurface drogued (about 40m deep) Lagrangian trajectory observations conducted since 1973 in the Sound (Royer et al., 1979) and along the Alaskan coast (Royer, 1975), the Alaskan Coastal Current (ACC) usually intrudes into the Sound from Hinchinbrook Entrance and drives the basin-scale cyclonic circulation. However, there are strong modulations due to synoptic scale, seasonal, and interannual variability.

This modeling study is part of the Sound Ecosystem Assessment (SEA) Program that involves observational and modeling studies of several trophic levels as well as the physical regime. The SEA Program is build, in part, to test the "river/lake" hypothesis, i.e., that there is large variability in the PWS ecosystem associated with the regime shifts due to the occurrence of a strong throughflow from the ACC (river) or a weak (lake) throughflow.

The purpose of this study is to 1) implement a 3-D numerical model for simulating the PWS circulation pattern under different atmospheric forcing and coastal inflow/outflow conditions; 2) examine the river/lake hypothesis which is essential for understanding the ecosystem variability of the Sound; 3) study wind-generated circulation under typical winter and summer wind forcing; and 4) develop a 3-D concentration model linked to the 3-D ocean model for examining the transport processes in the Sound. Oceanic tidal motion (which has current speeds of order of the throughflow currents treated here and hence, probably influence the mean circulation), seasonal heating/cooling and evaporation/precipitation, and local freshwater runoff are important topics in the Sound which will be addressed in separate studies.

Section 2 summarizes the observational background. Section 3 describes the 3-D numerical model and the passive tracer transport model, plus the model configuration, model parameters, initial and boundary conditions, and forcing. Section 4 presents the simulation results: general circulation, wind-driven circulation, mesoscale features, and passive tracer dispersal. Finally, section 5 summarizes the results and outlines the future effort.

2. Observational Background

The upper layer general circulation pattern is known to be cyclonic with an amplitude of 0.2 to 0.3 ms^{-1} due to the inflow from Hinchinbrook Entrance. In July 1976, three satellite-tracked, buoys (drogued at 40m) were deployed in GOA (Royer et al., 1979). The summer drifter tracks followed the ACC along the Alaskan coast and entered the Sound through Hinchinbrook Entrance. The drifters travelled through the Sound in a cyclonic loop. Generally speaking, the ACC advects fresher and warmer coastal water into the Sound in summer when there is inflow to the Sound, depending on coastal water properties (Schmidt, 1977; Salmon et al., 1996). Based on several ADCP cruises, dynamic height charts, and current meter moorings, Niebauer et al. (1994) found that in summer (August and September) 1978, the ACC entered the Sound through Hinchinbrook Entrance and exited from Montague Strait (Fig. 7 of Niebauer et al. 1994). The throughflow dominates the upper layer circulation pattern, which is also called the river-like regime, and a cyclonic gyre occurred in September 1978. In contrast, the intermediate and deep circulations have not been observed.

3. Description and Implementation of the Model

A version of the Princeton Ocean Model (POM, Blumberg and Mellor 1987), which has been successfully applied to the circulation of Hudson Bay (Wang et al., 1994), is utilized. It is based on the primitive equations (that include hydrostatic and Boussinesq approximations) and has the following features: (1) horizontal curvilinear coordinates (not used in PWS); (2) an Arakawa C grid; (3) sigma (terrain-following) coordinates in the vertical with realistic bottom topography; (4) a free surface; (5) a level 2.5 turbulence closure model for the vertical viscosity and diffusivity (Mellor and Yamada, 1982); (6) a mean flow shear parameterization for horizontal viscosity and diffusivity (Smagorinsky, 1963); (7) a semi-implicit scheme for the shallow water equations (Blumberg 1991; Wang et al. 1994); and (8) a predictor-corrector scheme for the time integration to avoid inertial instability (Wang and Ikeda, 1995, 1996, 1997a).

To simulate the transport of passive tracers (pollutants, biological particles, chemical substances, etc.), the following 3-D concentration transport model has been added to POM:

$$\frac{\partial C}{\partial t} + L(C) = \frac{\partial}{\partial z}\left(K_H \frac{\partial C}{\partial z}\right) + F_C - T_D C + Q_{source} - Q_{sink}. \tag{1}$$

where C is the concentration of the passive tracer, T_D is the decay time scale for C, $L(C)=\partial(uC)/\partial x + \partial(vC)/\partial y + \partial(wC)/\partial z$, K_H is the vertical diffusivity calculated from the Mellor-Yamada level 2.5 turbulence closure model, and F_c is the horizontal diffusivity term (applied in sigma space, cf. Mellor and Blumberg (1985)) whose diffusivity coefficient is calculated from the Smagorinsky parameterization, defined similarly to the temperature and salinity diffusivity terms. Source and sink terms, Q_{source} and Q_{sink}, for the variables of interest (e.g., biological species, fish larvae, pollutants, etc.) can be readily added to the right hand side of (1)

The model domain includes the entire PWS with two open boundaries (Hinchinbrook Entrance and Montague Strait, Fig 1), allowing water exchange with the Alaskan coastal waters (Schmidt, 1977). The model grid spacing is 1.2 km, which is eddy-resolving because the internal

Rossby radius of deformation is about 5 km (Niebauer et al., 1994). There are 15 vertical sigma levels, with a relatively dense resolution in the upper 50m to resolve the upper mixed layer. The integration time step is 62.1 seconds which is about six times CFL (Courant-Friedrichs-Lewy) constraint because the semi-implicit scheme has been used for the shallow water equations (Wang et al. 1994).

According to the observations at Hinchinbrook Entrance (Niebauer et al., 1994), the coastal inflow varies seasonally: from 0 to 0.3 Sv (Sverdrup; 1 Sv=10^6 m^3s^{-1}). The outflow through Montague Strait is of the same order of magnitude, although the water volume in the Sound may increase or decrease in response to transient forcing. Hence, an inflow of 0.3 Sv was specified for the summer season (Niebauer et al., 1994) through Hinchinbrook Entrance, while a radiation boundary condition (with self-adjusted outflow of 0.3 Sv) was applied to Montague Strait.

The initial temperature and salinity fields used are based on typical early summer profiles (Fig. 2, solid) as observed at the central Sound in July 1991 (Salmon et al. 1996) and spring profiles (Fig. 2, dashed) as observed at the same location in March 1995, and are specified to be horizontally uniform. The model was spun-up from these initial conditions for 30 days to reach a dynamical steady state, i.e., when the total kinetic energy and eddy kinetic energy have been constant for about 10 days. The restart file was saved for use as the initial condition for the next prognostic runs. The surface heat and salt fluxes were specified to be zero. The vertical viscosity is determined from the Mellor-Yamada 2.5 turbulence closure model with a background viscosity of 10^{-5} m^2s^{-1} (i.e., the value used if the calculated viscosity is smaller than this minimum value). The horizontal viscosity is determined from the Smagorinsky parameterization with the non-dimensional coefficient, C or HORCON equal to 0.2; the typical computed horizontal viscosity is about 5 to 10 m^2s^{-1}.

4. Simulation Results

4.1 General Circulation Pattern with Throughflow (Control Run, No Wind-forcing Case)

The vertical distribution of the specified inflow decreases linearly from the surface to 150m depth, and it is horizontally uniform. There is no wind-forcing in this case. The inflow temperature and salinity profiles were kept constant and equal to the initial (summer) interior profiles that were specified horizontal uniform, i.e., the zero horizontal gradient condition was used; thus, there were no defeasive and advective heat and salt fluxes into PWS.

The flow pattern at 3m depth (for the summer stratification) on day 33 (beginning from the restart fields) (Fig. 3a) indicates a coastal inflow entering the Sound through Hinchinbrook Entrance and exiting through Montague Strait, forming a cyclonically looping throughflow. The throughflow has three branches, the primary one between Knight Island and Montague Island, one through the channel between Knight Island and Naked Island (NI), and the other turning to the northeast to form a persistent cyclonic gyre in the northern Sound. (The term "gyre" is used here to distinguish between such persistent features and transient mesoscale eddies.) These two secondary branches join in the northwestern Sound and pass through Knight Island Passage (to the west of Knight Island).

At 100m (intermediate layer, Fig. 3b), the basin-scale pattern is cyclonic, while there are several mesoscale gyres: for example, the largest ones are near Hinchinbrook Entrance (cyclonic) and in the central (anticyclonic), north-central (cyclonic), and northwestern Sound (cyclonic).

At both 3m and 100m, the outflow is largely channelled through Knight Island Passage to Montague Strait.

At 300m depth (deep layer), there are several smallscale eddies constrained to the narrow deep basins (Fig. 3c). The positions of the eddy centers are displaced from those at 100m (Fig. 3b), indicating strong baroclinicity (Fig. 4a versus Fig. 4b) and tilted axis between 100m and 300m depths (Wang and Ikeda, 1997b). Obviously, some of these eddies do not exist at 3m depth.

The vertical structure of the meridional (V) and zonal (U) velocity is demonstrated with zonal and meridional transects. Along the zonal (60.4N) transect (Fig. 4a), the meridional velocity is northward (up to 30 cm s^{-1}), flowing along the eastern coast, while the southward current (up to 15 cm s^{-1}) flows along the eastern coast of Knight Island. In Knight Island Passage, a southward flow (up to 10 to 15 cm s^{-1}) is confined to the upper 200m layer, while below there is a weak northward flow, indicating a baroclinic structure. Along the meridional (147.2W) transect (Fig. 4b), the zonal velocity distribution is dominated by three gyres, the primary throughflow and other two (Fig. 3b). The maximum velocity cores of the primary throughflow and the gyre in the northern Sound have vertical tilts, indicating a moderate vertical shear of the horizontal velocity (Wang and Ikeda 1996).

The vertical structures of density along the same meridional and zonal transects (Fig. 5) indicate typical summer stratification. However, along the zonal (60.4N) transect (Fig. 5a) there is a density dome in the central Sound; along the meridional transect (Fig. 5b), there is a density dome adjacent to Montague Island, both consistent with the cyclonic throughflow circulation. Along the meridional (147.2W) transect (Fig. 5b), there is a density dome in the lower layer between 200m and 300m, indicating a cyclonic eddy (Fig. 4b).

A parallel experiment to the summer stratification (Fig. 2, solid) was conducted using the spring stratification (Fig. 2, dashed). The 3m flow pattern (Fig. 3d) indicates the absence of the recirculations and gyres to the north of Montague Island, in the central Sound, and to the northeast of Naked Island. The primary throughflow jet and one secondary branch towards north from the east of Naked Island are strong, while the branch through the channel between Knight Island and Naked Island is relatively weak. Thus, the flow pattern (Fig. 3d) is quite different from that under the strong stratification (Fig. 3a). The 100m intermediate flow pattern (not shown) is quite similar to the surface one. However, in the 300m deep layer, there are smallscale eddies (not shown) confined in the narrow basins, indicating baroclinicity in the deep layer flow pattern.

The inflow to the Sound has seasonal and interannual variability (Niebauer et al. 1994), which needs further field studies and numerical simulations to define better the variations. As a first step in this direction, the influence on the PWS circulation pattern of larger and smaller inflows through Hinchinbrook Entrance are examined. In the following experiments, the inflow was doubled (0.6 Sv) and halved (0.15 Sv) relative to the control run value (0.3 Sv). Overall, the resulting circulation patterns are similar but the separation of the inflow differs (Fig. 6). However, the basic throughflow pattern (i.e., inflow from Hinchinbrook Entrance and outflow through Montague Strait), the primary branch and the two secondary branches, is similar.

For the doubled-inflow case (Fig. 6a), the main stream has two very strong separations southeast of Naked Island, one branch flowing northeast to form a cyclonic gyre plus a pair of anticyclonic/cyclonic gyres and the other branch flowing westward through the channel south of

Naked Island to form a cyclonic gyre northwest of Knight Island. For the halved-inflow case (Fig. 6b), the two branches near Naked Island are relatively weak, with an anticyclonic gyre in the central Sound and an anticyclonic gyre northwest of Knight Island, differing significantly from the doubled-inflow case.

Therefore, the circulation pattern in the Sound is significantly influenced by the magnitude of the inflow from Hinchinbrook Entrance, particularly in the northern and the central Sound. In the control run, the primary throughflow branch penetrates to 60.55N, while the doubled-inflow case penetrates to 60.65N, corresponding to an extreme river-like regime, and the halved-inflow case penetrates to only 60.45N, corresponding to a lake-like regime.

4.2 Buoyant Throughflow

To examine the inflow accompanied by the fresher Alaskan coastal water (i.e., buoyant throughflow), an inflow of 0.3 Sv (same as the control run) is specified at Hinchinbrook Entrance, together with a negative density flux (i.e., positive buoyancy) in the upper 40m layer (-1 kg m^{-3}, i.e., the density is 1 kg m^{-3} lower than the interior value) injected for four days, representing a coastal event on a synoptic time scale.

The advection of the fresh Alaskan coastal water is demonstrated (Fig. 7). At day 8, the fresh water of 22.9 kg m^{-3} is advected to the central region of the throughflow. Along the coasts of the Sound, there is higher density water (higher than 23 kg m^{-3}). Thus, there are two regimes in the density pattern. At day 8, a low density filament east of Naked Island is due to the advection. At days 8 and 33, the low density water of 22.9 kg m^{-3} occupies Montague Strait and a filament has been advected to the northeast of Naked Island. The two distinct regimes, lower (fresher) density in Montague Strait and higher density along the coasts, are the consequence of the advection of fresher Alaskan coastal water.

4.3 Wind-Driven Circulation

As mentioned earlier, monthly averaged wind regimes over the Sound vary seasonally with changes in the position and strength of the Aleutian Low in winter and the North Pacific High in summer. Eastward (i.e., winds blowing from the west) winds (i.e., coastal upwelling-favorable winds) and northward winds tend to occur during summer when the North Pacific High strengthens, while strong westward and southwestward winds (i.e., coastal downwelling-favorable winds) tend to occur during winter when the Aleutian Low strengthens. Thus, the surface current fields under forcing from eastward, southward, westward, and northward winds of 7 ms^{-1} (the windstress is about 0.1 Newton m^{-2}=0.1 Pa=1 dyne cm^{-2}) are examined together with the same inflow as the control run.

To determine the steady-state response of the PWS circulation to wind forcing, the growth rate of eddy kinetic energy (EKE), following the approach of Wang and Ikeda (1996), is examined (Fig. 8). The EKE growth rate responds to the eastward wind at the inertial frequency in less than 4 days. The time scale to reach a steady state is about 4 to 5 days. Thus, the wind-generated circulation patterns are examined at day 4 in the following.

After applying westward wind for four days (Fig. 9a), the two secondary branches at 3m near Naked Island are stronger than those without wind forcing (Fig. 3a). In the eastern Sound, a coastal current is generated and flows along the northern coast, a strong branch of which flows northeastward and reaches the Valdez Arm due to Ekman transport. Along the northern coast, the alongshore current flows into Port Wells (i.e., near Whittier). The southwestward flow through Knight Island Passage is much weaker. By contrast, the flow pattern with eastward wind-forcing has a quite different pattern (Fig. 9b) compared to the westward wind-forcing, particularly away from the inflow jet. The surface current in the central, northern, and western Sound is southward due to Ekman flow. There are no branches near Naked Island. Consequently, the southward surface current through Knight Island Passage is much stronger than in the control run.

With northward wind-forcing, the eastward Ekman flow dominates the surface pattern and there is only one strong secondary branch near Naked Island that flows northeastward (Fig. 9c). This branch flows directly into the Valdez Arm. A strong eastern coastal current is also generated. In the northern Sound, there is a weak cyclonic gyre, similar to the control run. There is no southward flow through Knight Island Passage, similar to the westward wind-forcing case (Fig. 9a). With southward wind-forcing, the westward Ekman flow dominates the surface flow (Fig. 9d), while the jet flow is more or less the same as the control run (Fig. 3a). However, there is no cyclonic gyre north of Montague Island, and there is only one secondary branch from the jet that flows through the channel between Knight Island and Naked Island. The southward flow through Knight Island Passage is enhanced.

In summary, the PWS surface flow pattern is sensitive to the local wind forcing. The position of the throughflow jet displaces according to the wind direction and magnitude. The secondary branches separated from the primary jet to the south of Naked Island vary, depending on wind direction. Similarly, the southward and eastward (northward and westward) winds enhance (block) the southward flow through Knight Island Passage. Thus, the transient circulation in the Sound is an important factor in most regions away from the primary throughflow jet, in response to the synoptic wind forcing.

4.4 Passive Tracer Transport

Due to the Valdez Exxon oil spill event, the ocean pollution and ecological research has become a priority for the restoration of the ecosystem in the Sound. From a purely ecological point of view, the transport of offshore water and biota into and within the Sound needs to be examined.

In the following, five passive tracer transport experiments are conducted using the circulation patterns derived from the above section. The control run, for example, uses the 3-D current field with no wind-forcing, and the other runs use the 3-D current fields with wind-forcing from the four different directions. The concentration source was placed within the upper 40m at Hinchinbrook Entrance, representing a coastal pollutant or phytoplankton bloom intrusion into the Sound. After four days, the concentration source was cut off, and the passive tracers were tracked to investigate the movement and distribution in the Sound.

For the control run at 3m, the tracer (concentration, C, varying from 0 to 100) has been advected by the throughflow jet to Montague Strait on day 4 (Fig. 10a). Some of the tracer also passes through the channel between Knight Island and Naked Island. However, there is little advection through Knight Island Passage.

On day 8 (Fig. 10b), a tracer filament has been transported 25km to the northeast of Naked Island. By day 12, the north central Sound has been covered by the tracer, while most of the tracer has been removed from the southern Sound (Fig. 10c). By day 25 (not shown), although most of the tracer has been transported out of the domain, there are a few places with high concentration, such as the northern and western coasts of Montague Island (due to a cyclonic gyre), northeast of Naked Island (due to a cyclonic gyre), and northwest (due to very weak advection), and Knight Island Passage. By day 33 (Fig. 10d), almost all of the tracer along the throughflow has been transported out of the Sound; however, there are low concentration (around 10% of the source) zones, indicating the residence time in those zones under these conditions (throughflow and no wind) is much longer than one month. Thus, under river-like regime conditions, passive tracer from Alaskan coastal waters can reach the northern and northwestern Sound.

When the wind blows in different directions, the tracer distributions vary (Fig. 11) depending heavily on the different flow patterns, as discussed in the above section. For example, by day 4, the westward wind transports much of the tracer to the northeastern Sound (Fig. 11a), while eastward wind (Fig. 11b) transports much of the tracer to the south into Montague Strait. Similarly, the northward wind (Fig. 11c) transports the tracer to the eastern Sound and decreases the tracer advection into Montague Strait, while the southward wind (Fig. 11d) transports the tracer further into Montague Strait, and to the west through the channel between Knight Island and Naked Island.

To quantify how much of the tracer still resides in the Sound after an integration of one month, time series of volume averaged concentration (VAC) for the five cases are examined (Fig. 12). On day 4, of course, VAC reaches a maximum (2.1 or 2.2) for each case. On day 33, the control run (solid line) has a VAC of 0.9, which is about 43% of the source volume. Southward wind-forcing, which often occurs in winter, is most efficient in removing the tracer from the Sound. Similarly, eastward wind-forcing is the secondmost efficient compared to the other cases. The northward and westward winds increase the residence time in the Sound.

5. Concluding Remarks

POM has been applied to the Sound and some important dynamical factors influencing the circulation pattern have been demonstrated. The simulation results indicate that PWS-POM has produced basically correct circulation patterns under throughflow and wind-forcing. Vigorous mesoscale gyres are a prominent phenomenon and may be important for biomass distribution, because they influence the biomass concentration, residence time, and possibly abundance. Furthermore, different wind conditions change the residence time by changing the surface Ekman flow, the circulation pattern, and stratification. The present investigations are summarized as follows:

1) If the Alaskan Coastal Current enters the Sound, the throughflow jet dominates the basic circulation pattern. Two secondary branches separate south of Naked Island are due to topographic blocking. In the intermediate (100m) and deep (300m) layers, there are strong baroclinic mesoscale eddies and gyres. The strength of the separated branches depends strongly on the magnitude of the inflow;

2) There are two distinct density regimes if fresh Alaskan coastal water enters from Hinchinbrook Entrance. In Montague Strait, the fresher water dominates and differs from the dense water along the coasts of the Sound;

3) The other circulation pattern depends heavily on the wind direction. The areas most sensitive to wind forcing are those away from the throughflow jet, particularly in the eastern, central and northern Sound; and

4) The transport of a passive tracer released in the upper layer of Hinchinbrook Entrance, therefore, is largely controlled by the throughflow and determined by the surface circulation

pattern driven by the wind. Southward and eastward winds increase the removal rate of passive tracers from the Sound, while northward and westward winds decrease the removal rate. The residence times in these cases are much longer than one month, although the advection time scale of the throughflow jet is of the order of a few days.

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Figure Captions

Fig. 1. Bottom topography of Prince William Sound (depths in meters).

Fig. 2. The summer (solid lines) and spring (dashed) vertical temperature, salinity, and density distributions in the central Prince William Sound.

Fig. 3. The mean velocity fields under forcing of inflow/outflow of 0.3 Sv only at 3m (a), at 100m (b), at 300m (c) under summer stratification, and at 3m under spring stratification (d).

Fig. 4. The vertical distributions of meridional velocity (V) along the 60.4N west-to-east transect (upper panel) and of zonal velocity (U) along the 147.2W south-to-north transect (lower panel).

Fig. 5. The same as Fig. 4, except for density.

Fig. 6. Same as Fig. 3a, except under forcing of 0.6 Sv (a) and 0.15 Sv (b).

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Fig. 8. The series of eddy kinetic energy growth rate under constant eastward wind-forcing of 7 ms^{-1}.

Fig. 9. The same as Fig. 3a, except under forcing of wind of 7 ms^{-1} a) westward, b) eastward, c) northward, and d) southward.

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Fig. 12. The time series of volume averaged concentrations in Prince William Sound for the control run (no wind case, solid line), and for the wind forcing a) westward (denoted by E), b) eastward (denoted by W), c) northward (denoted by S), and d) southward (denoted by N).

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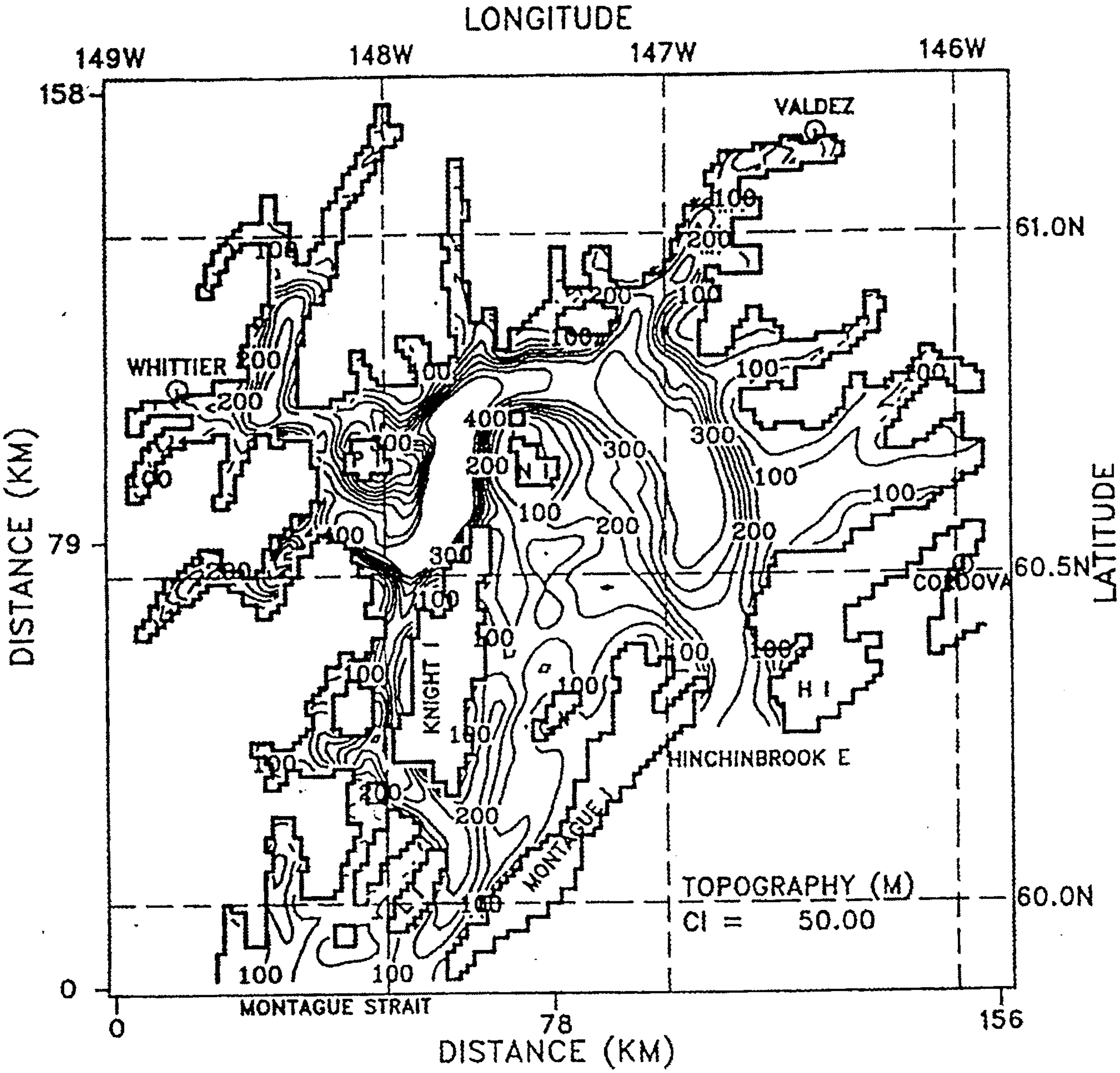

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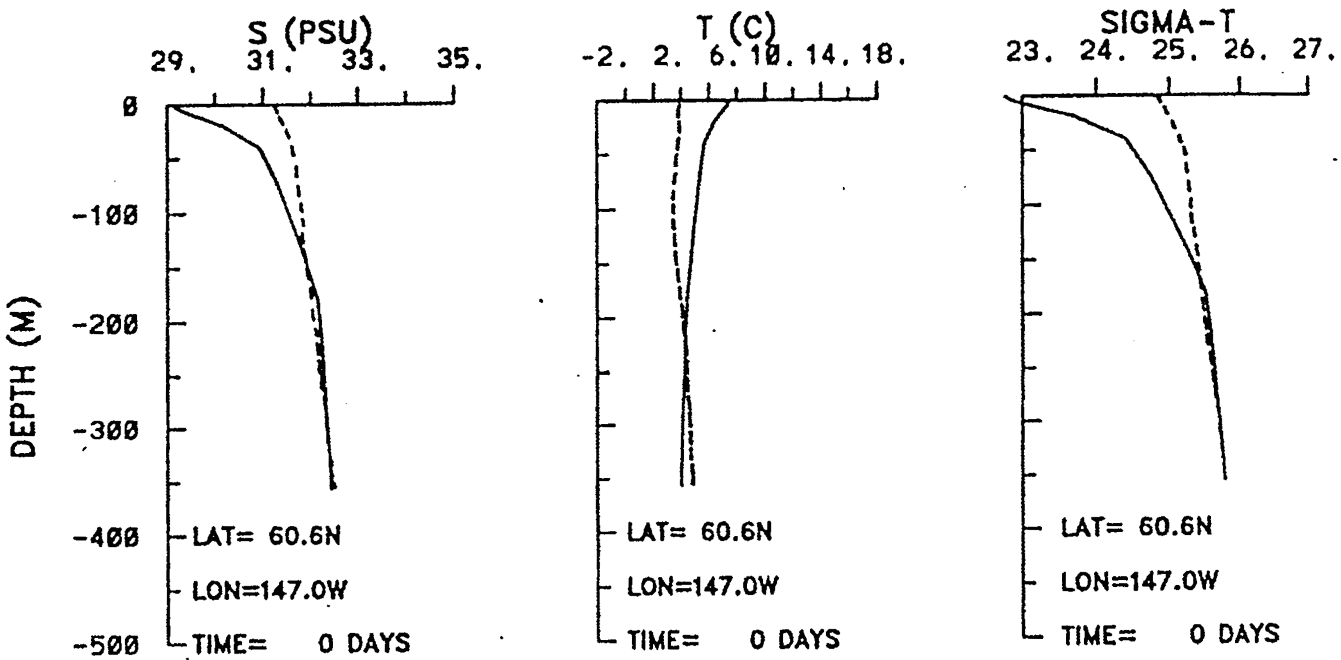

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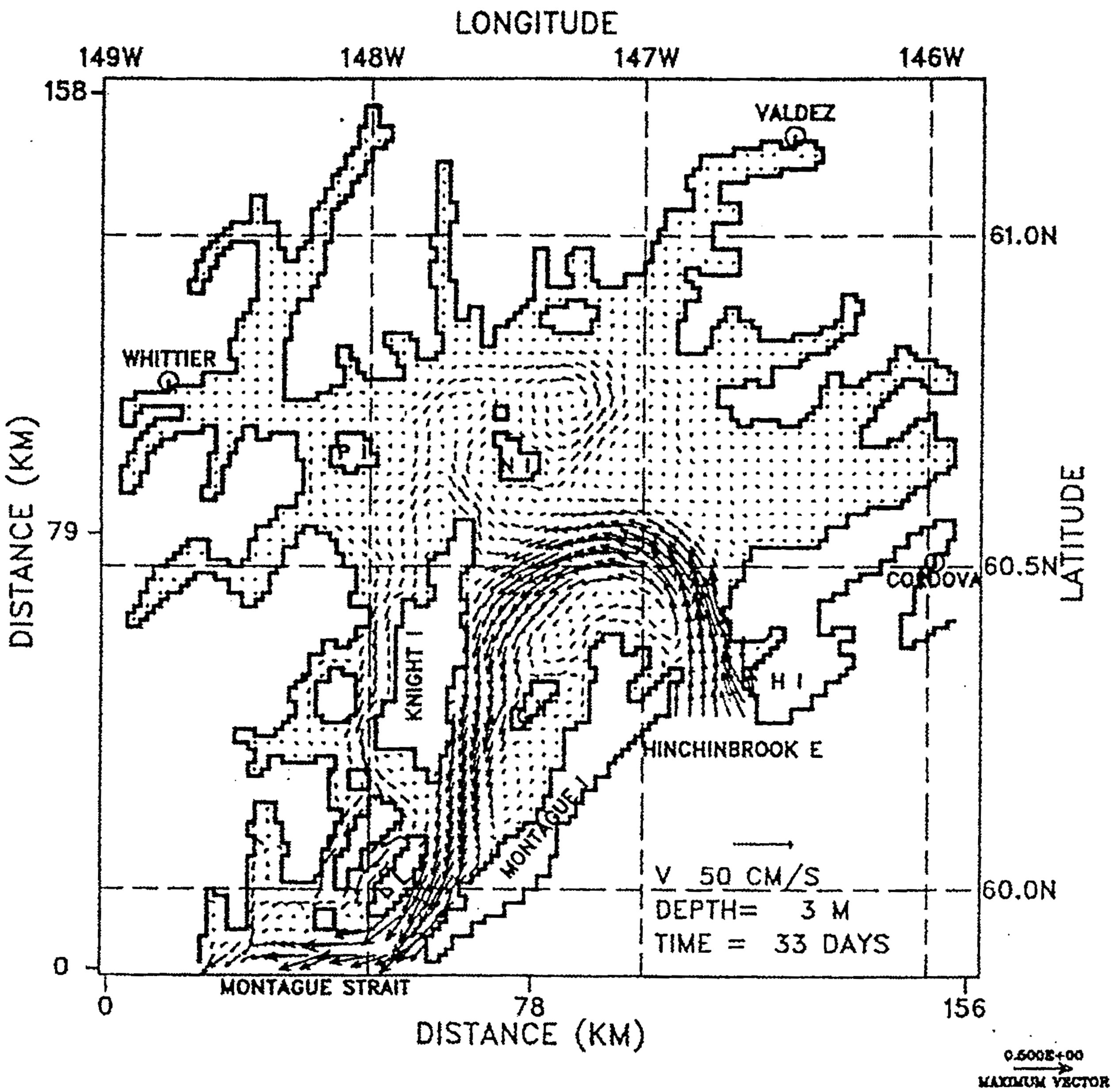

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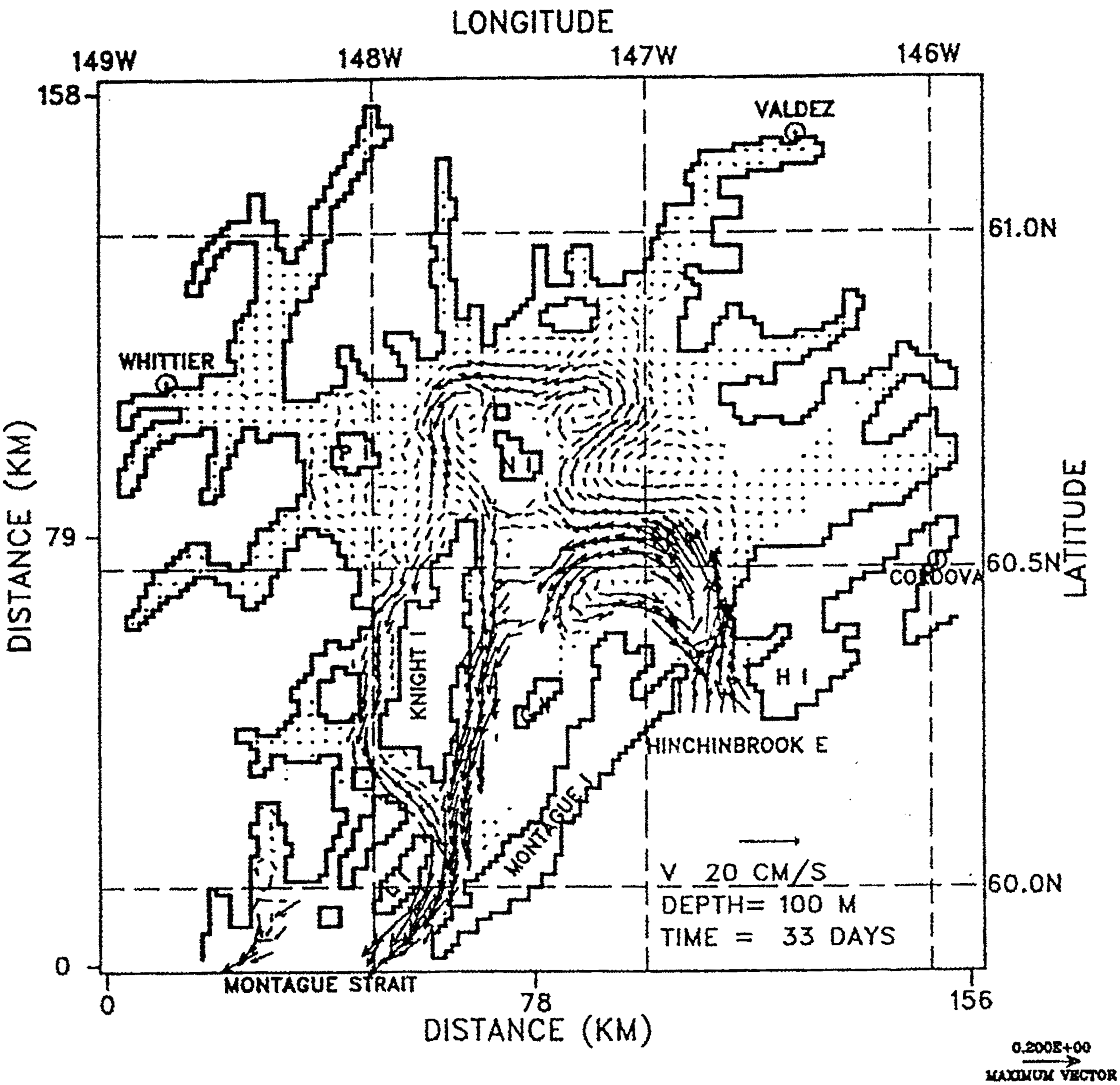

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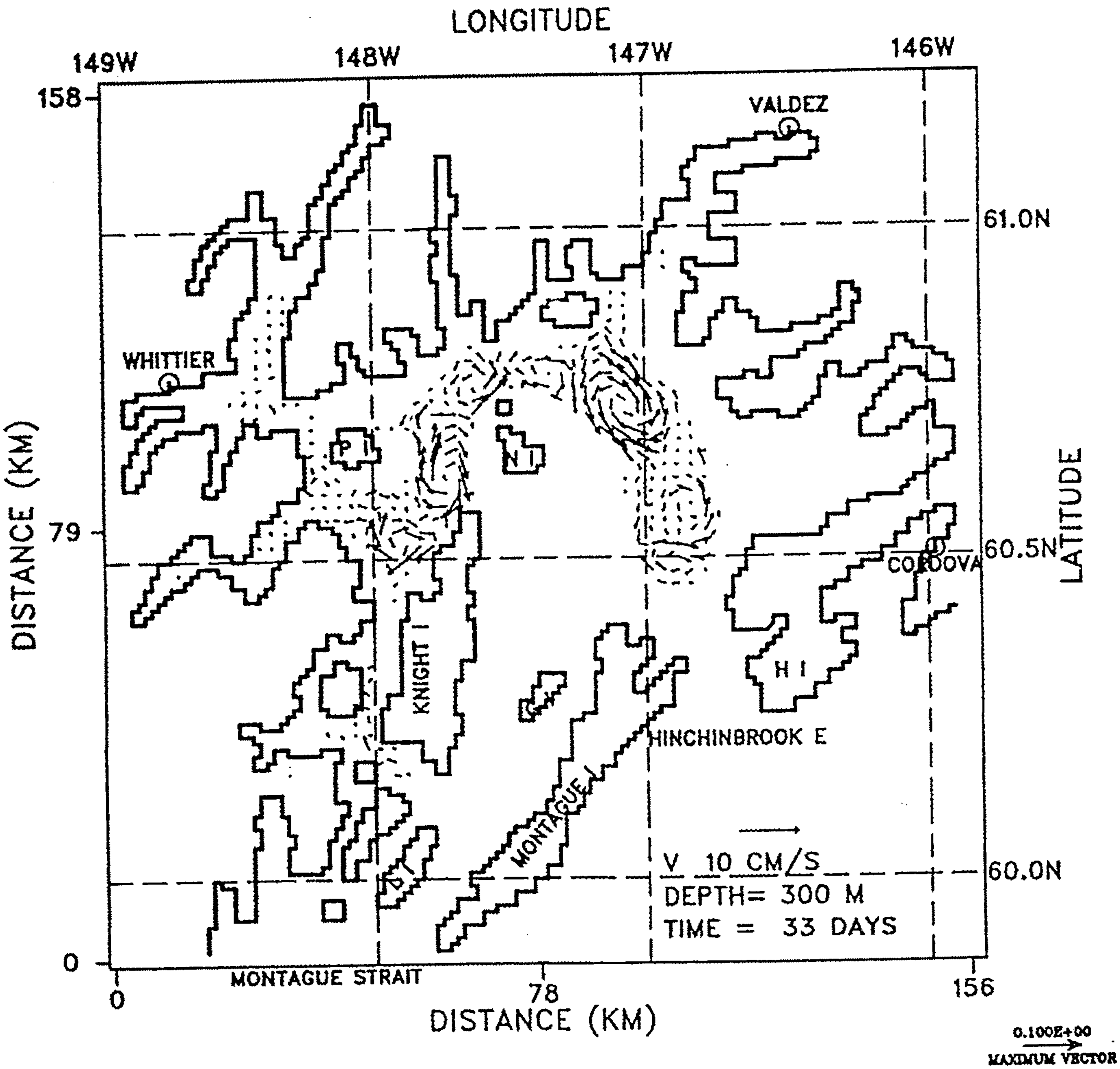
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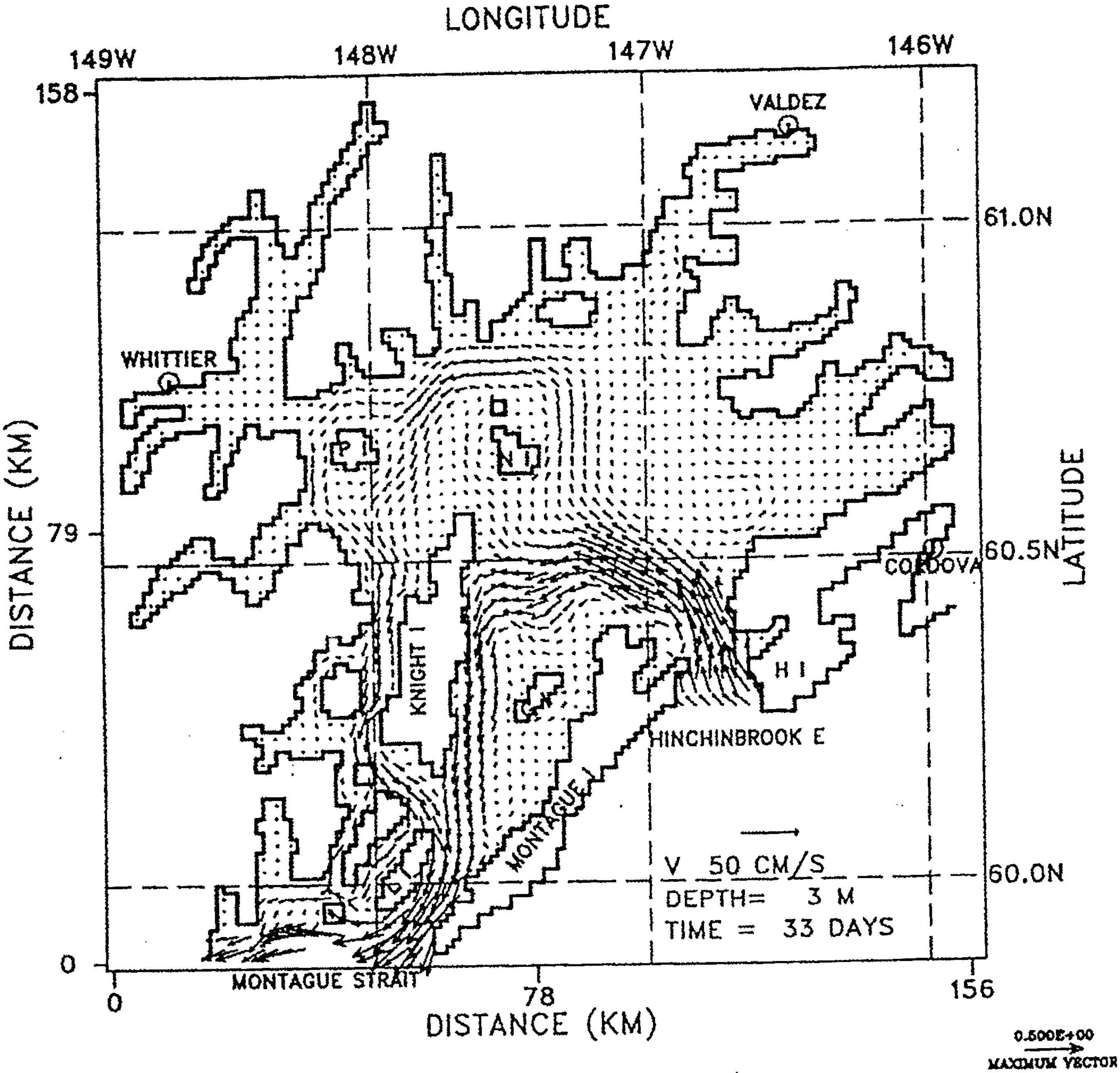

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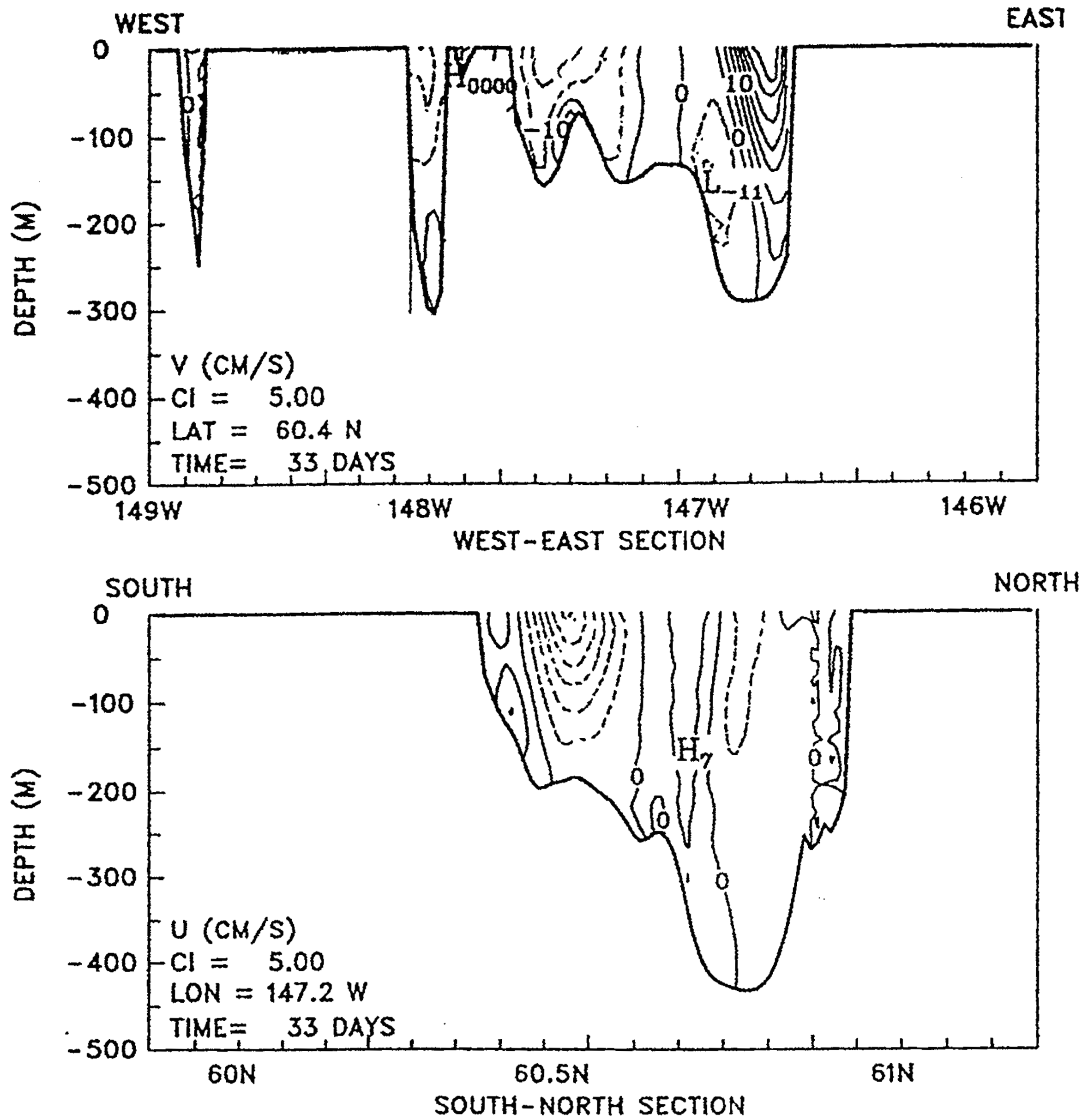

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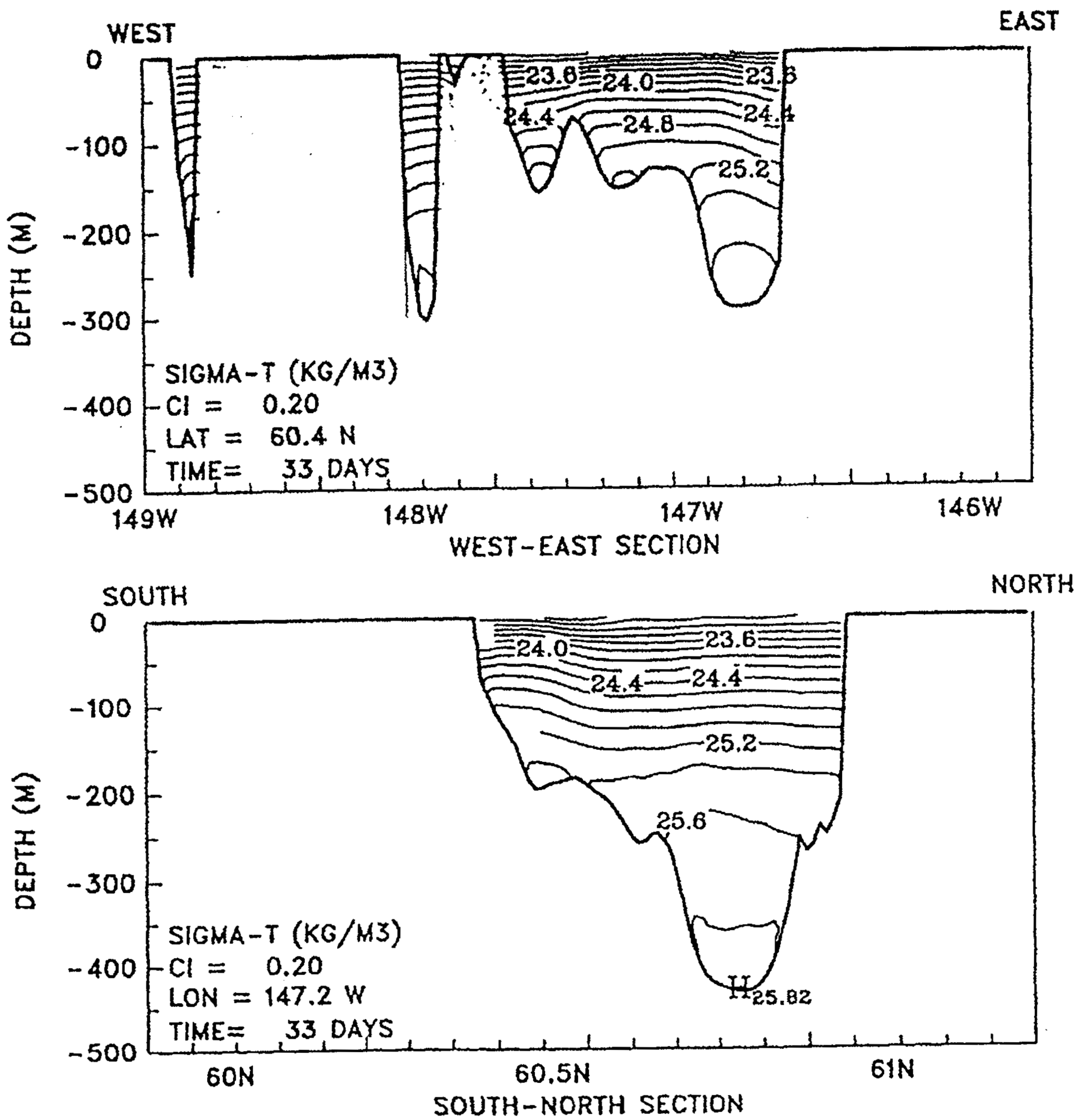

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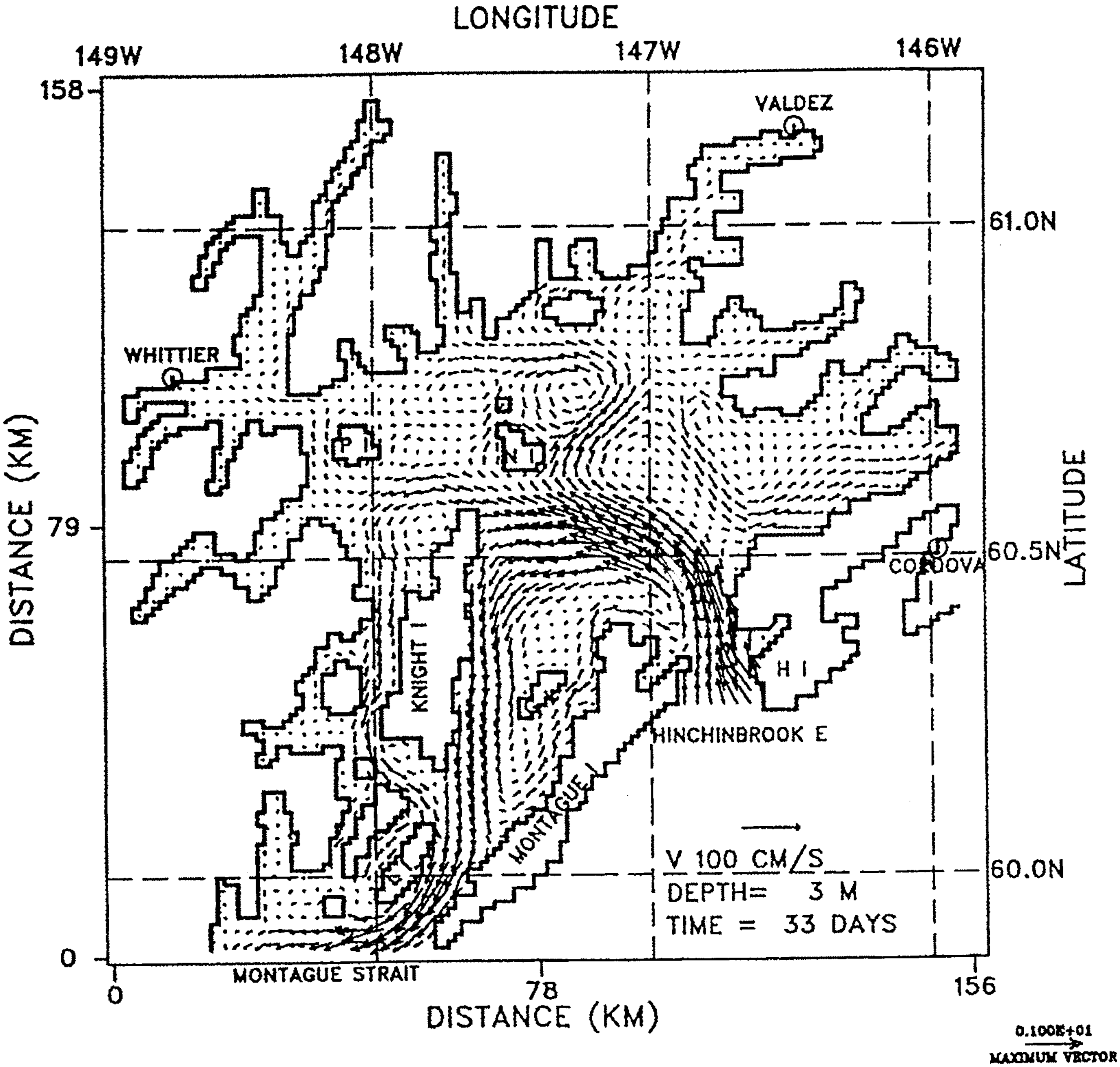

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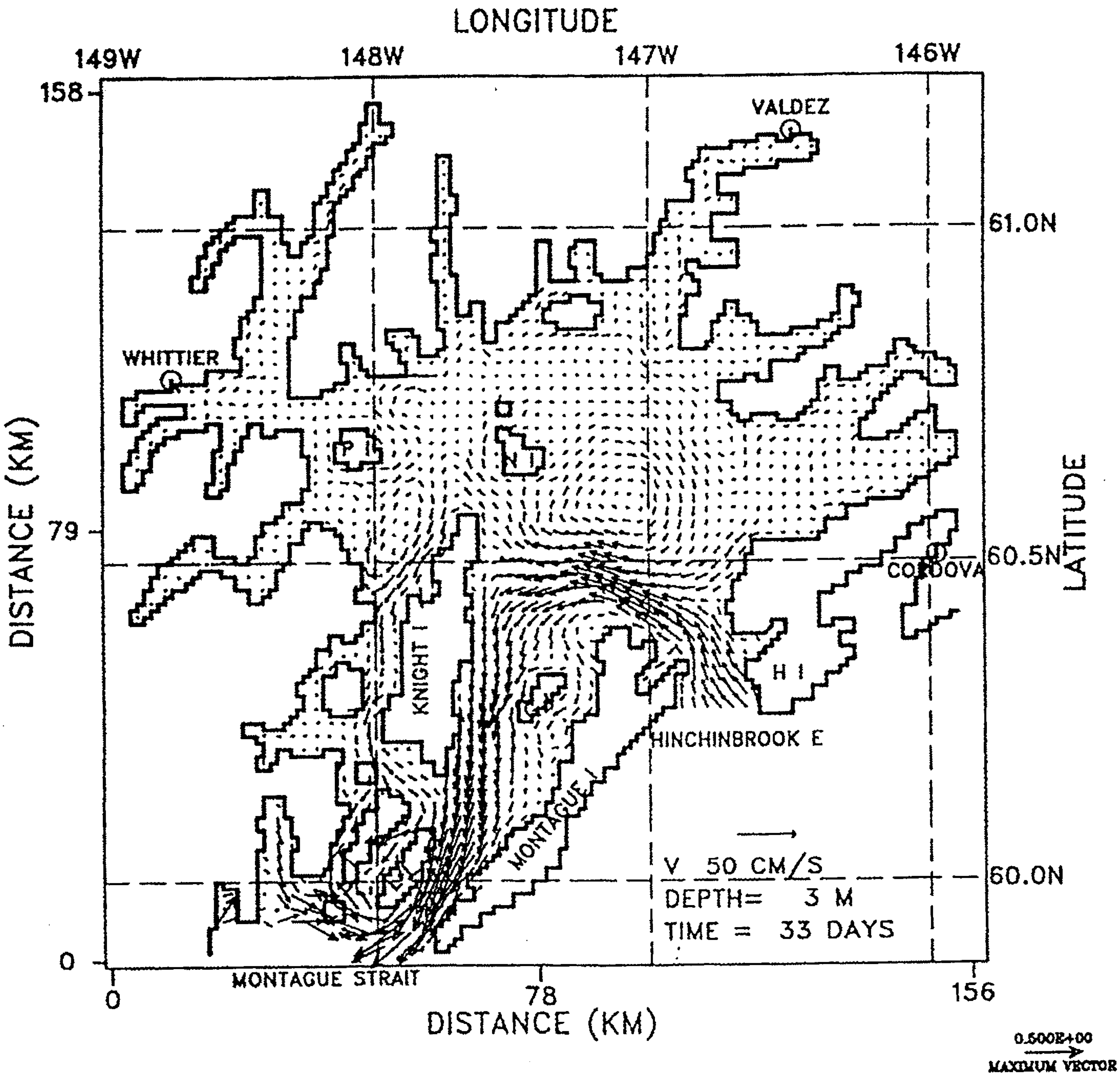

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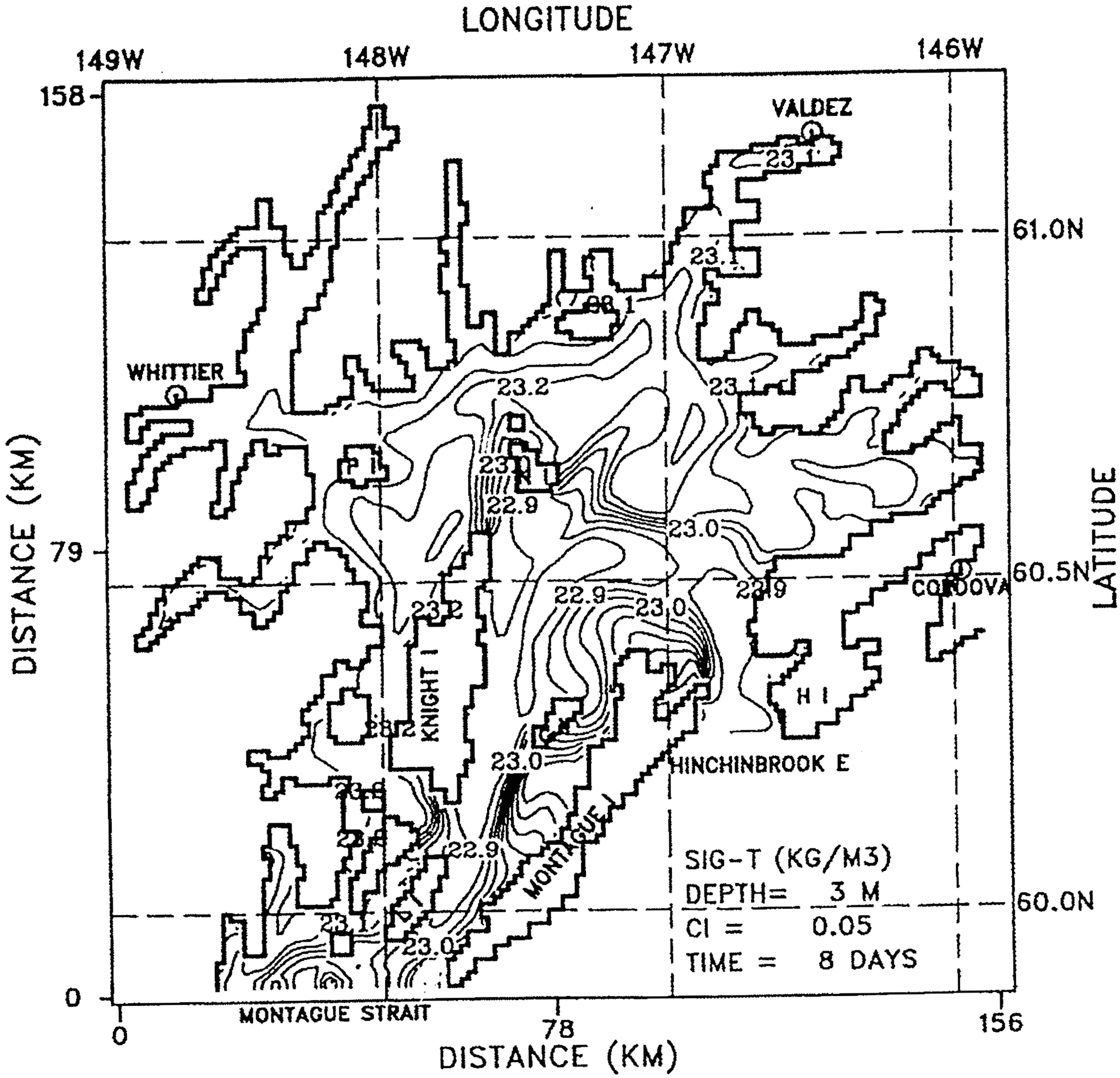

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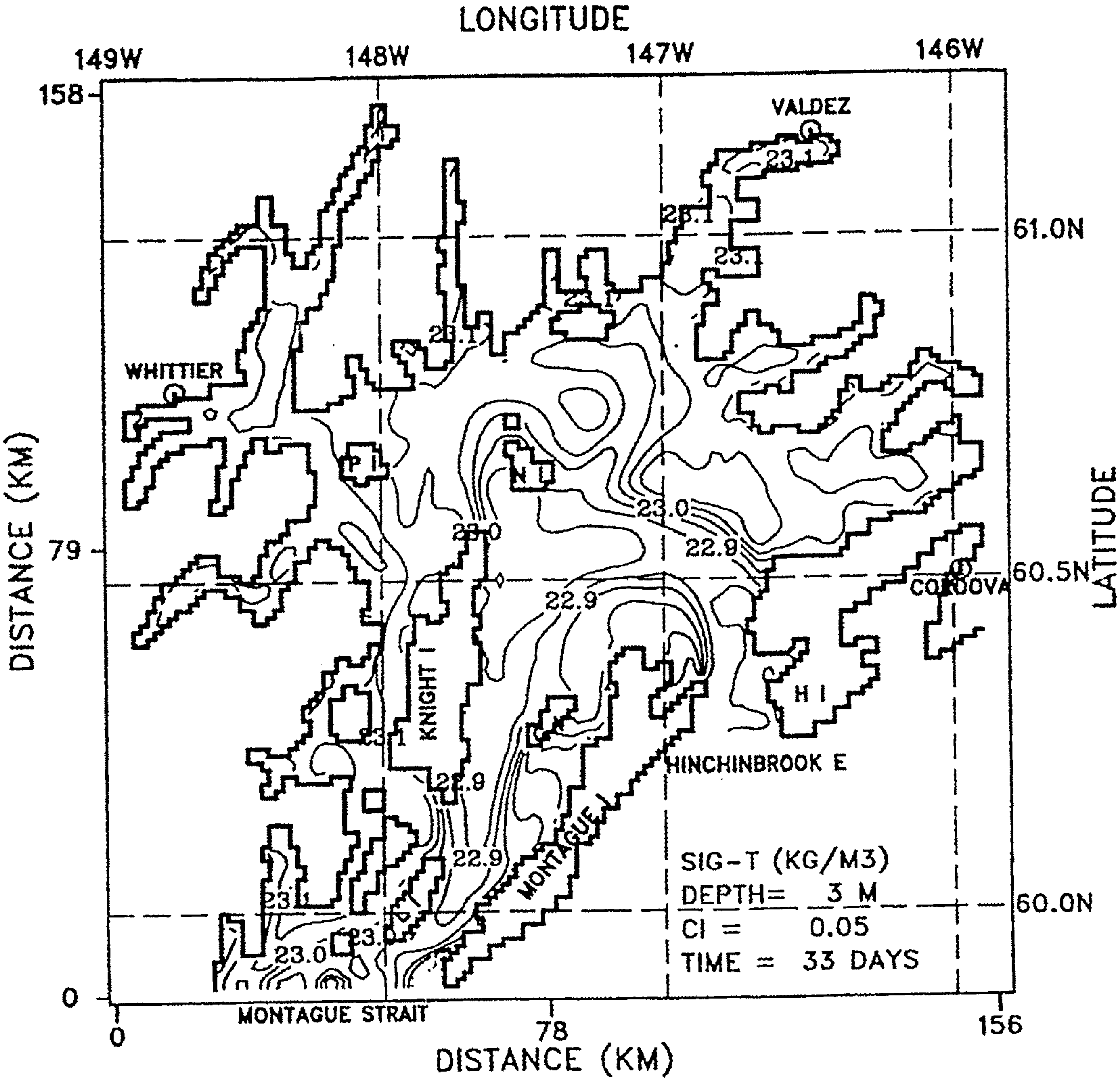
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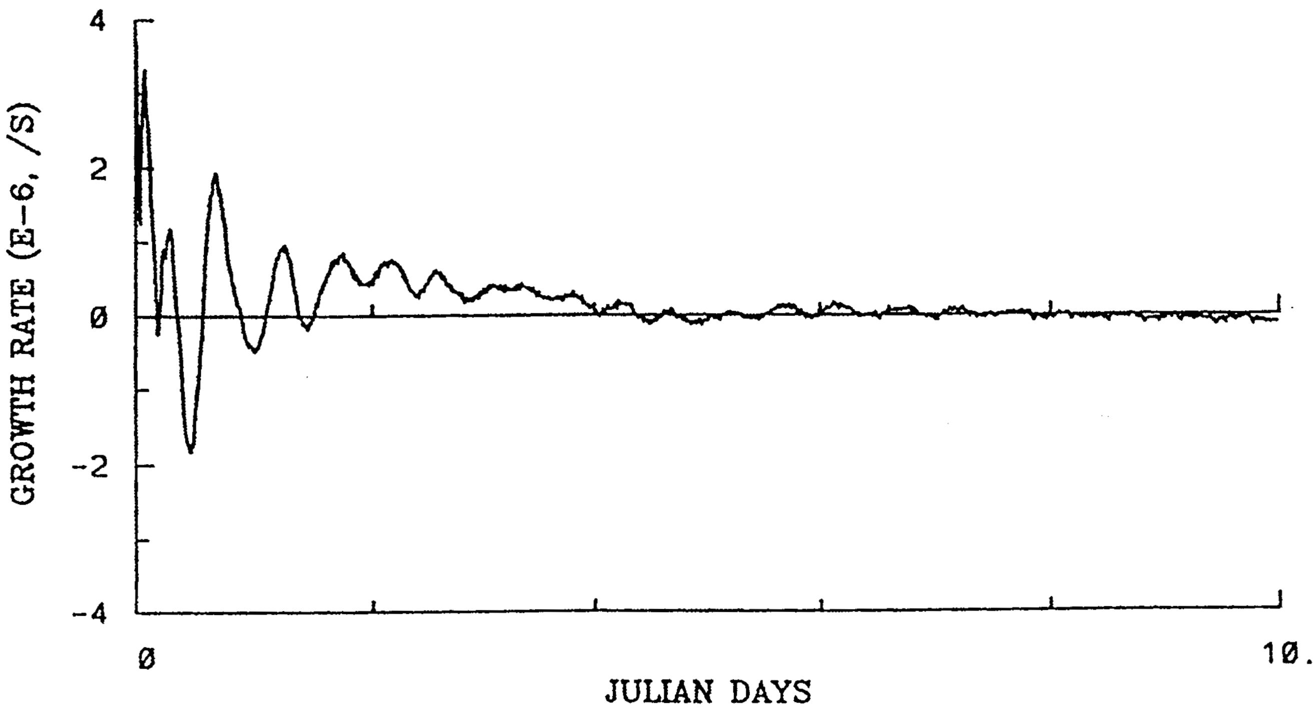

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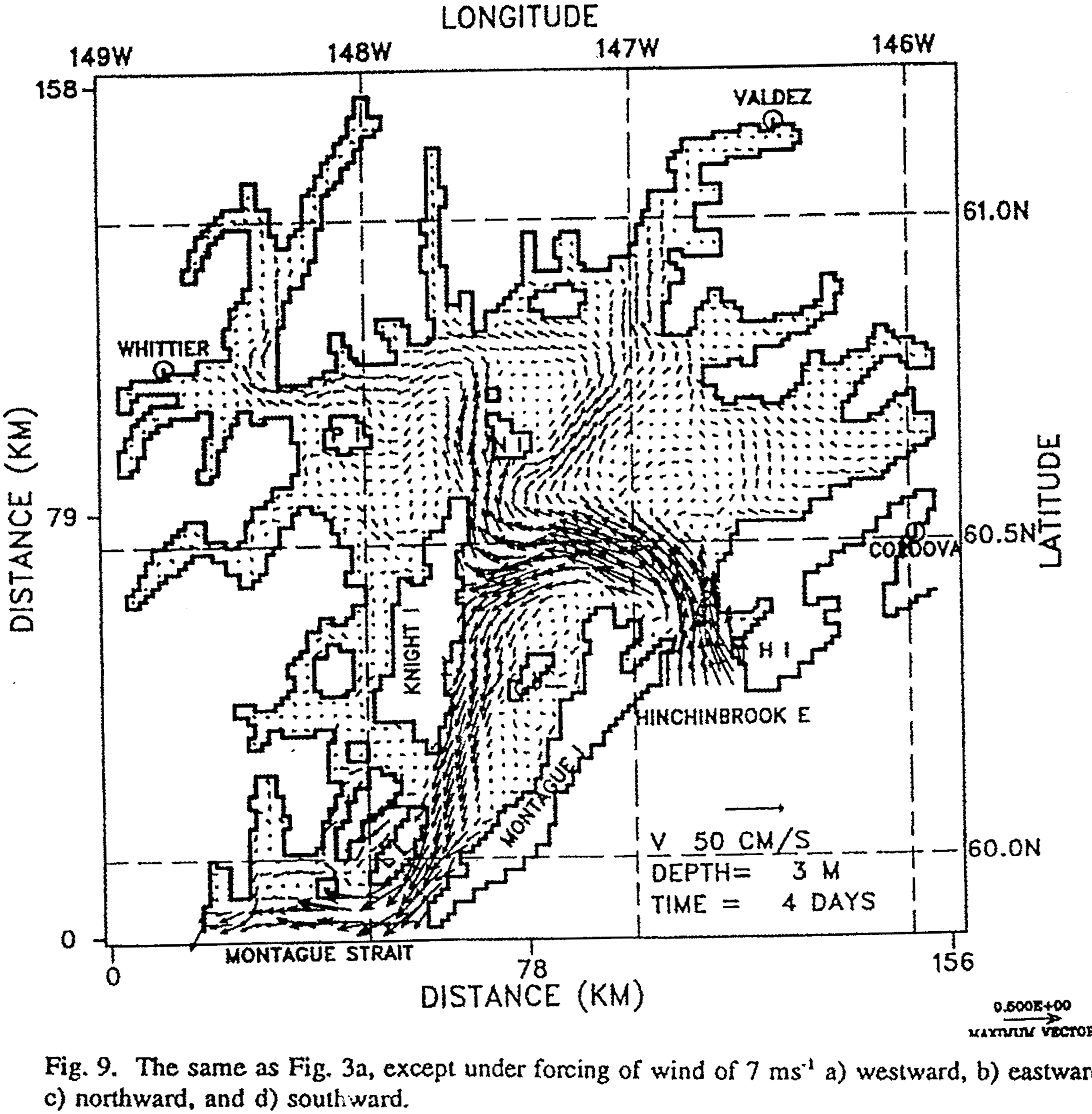

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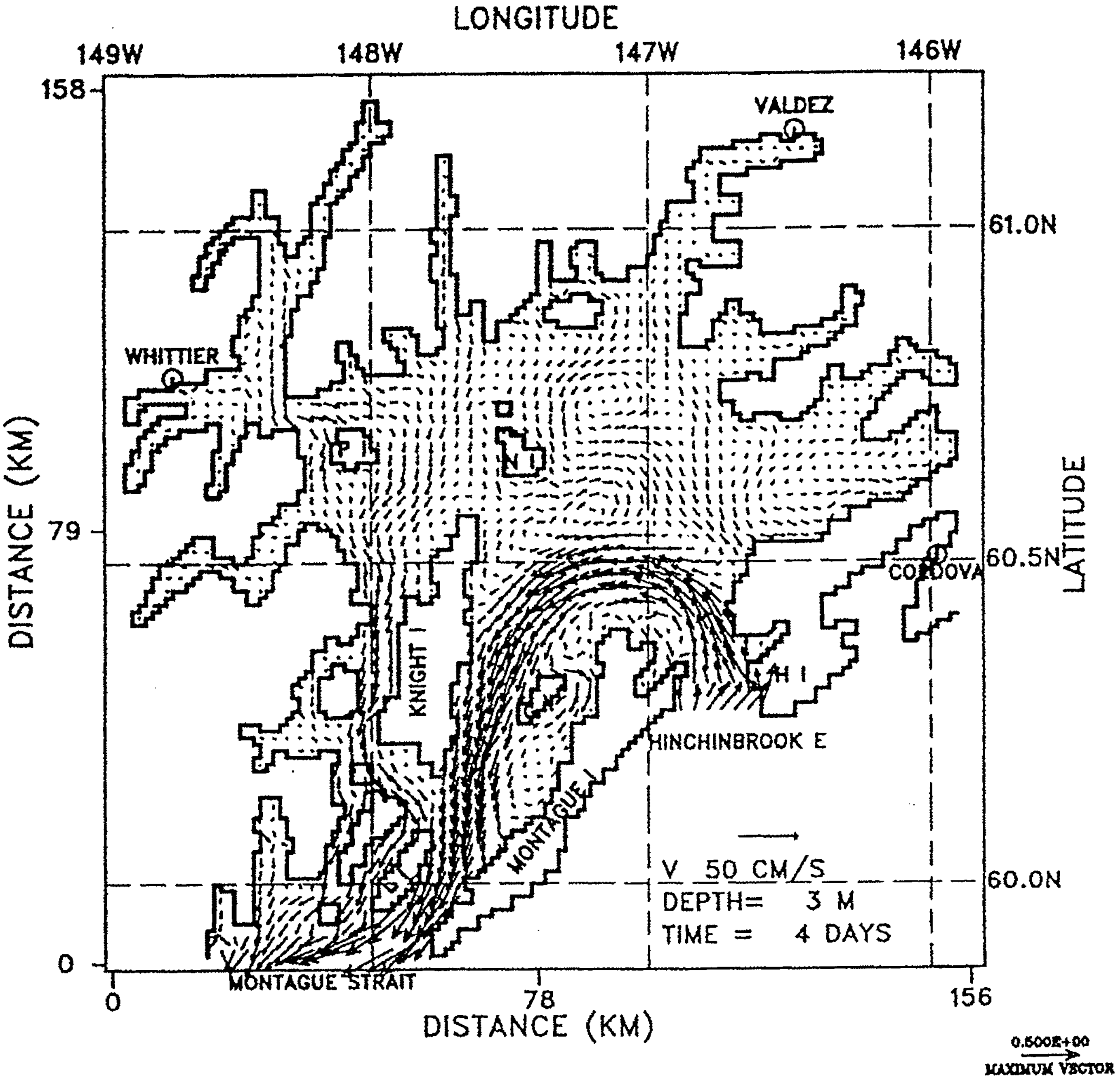
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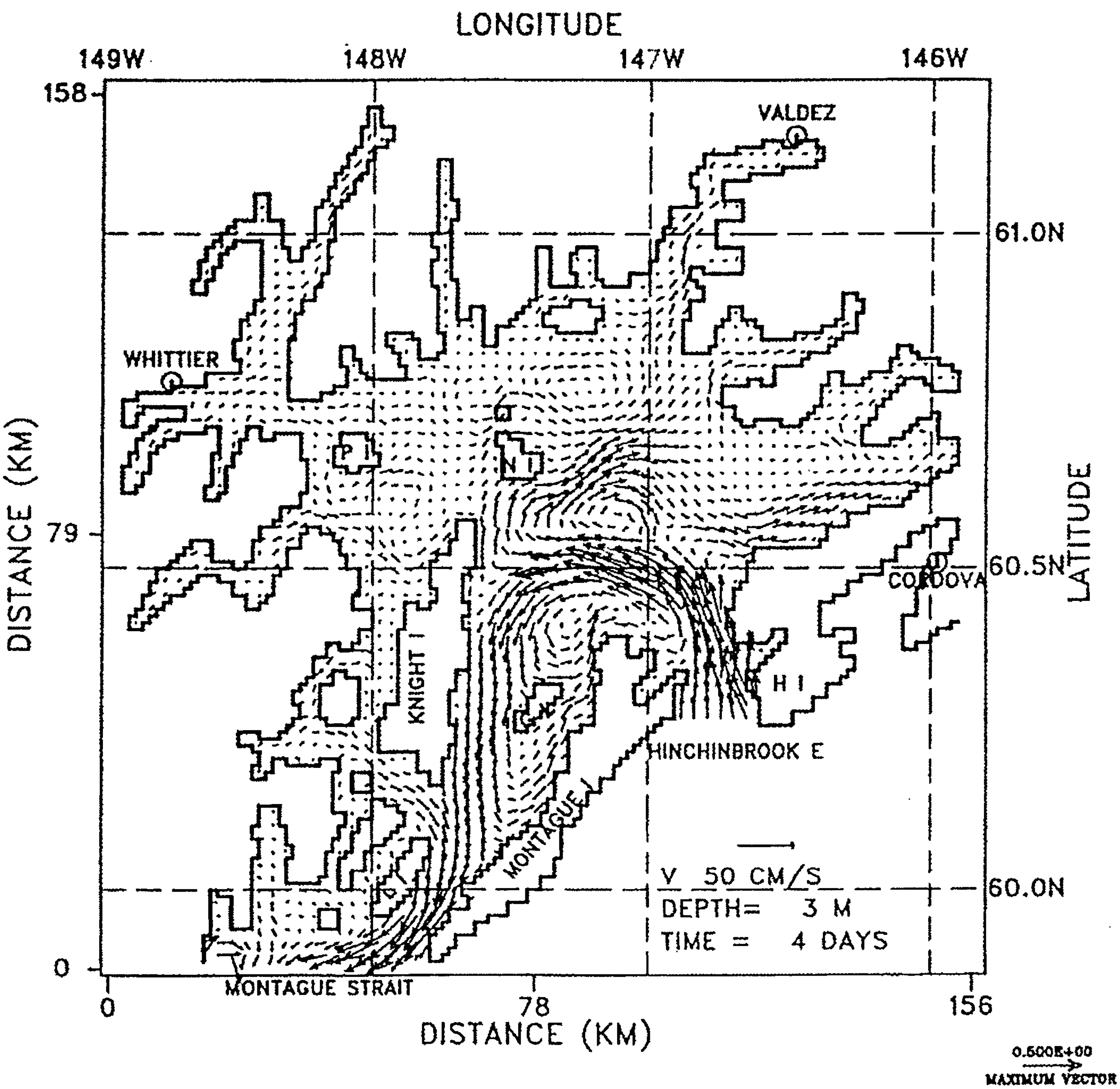
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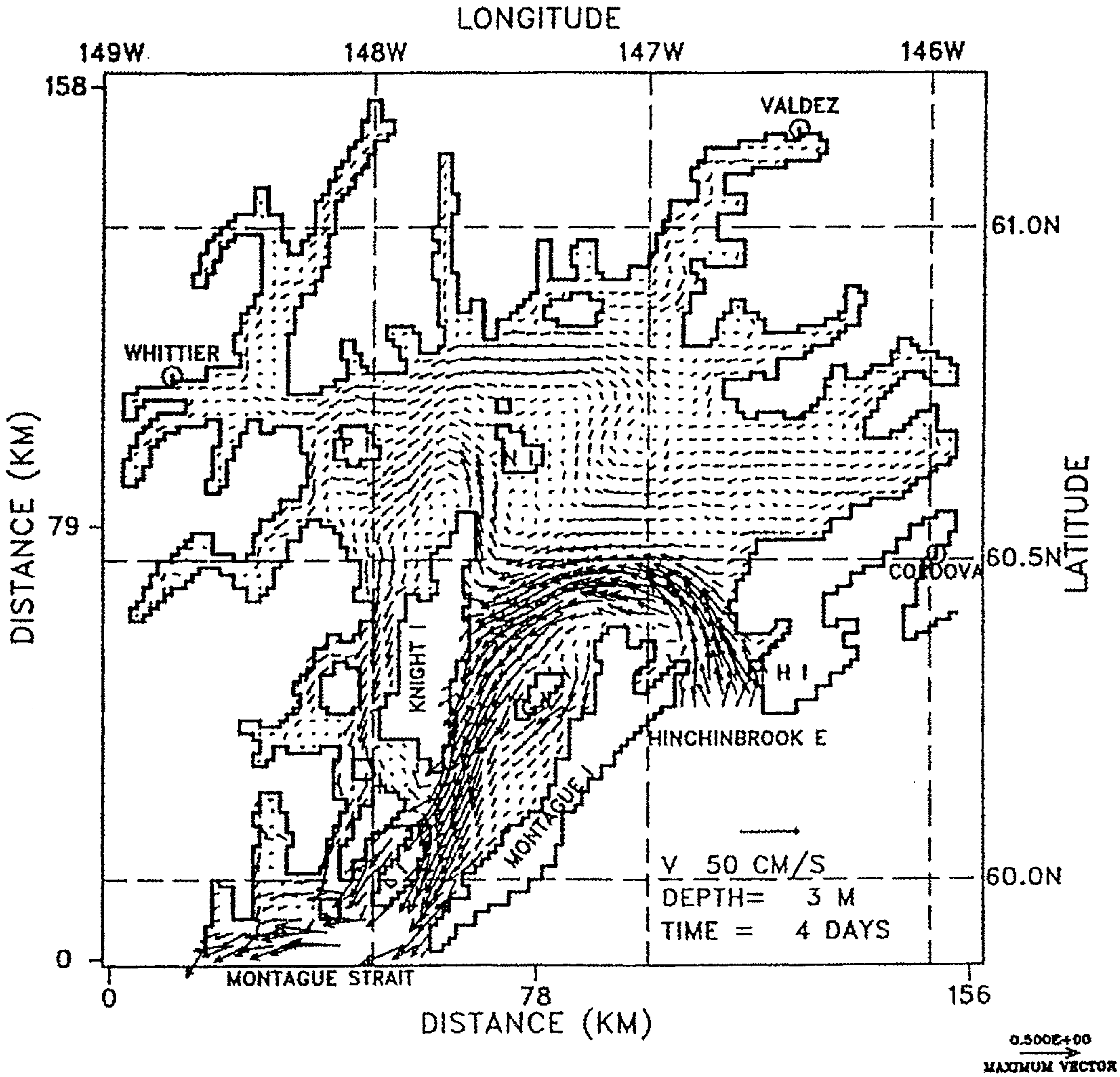
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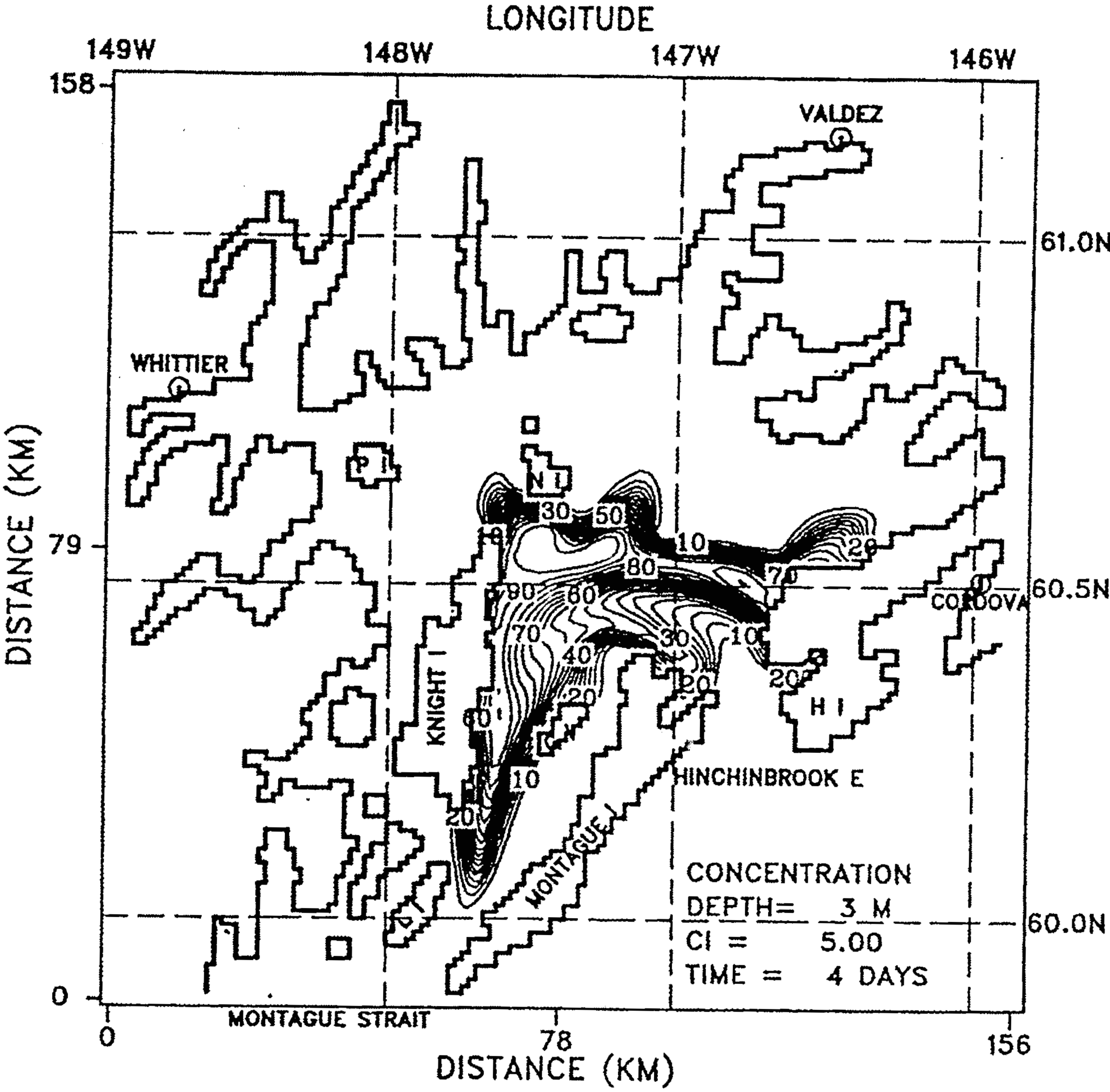

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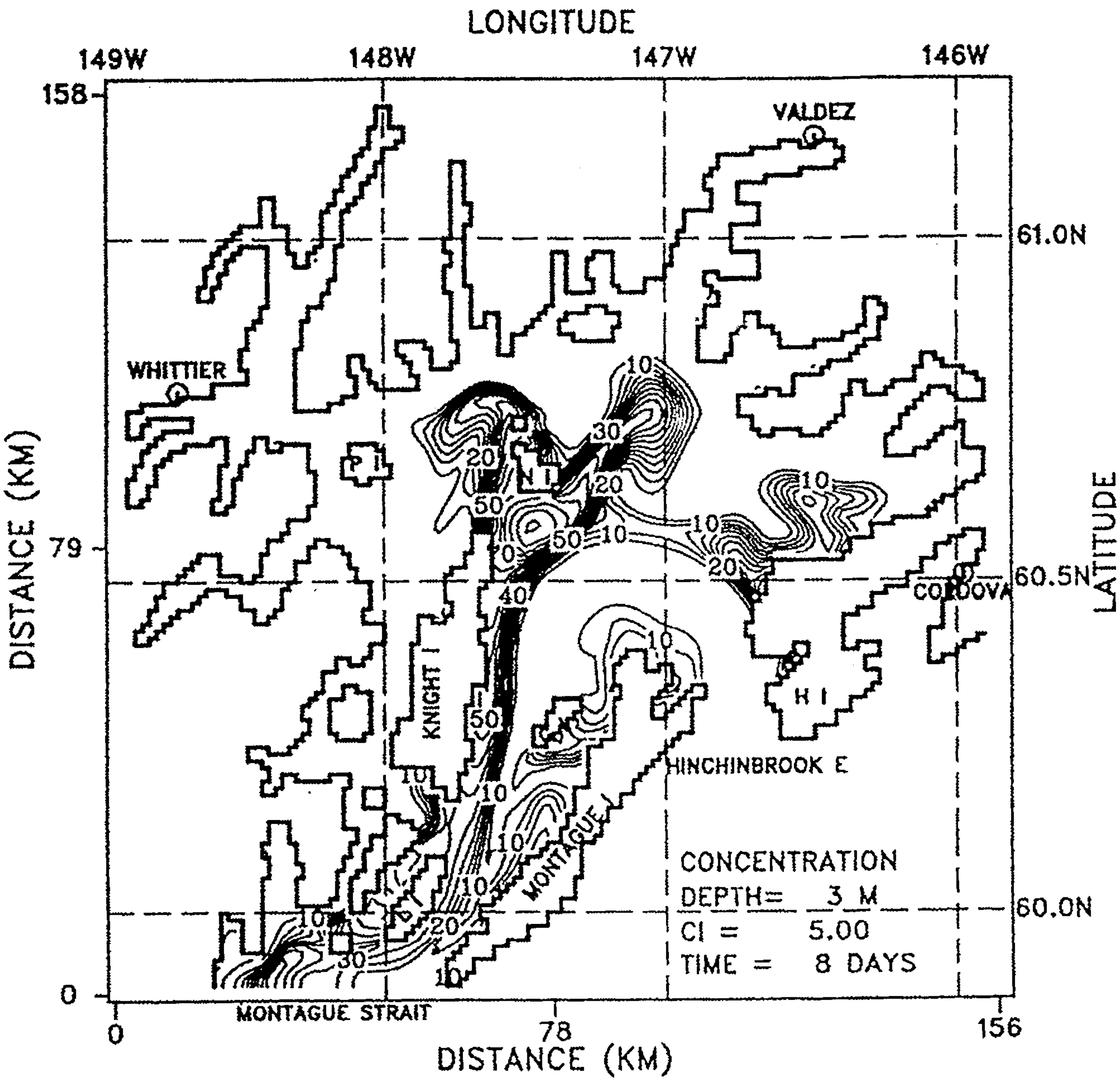

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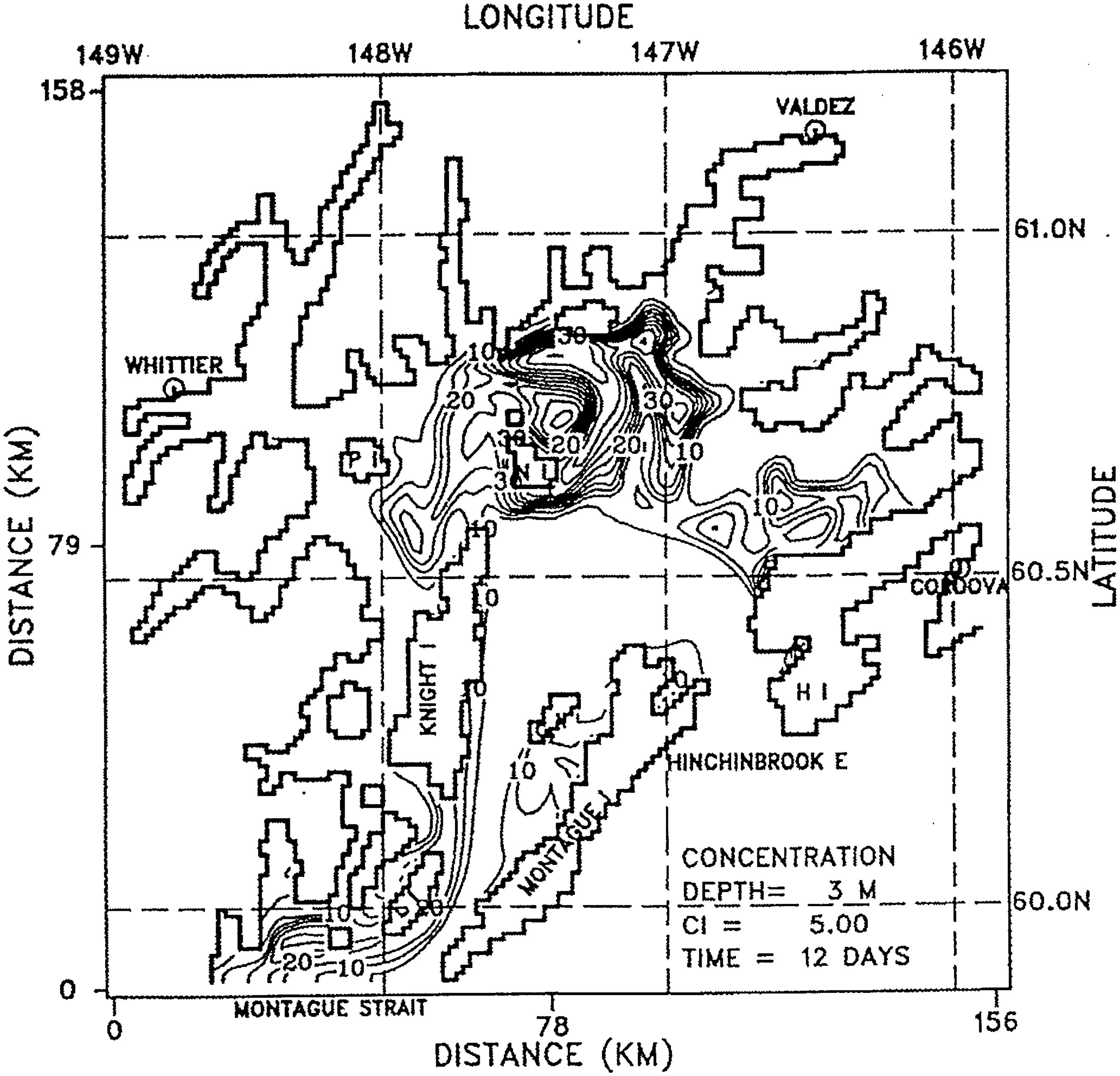

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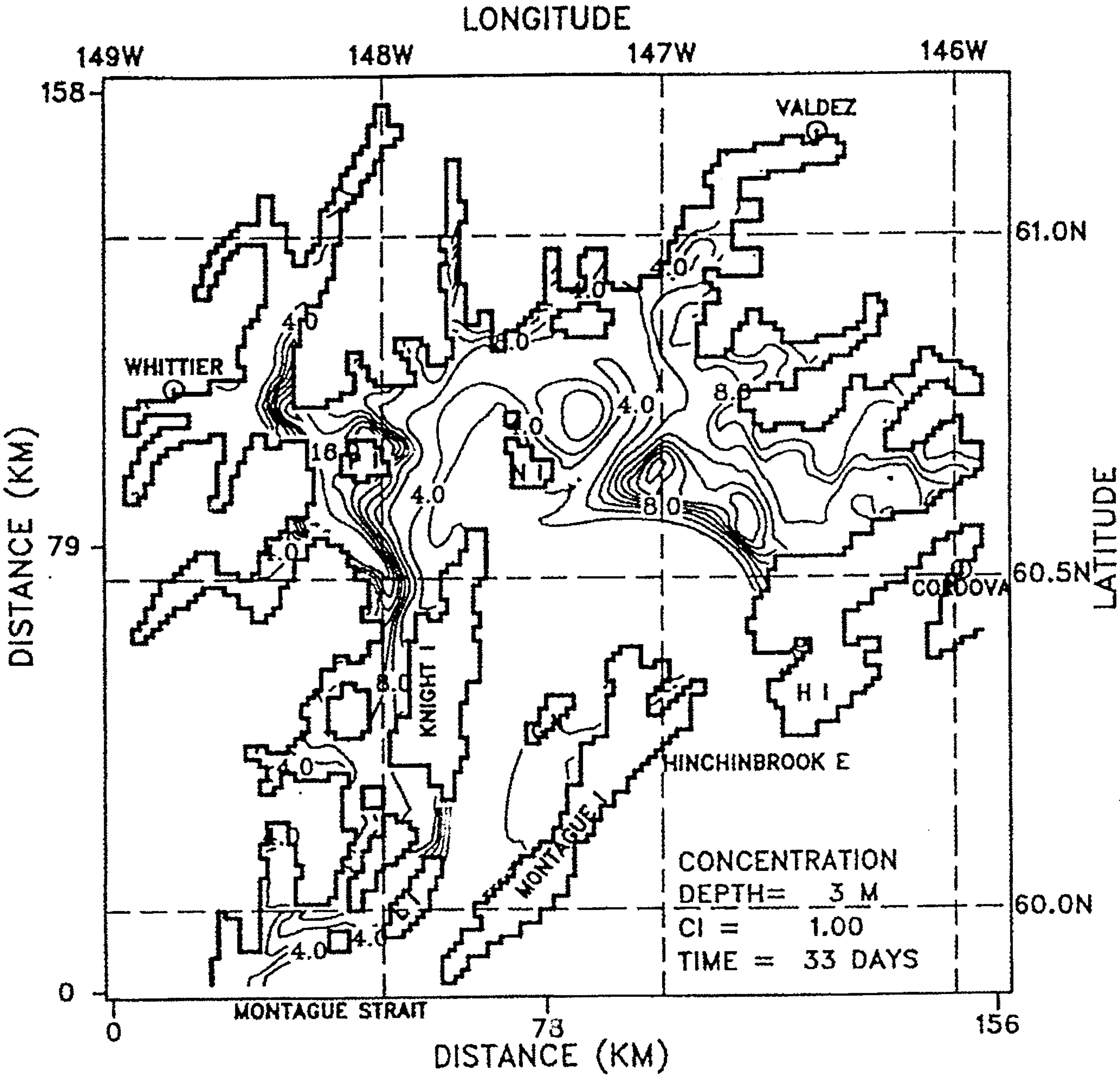

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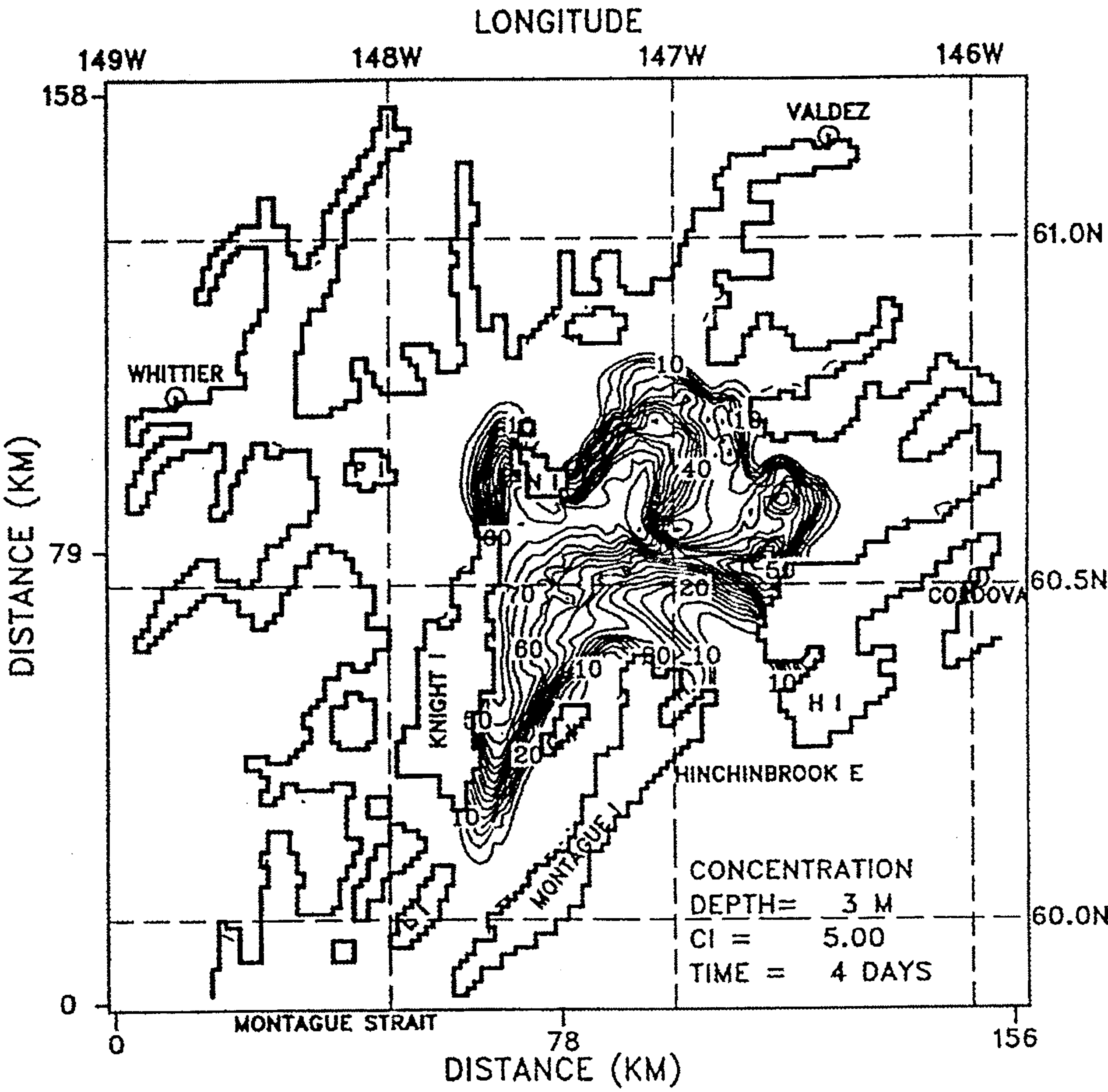

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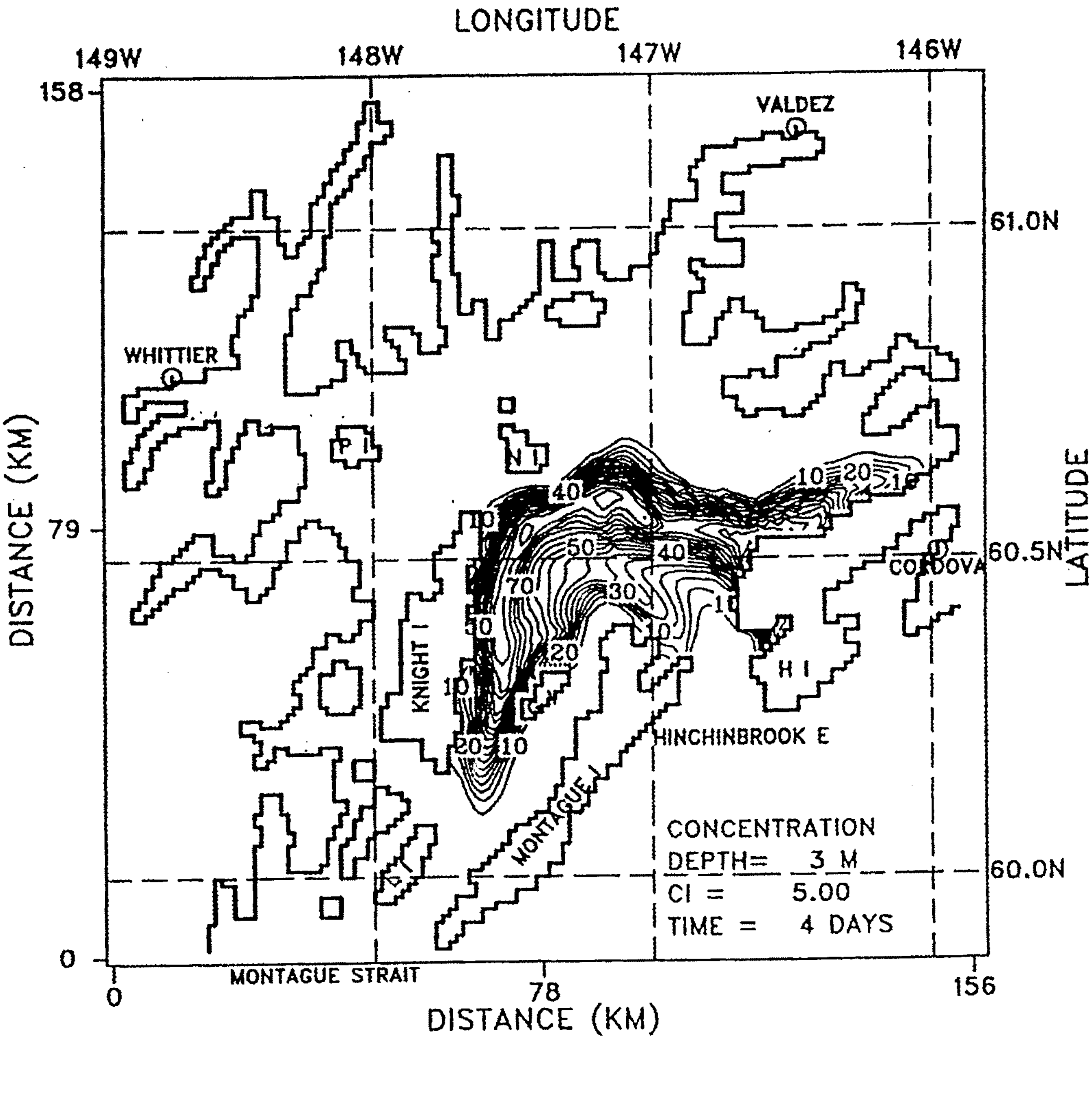
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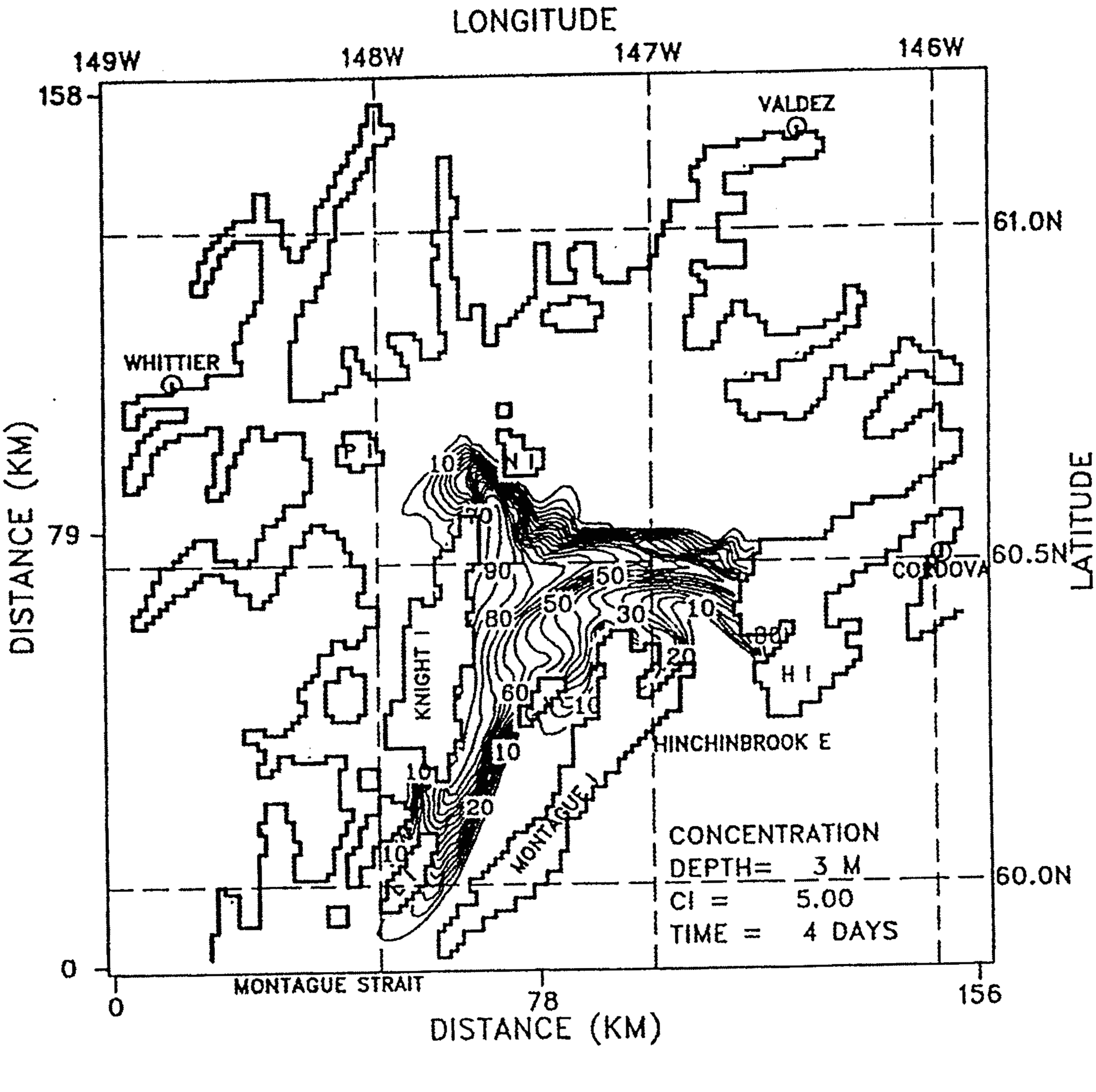
61.0N
WHITTIER
P I
N I
10
20
40
50
40
70
30
10
20
CORDOVA
60.5N
LATITUDE
DISTANCE (KM)
KNIGHT I
H I
HINCHINBROOK E
MONTAGUE I
CONCENTRATION
DEPTH= 3 M
CI = 5.00
TIME = 4 DAYS
60.0N
MONTAGUE STRAIT
0
78
156
DISTANCE (KM)


LONGITUDE
149W
148W
147W
146W
158
79
0
VALDEZ
61.0N
WHITTIER
P I
N I
60.5N
CORDOVA
LATITUDE
DISTANCE (KM)
KNIGHT I
H I
HINCHINBROOK E
MONTAGUE I
CONCENTRATION
DEPTH= 3 M
CI = 5.00
TIME = 4 DAYS
60.0N
MONTAGUE STRAIT
0
78
156
DISTANCE (KM)

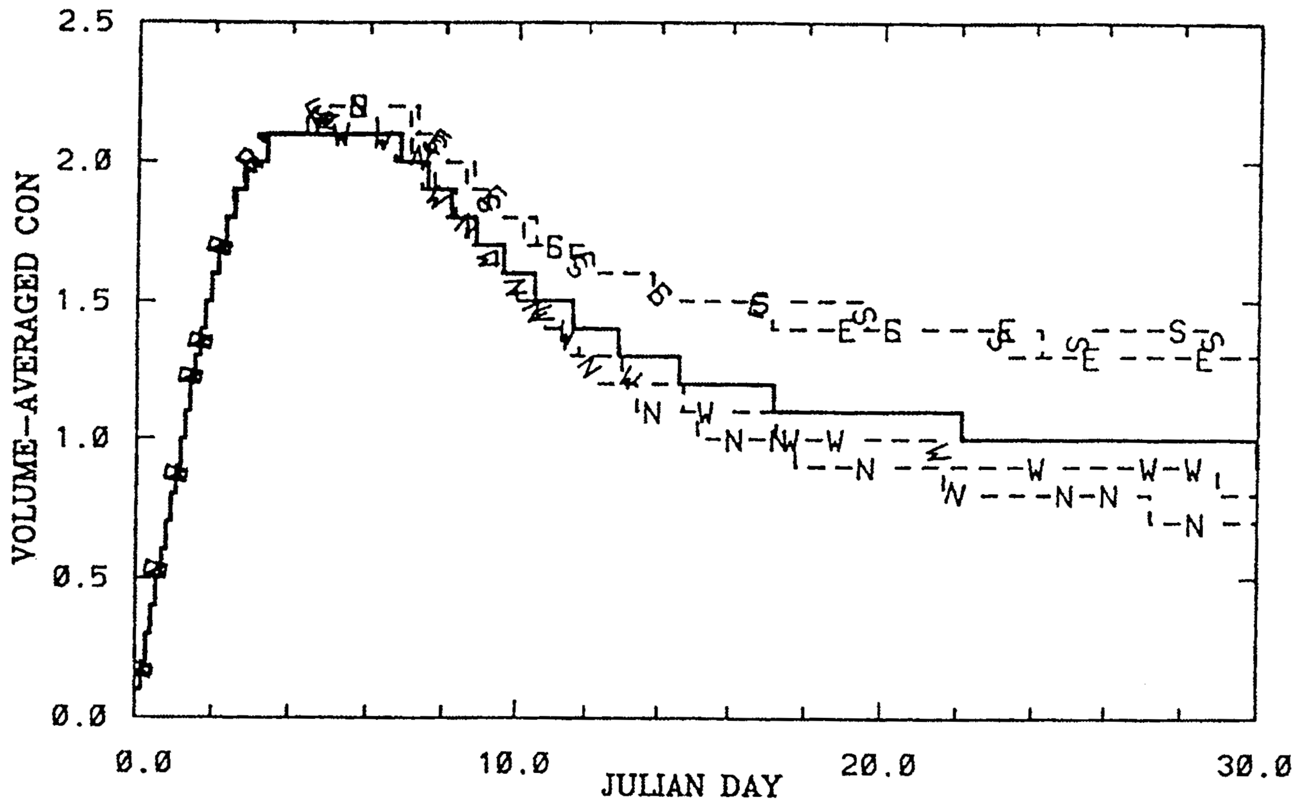


Fig. 12. The time series of volume averaged concentrations in Prince William Sound for the control run (no wind case, solid line), and for the wind forcing a) westward (denoted by E), b) eastward (denoted by W), c) northward (denoted by S), and d) southward (denoted by N).

Appendix 4

Progress Report 1 (1996)
on the development of the 2D and 3D SEA nekton model

PROGRESS REPORT 1 (1996)

RICARDO H. NOCHETTO and SRIDHAR RAO

1. Formulation of 2D hybrid and mixed methods. Consider the scalar advection-diffusion PDE arising from the taxis model for population interactions

$$\partial_t u - \text{div}\left(D\nabla u + \chi\, u\nabla\lambda\right) = f \qquad \text{in } \Omega.$$

Here u is the population density and Ω is a bounded, but otherwise arbitrary, domain in $\mathbf{R}^2$. After discretization in time with backward finite differences with time-step Δt, and using exponential fitting, (1) can be converted into the following elliptic PDE with variable diffusivity for the new unknown $\rho = u^n \exp(\lambda/\varepsilon)$ with $\varepsilon = D/\chi$:

$$\exp(-\lambda/\varepsilon)\rho - D\Delta t\ \text{div}\left(\exp(-\lambda/\varepsilon)\nabla\rho\right) = u^{n-1} + \Delta t f^{n-1}. \tag{2}$$

We devised both a hybrid and mixed method for space discretization of (2), thereby extending the results of [3,4]. The former, which is being implemented, exhibits exact mass conservation, a very desirable property.

2. Scaled exponentials in 2D. The resulting method in the variable ρ is symmetric but subject to severe limitations due to the occurrence of exponentials. This is much like what happens in 1D, as is a way around it. The idea is thus to rescaled back to the original variables u, which should possess a moderate size. This destroys the symmetry, and requires a carefull elementwise calculation of compensating exponential that allow for cancellation. This computation is performed exactly, since quadrature may yield unacceptably large errors and limit the applicability of our scheme. The desired integrals are thus computed on the master element, depending on the relative values of taxis λ at the nodes. This has already been implemented and is being tested.

3. GMRES. The effective solution of the resulting *nonsymmetric* linear system has been carried out by LU decomposition in 1D. The computational cost of this direct method may be prohibitive in 2D, and specially in 3D, due to fill-in. The generalized minimal residual method (GMRES) of [7] appears to be the iterative method of choice. We studied its fundamentals, and practiced with several implementations of it. The critical point, still to be assessed for (2), is the design of an effective preconditioner.

4. Recursive enrichment/coarsening mesh adaptation. To optimize the computational effort, and make it possible in 3D, it is crucial to exploit mesh and time stepping adaptation capabilities. The simplest and most effective way to migrate from 2D to 3D is to use bisection techniques for mesh adaptation. We studied its use for enrichment/coarsening of a mesh [1], along with its recursive implementation [5]. This is an essential component of Bänsch code, and is rather problem independent. What remains to be studied is an error estimator suitable for (1) in both advection dominated and diffusion dominated regimes.

Typeset by $\mathcal{A}\mathcal{M}\mathcal{S}$-TEX

5. Review of finite element packages. We have experimented with several codes for finite element computations in 2D, namely KASKADE [2], MGGHAT [6], and a code by Bänsch that is very flexible and incorporates the recursive enrichment/coarsening strategies of §4. We will experiment more with the latter, and work in collaboration with Bänsch in the design, implementation, and full testing of a code for 2D simulations of the taxis model (1).

REFERENCES

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Appendix 5

Task Report
Applegate Rock Meteorological Station

with 4 figures

TASK REPORT:

Applegate Rock Meteorological Station

Stephen Bodnar and Jennifer Allen

April 1996

ABSTRACT

Installation of meteorological monitoring equipment at Applegate Rock, northeast of Green Island in Prince William Sound, and development of an automated system for data download and processing, were completed as part of EVOS restoration project #96320J. Half-hourly observations of nine air temperature, air pressure, wind direction, wind speed and light intensity parameters are downloaded daily via the SEA packet radio network. The data are served in tabular and graphic form via the SEA weather site on the world wide web.

TECHNICAL REPORT

The objective of the Applegate Rock weather station is to provide near realtime weather data for two primary purposes: (1) informing the SEA project regarding local weather conditions in the important herring spawning areas of Green Island and the north end of Montague Island; and (2) providing nowcast/forecast forcing input to the ocean circulation model.

The weather station equipment was installed on April 19, 1996. Modifications and maintenance were performed on 7/5/96, 9/6/96, 11/7/96, 2/14/97, 2/18/97, 3/1/97. The following instruments are present:

Wind:	R. M. Young 05103-5 Wind Monitor
Air Temperature:	CS-107B thermistor
Barometric Pressure:	Vaisala PTB101B
Pyranometer:	LiCor LI200X
Datalogger:	Campbell Scientific CR10
Power Supply :	9 x 1.5v AirCel batteries, nonrechargeable

Half-hourly observations of minimum, maximum and mean air temperature, mean wind speed, maximum wind gust speed, wind direction and deviation, barometric pressure, and light level are stored in the CR10 datalogger, which also functions as the system clock. Once daily, for 3 hours beginning at 7:00 am, the datalogger switches on the computer and communications system. On bootup, the 486 communications controller executes a batch file which moves the most recent data from the datalogger to permanent storage on the computer. Before terminating, the batch file initializes the radio modem, putting it into standby mode. The modem then awaits daily contact, initiated by the weather data host computer at the Prince William Sound Science Center (PWSSC), to download the current 24 hours of data via the UHF packet radio network. This download from Applegate Rock to PWSSC is transmitted via the SEA packet radio repeater (digipeater) on Naked Island and is controlled by custom interrupt-driven DOS-based communications software written by Roy Murray of the SEADATA group.

Downloaded data are transferred immediately to the SEA Unix-based network by FTP to the PWSSC dataserver workstation, replacing the previous day's data which is automatically concatenated onto a year-to-date data file. At the same time the current system date and time is automatically stored for reference by the web server. The last line of the download/transfer script invokes a second script which automatically performs several functions preparatory to serving the data on the SEA world wide web site. This script (1) reformats the data from a comma delimited steam to a tab delimited table; (2) extracts four columns (mean temperature, air pressure, wind direction, wind speed) to be plotted; and (3) iteratively calls a plotting routine which plots the day's time series for each variable, converts each plot to GIF format, and generates an HTML coded file packaging the plots.

The data are served via the Applegate link on the SEA Weather web page (reached by the weather button at http://www.pwssc.gen.ak.us/sea/sea.html) (Figure 1). The Applegate page (Figure 2) is dynamically generated by a GCI script which creates the layout page, reads the date.txt file and displays a "date of last update" message at the top of the web page, as well as providing links to static information such as a map, photographs, key to variable units, documentation and history of the site. Two buttons near the bottom of this page provide access to the current day's data. The TABLE button activates a CGI script which generates a dynamic html header showing the last updated time-date of the data, and then reads and serves the previously formatted data table. It also provides links to a Julian day lookup table (Figure 3). The PLOT button links to the previously formatted HTML file containing the current day's plots (Figure 4).

This system allows automated processing of the downloaded data without human intervention, but without compromising speed of web access for users of the data. The table and plots are transparently generated and moved to web tree directories once per day at download time, thereby minimizing delay on responses to subsequent web access requests. Use of a CGI script behind the Applegate web page allows incorporation of dynamic date and time data or message information, but the retains speed by assembling the web pages from pre-built components.

Appendix 5, Figure 1

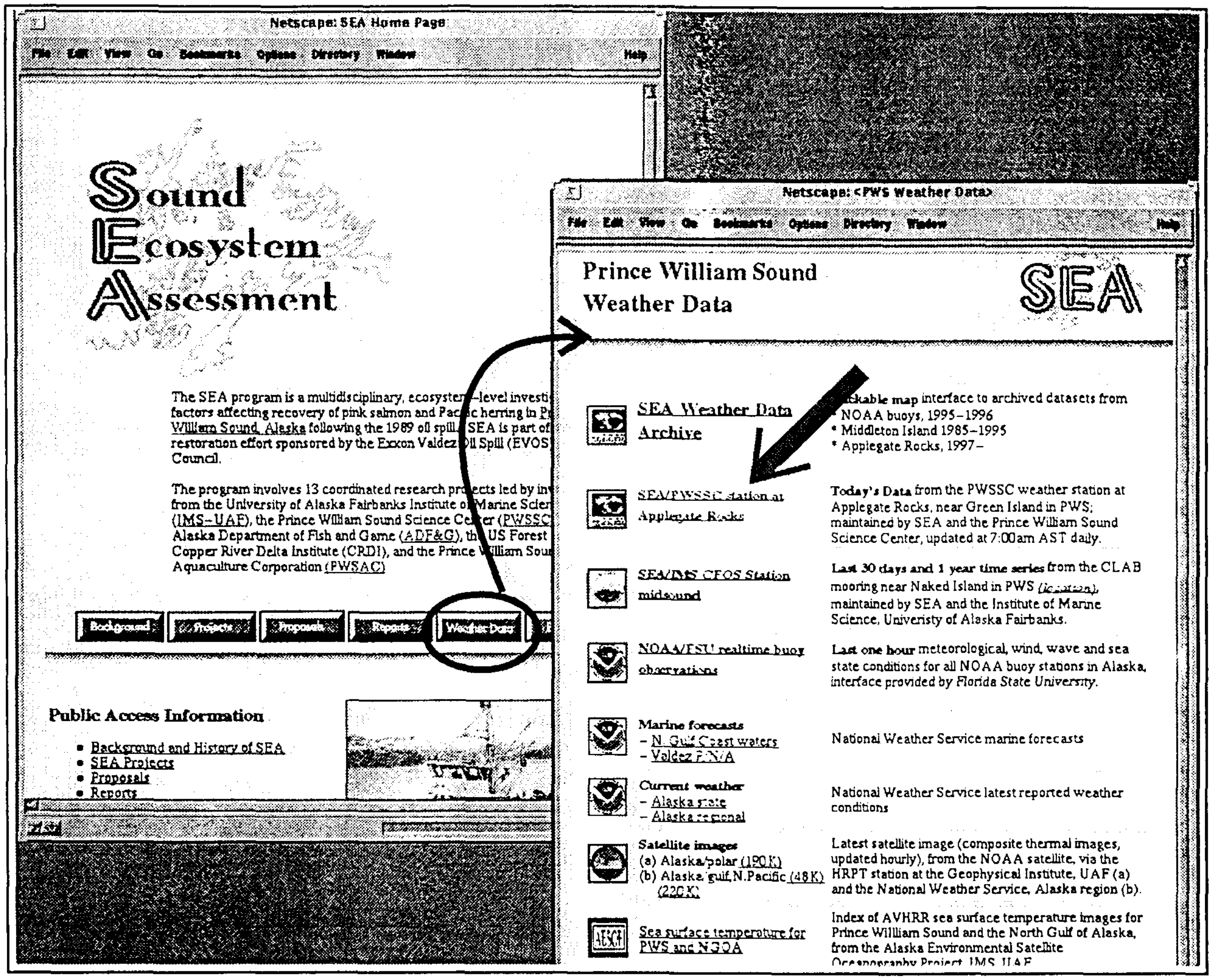

Figure 1: The SEA web site home page (left) and main SEA weather page. The Applegate link is indicated

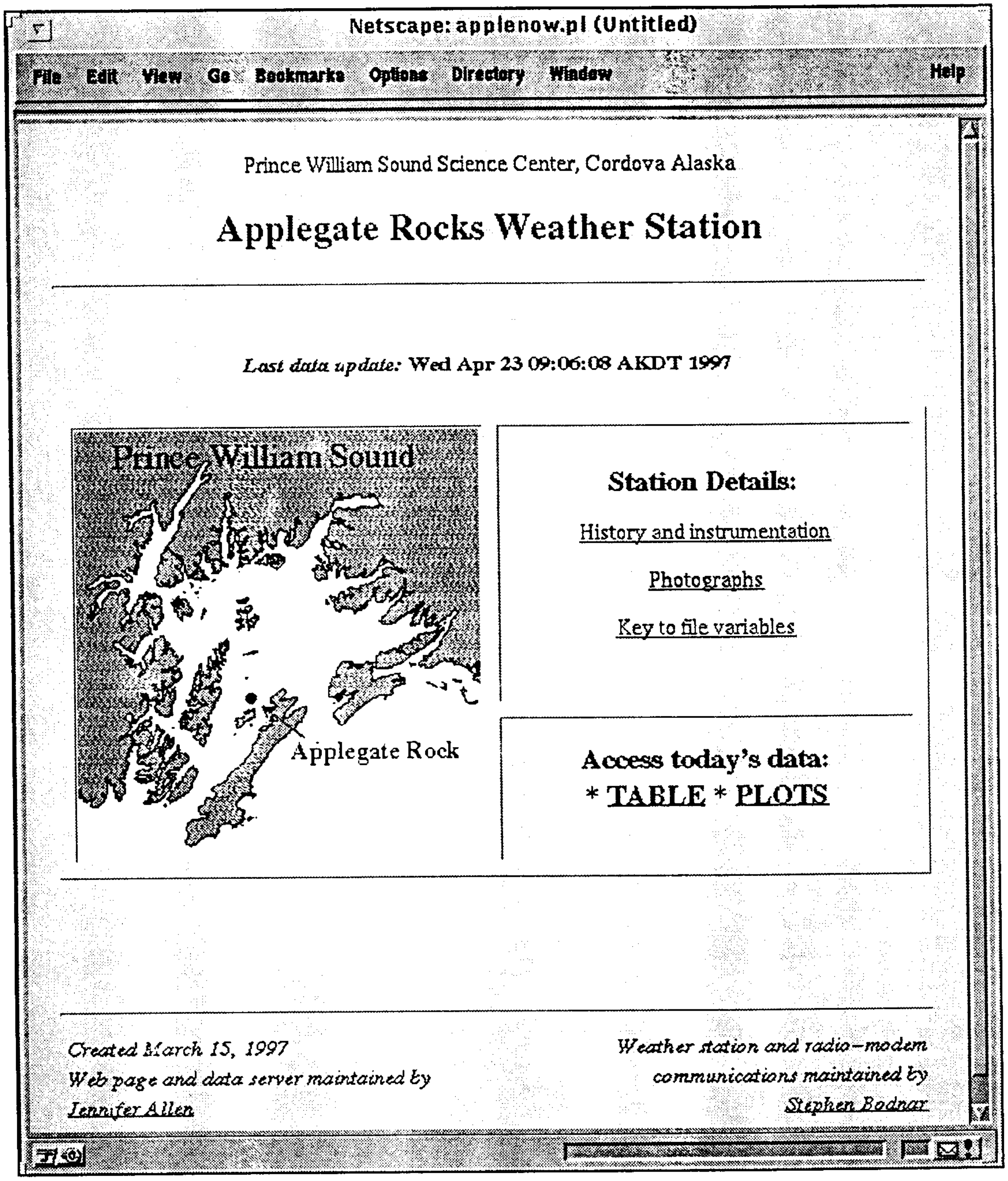

Figure 2: The web interface to the Applegate Rock weather data.

Netscape: applenow.tab.pl (Untitled)

File Edit View Go Bookmarks Options Directory Window Help

Prince William Sound Science Center, Cordova Alaska

Applegate Rocks Weather Station

Data last updated: Wed Apr 23 09:06:08 AKDT 1997

(key to variable names)
(lookup table for Julian Day)
Note: 1630 GMT (Greenwich Mean Time) = 0830 AKDT (Alaska Daylight Time)

id	year	jd	GMT	w_spd S	w_spd U	w_dir	w_dev	w_gust	t_mean	t_min	t_max	s
5	1997	112	1630	6.295	6.268	83.7	5.292	8.23	5.041	4.962	5.107	6
5	1997	112	1700	5.921	5.883	76.5	6.531	7.68	5.014	4.94	5.087	9
5	1997	112	1730	6.857	6.77	82.4	9.14	9.47	5.144	5.046	5.297	2
5	1997	112	1800	5.629	5.553	70.2	9.42	7.88	5.23	5.122	5.316	2
5	1997	112	1830	6.089	6.054	74.3	6.16	8.25	5.093	4.988	5.189	6
5	1997	112	1900	7.7	7.66	74.2	6.401	9.91	4.878	4.738	4.998	7
5	1997	112	1930	7.99	7.93	83.6	6.878	10.45	4.776	4.69	4.854	8
5	1997	112	2000	9.08	9.04	94.4	5.129	11.12	4.857	4.795	4.989	1
5	1997	112	2030	8.38	8.34	89.8	5.462	10.86	4.896	4.835	5.027	8
5	1997	112	2100	8.92	8.88	93.6	5.224	11.02	4.947	4.902	4.988	8
5	1997	112	2130	8.16	8.12	87.4	5.953	10.65	4.957	4.854	5.027	8
5	1997	112	2200	7.87	7.83	92.9	5.593	9.8	4.938	4.863	5.027	1
5	1997	112	2230	7.88	7.85	96.9	4.731	10.31	5.101	4.987	5.229	1
5	1997	112	2300	8.52	8.4	103.4	9.36	11.4	5.354	5.132	5.672	1
5	1997	112	2330	9.03	9	114	4.756	10.73	5.57	5.518	5.654	1
5	1997	113	0	8.41	8.38	113.2	4.516	11.02	5.525	5.412	5.702	1
5	1997	113	30	8.15	8.08	108.2	7.37	10.2	5.72	5.595	5.857	9
5	1997	113	100	8.84	8.78	102.8	6.56	11.09	5.71	5.49	5.857	1
5	1997	113	130	8.83	8.75	107.4	7.7	11.26	5.755	5.644	5.856	9
5	1997	113	200	7.49	7.42	93.8	8.05	9.34	5.5	5.162	5.885	7
5	1997	113	230	6.699	6.658	79.9	6.28	8.43	5.205	5.077	5.394	4
5	1997	113	300	6.32	6.292	77.3	5.39	7.82	5.208	5.114	5.289	2
5	1997	113	330	6.479	6.445	81.7	5.883	8.36	5.316	5.219	5.404	3
5	1997	113	400	6.687	6.622	93.8	7.99	8.48	5.572	5.337	5.808	2
5	1997	113	430	5.043	5.026	67.19	4.707	6.331	5.168	5.075	5.529	1
5	1997	113	500	5.674	5.649	50.55	5.317	6.654	5.049	4.93	5.172	1
5	1997	113	530	6.177	6.169	49.76	2.986	7.05	5.051	4.95	5.171	6
5	1997	113	600	5.7	5.69	50.63	3.264	6.742	5.131	5.083	5.231	5
5	1997	113	630	5.317	5.306	49.71	3.657	6.38	5.222	5.144	5.277	5
5	1997	113	700	5.3	5.288	50.62	3.852	6.252	5.323	5.24	5.393	5
5	1997	113	730	4.164	4.154	47.73	3.919	5.292	5.23	5.113	5.383	5
5	1997	113	800	3.849	3.817	44.28	7.31	4.743	5.149	5.113	5.2	5
5	1997	113	830	2.826	2.816	27.45	4.731	3.861	5.027	4.882	5.181	5
5	1997	113	900	4.427	4.402	42.83	6.114	5.958	4.955	4.872	5.019	5
5	1997	113	930	5.324	5.306	47.34	4.755	6.125	4.971	4.911	5.058	5
5	1997	113	1000	4.249	4.166	59.08	11.3	5.851	5.03	4.951	5.086	5
5	1997	113	1030	3.692	3.617	74.2	11.59	4.861	4.976	4.911	5.028	5
5	1997	113	1100	3.827	3.791	68.86	7.81	4.822	5.093	4.961	5.172	5

Figure 3: Applegate data presentation, tabular format

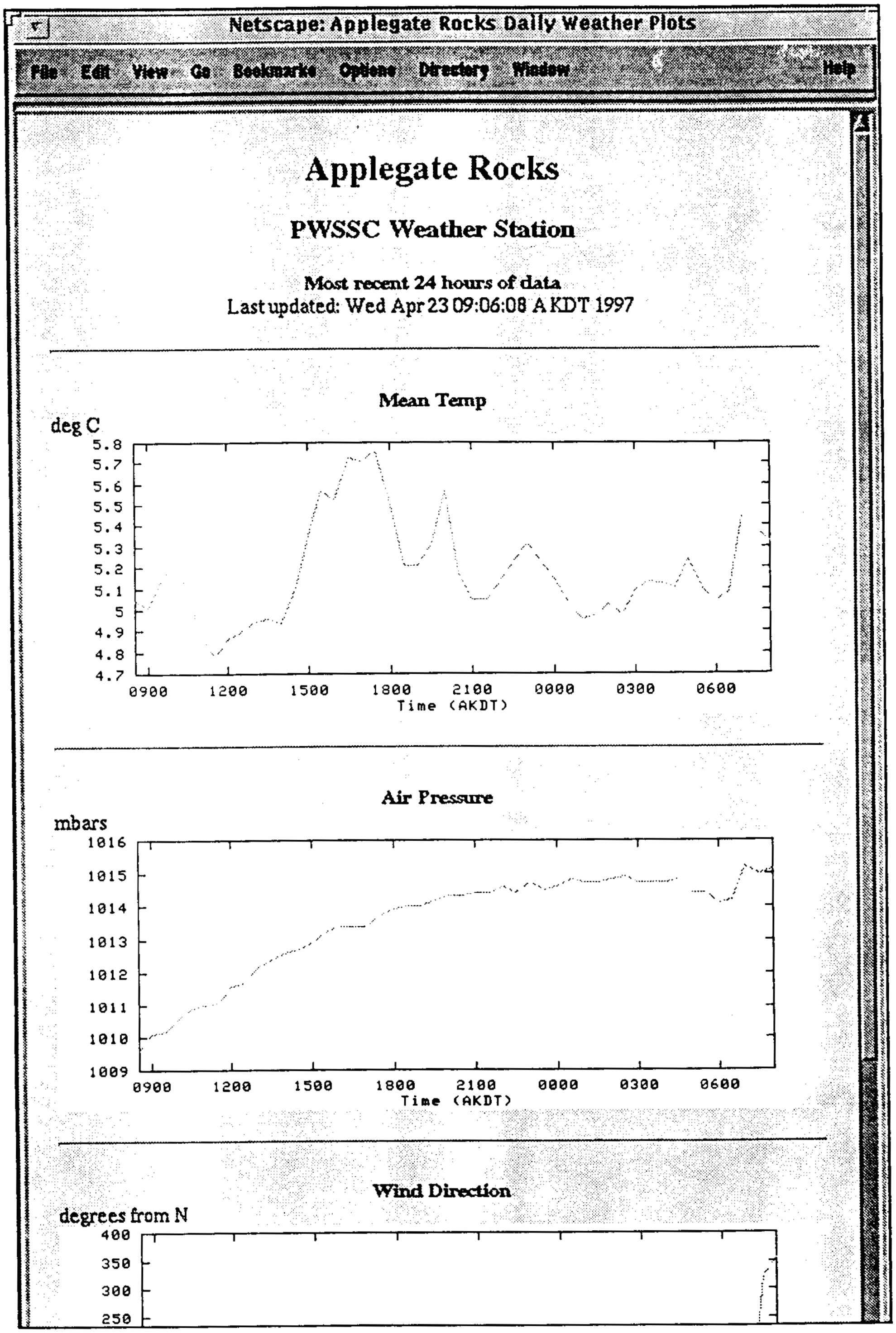

Figure 4: Applegate data presentation, graphic format