Report from CIFAR to NOAA on the first year of Cooperative Agreement No. NA17RJ1224

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Table of Contents

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Overview

The Cooperative Institute for Arctic Research (CIFAR) was established through a Memorandum of Understanding between NOAA and the University of Alaska in April 1994. It is one of eleven national NOAA–University joint institutes. The goal of these institutes is to promote closer cooperation between researchers from NOAA laboratories and universities. CIFAR is the only joint institute exclusively concerned with arctic research and cooperates most closely with NOAA's Pacific Marine Environmental Laboratory (PMEL) in Seattle.

With a new 5-year cooperative agreement in place as of 1 July 2001, CIFAR looks forward to its continuing partnership with NOAA in supporting research addressing critical issues in the Arctic. During the first year of this cooperative agreement, projects totaling over $4.8M were funded. Research supported by CIFAR falls under several general research themes that characterize the scope of interest of the Institute. Thematic emphasis has changed somewhat from year to year but the themes have remained focused on the big problems of arctic research (see box).

During the period 1 July 2001 to 30 June 2002, 30 projects were supported. A full list of these projects is presented in Appendix 1. Research funded through CIFAR consisted of: 1) projects funded through the Arctic Research Initiative; 2) projects funded to address the decline of the western population of Steller's sea lion; and 3) projects funded individually by NOAA addressing CIFAR's research themes.

CIFAR RESEARCH THEMES

Atmospheric and Climate Research
- Arctic Oscillation
- Arctic clouds and energy balance
- Paleoclimates

Climate Modeling
- Coupled models
- Model inter-comparisons

UV and Arctic Haze Studies
- Ozone and UV radiation
- Arctic Haze

Marine Ecosystem Studies
- South Eastern Bering Sea Carrying Capacity (SEBSCC)
- Bering Sea productivity

Fisheries Oceanography
- Global Ocean Ecosystem Dynamics Program (GLOBEC)
- Fisheries studies

Hydrographic and Sea Ice Studies
- Sea ice research
- Tides and currents
- Ocean fluxes and circulation

Tsunami Research

Contaminant Effects
- Arctic pollution
- Effects on indicator species

Data Archiving and Support

Arctic Research Initiative

In FY 2001, CIFAR released an announcement of opportunity for the continuation of the Arctic Research Initiative, a competitive grant program begun in 1997 that addresses topics of interest to NOAA and is managed by CIFAR.

The 2001 Arctic Research Initiative had two research foci. The first was on climate variability and change in the Arctic, emphasizing the transport of freshwater, heat and nutrients to and from the Arctic, and a better understanding of the Arctic Oscillation. The second focus was on the productivity of the Bering Sea, the natural processes regulating productivity and the flow of energy through food webs supporting commercial, subsistence and protected or endangered species.

A total of 12 two-year projects were funded for just over $1M for the first year, with ~$575K funded through CIFAR and the remainder funded directly by NOAA. A list of these projects is presented in Table 1. Project abstracts are posted on the CIFAR web site, http://www.cifar.uaf.edu, and the progress reports in this document will also be posted there. Two of these projects (PIs Jennifer Francis, Rosanne D'Arrigo) did not receive their funds in time to make significant progress during this reporting period. Their reports will appear in the 2003 CIFAR Annual Report.

Table 1: 2001–2002 Arctic Research Initiative Awards

PI	Institution	Project Title	Award Yr 1
Funded through CIFAR			
Igor Belkin	Univ. of Rhode Island	Ocean Fronts of the Bering, Chukchi and Beaufort Seas	$ 39,586
Rosanne D'Arrigo	Columbia Univ.	Paleoclimatic Reconstruction of the Arctic Oscillation	$ 85,946
Jennifer Francis (with Key)	Rutgers Univ.	Interactions of Laterally Advected Heat and Moisture with Arctic Cloud Properties	$ 67,751
Lyn McNutt (with Overland)	Univ. of Alaska Fairbanks	Do Recent Changes in Sea Ice and Snow Cover Impact the Arctic Oscillation?	$ 16,912
Alan Springer	Univ. of Alaska Fairbanks	Trophic Pathways on the Chukchi-Beaufort Shelf: Where do the Ice Algae Go?	$ 208,657
John Walsh	Univ. of Illinois	An Arctic Archive of Model Output and Application to SEARCH	$ 75,347
Daqing Yang	Univ. of Alaska Fairbanks	Hydrologic Response of Siberian Major Rivers to Climate Change and Variation	$ 31,325
Subaward costs	Univ. of Alaska Fairbanks		$ 47,100
Subtotal CIFAR			**$ 572,624**
Funded directly by NOAA			
Jeffrey Key (with Francis)	CIMSS	Interactions of Laterally Advected Heat and Moisture with Arctic Cloud Properties	$ 38,537
Jim Overland (with McNutt)	NOAA/PMEL	Do Recent Changes in Sea Ice and Snow Cover Impact the Arctic Oscillation?	
Andrey Proshutinksy	CICOR	Variability of Thermohaline Circulation and Freshwater Storage in the Arctic Ocean	$ 125,000
Peter Rhines	U. Washington/ JISAO	Observation and Modeling of the Freshwater Dynamics Connecting the Arctic and Atlantic: A Feasibility Study	$ 150,000
Joseph Shaw	NOAA/ETL	Temporal and Spatial Variability of Alaskan Clouds Studied with a Ground-based Infrared Cloud Imager	$ 55,000
John Weatherly	CRREL	Connections between Arctic–Subarctic Ocean Fluxes and the Arctic Oscillation	$ 38,606
Subtotal NOAA			**$ 458,143**
TOTAL ARI			**$1,030,767**

Steller's Sea Lion Research

In FY 2001, NOAA received supplemental funding to provide scientific support for management decisions regarding fisheries and marine mammal interactions in the Gulf of Alaska and Bering Sea. The western population of Steller's sea lion (SSL) has been in decline for several decades and is now considered endangered. There are several possible factors causing this decline. One of these factors is commercial fishing in habitats critical to the SSL, thought to cause a harmful reduction in SSL prey availability. Current management efforts are focused on this factor alone. To determine if other factors might be important in the decline of the western SSL population, NOAA was directed to conduct research focused on two of the other hypothesized factors—impacts of ocean climate regime shifts and changes in predator/prey relationships. The NOAA Office of Oceanic and Atmospheric Research and the NOAA National Ocean Service asked CIFAR to help organize the scientific community to respond to these needs. CIFAR released an announcement of opportunity in February 2001. A total of 12 projects were funded in this competition at a total level of $3.8M for two years, with about $2.5M funded through CIFAR. The list of projects is presented in Table 2. Abstracts for the Steller's sea lion awards are posted on the CIFAR web site, http://www.cifar.uaf.edu, and the progress reports in this document will also be posted there.

Research Themes

Twelve of the projects funded during the period 1 July 2001 to 30 June 2002 were individually funded by NOAA and address CIFAR research themes. The project "Persistent Organic and Trace Element Pollutants in the Alaskan and Eastern Russian Arctic" addresses the Contaminants theme. It is part of the Study of Atmospheric Deposition of Contaminants in the Arctic, jointly funded by NOAA and the U.S. State Department. A key scientific objective is to

Table 2: 2001-2002 Steller's Sea Lion Research Awards

PI	Institution	Project Title	2-Year Total
Funded through CIFAR			
Matt Berman (with McBeath)	Univ. of Alaska Anchorage	Decision-making Under Uncertainty: Management of Commercial Fisheries and Marine Mammals	$ 54,172
Jennifer Burns	Univ. of Alaska Anchorage	The Role of Physiological Constraint in the Acquisition of Foraging Ability: Development of Diving Capacity in Juvenile Steller Sea Lions	$ 153,924
Ken Coyle (with Hunt)	Univ. of Alaska Fairbanks	Climate-driven Bottom-up Processes and Killer Whale Abundance as Factors in Steller Sea Lion Population Trends in the Aleutian Islands	$ 694,218
Ron Dearborn	Univ. of Alaska Fairbanks	Publication Support for Is It Food II? A Workshop on Steller Sea Lion Declines	$ 23,300
Bruce Finney	Univ. of Alaska Fairbanks	Impacts of Climate Change on the Bering Sea Ecosystem over the Past 500 Years	$ 198,507
Robert Foy	Univ. of Alaska Fairbanks	Seasonal Assessment of Prey Competition between Steller Sea Lions and Walleye Pollock	$ 202,308
Gerald McBeath (with Berman)	Univ. of Alaska Fairbanks	Decision-making Under Uncertainty: Management of Commercial Fisheries and Marine Mammals	$ 65,828
Stephen Okkonen (with Maslowski)	Univ. of Alaska Fairbanks	Interannual Variability of Biophysical Linkages between the Basin and Shelf in the Bering Sea	$ 113,340
Thomas Royer	Old Dominion Univ.	Ocean Climate Variability as a Potential Influence on Steller's Sea Lion Populations	$ 192,548
Jan Straley (joint with Trites)	Univ. of Alaska Fairbanks	Predator/Prey Investigations of Killer Whales and Steller Sea Lions in Alaska	$ 32,655
Richard Thorne (with Churnside)	Prince William Sound Sci. Ctr.	Investigation of the Foraging Behavior of Steller Sea Lions in the Vicinity of Kodiak Island, Alaska	$ 541,200
Andrew Trites (with Straley)	North Pacific Marine Sci. Fdn.	Predator/Prey Investigations of Killer Whales and Steller Sea Lions in Alaska	$ 168,165
Subaward costs	Univ. of Alaska Fairbanks		$ 35,325
Total CIFAR			**$2,475,490**
Funded directly by NOAA			
Steven Bograd, Michael Alexander, Arthur Miller	NOAA/NMFS NOAA/CDC UCSD/JIMO	North Pacific Climate Variability and Steller Sea Lion Ecology: A Retrospective and Modeling Analysis	$ 155,000 $ 58,190 $ 250,000
James Churnside (with Thorne)	NOAA/ETL	Investigation of the Foraging Behavior of Steller Sea Lions in the Vicinity of Kodiak Island, Alaska	$ 156,300
George Hunt (with Coyle)	UC Irvine/JIMO	Climate-driven Bottom-up Processes and Killer Whale Abundance as Factors in Steller Sea Lion Population Trends in the Aleutian Islands	$ 405,634
Wieslaw Maslowski (with Okkonen)	Naval Post-graduate School	Interannual Variability of Biophysical Linkages between the Basin and Shelf in the Bering Sea	$ 92,648
Edward Miles	U. Washington/ JISAO	Retrospective Studies of Climate Impacts on Alaska Steller Sea Lions	$ 149,490
Donald Percival	U. Washington/ JISAO	The Temporal and Spatial Nature of Regime Shifts and their Impact on Steller Sea Lions	$ 120,000
Subtotal NOAA			**$1,387,262**
TOTAL SSL			**$3,862,752**

study the sources, occurrence and environmental fate of persistent organic herbicides, pesticides, industrial chlorinate compounds, and aerosol trace elements in the atmosphere of the Alaskan and Eastern Russian Arctic. This project is in the initial stages of sampling and analysis.

Eight of the funded projects fall under the Fisheries Oceanography theme. In any given year, the largest number of individually funded projects are usually in this area. The fisheries of the Arctic, particularly the Bering Sea, are among the most productive in the world. The productivity and sustainability of these fisheries have been the focus of numerous CIFAR-funded research projects. Research focused primarily on the most important fish stocks in various regions, including salmon and pollock. Funding also included ship support for a Global Ocean Ecosystem Dynamics Program (GLOBEC) project, “Physical-Chemical Structures, Primary Production and Distribution of Zooplankton and Planktivorous Fish on the Gulf of Alaska Shelf: A GLOBEC Monitoring Proposal.” Two of these projects (PIs Stephen Jewett and Sathy Naidu) received their funds in April 2002 and will report on progress in the 2003 CIFAR Annual Report.

The project entitled “Observational and Theoretical Foundation for the Dynamics in a High-resolution Sea Ice Model” addresses CIFAR’s Hydrographic and Sea Ice Studies theme; it is a continuation from CIFAR’s last 5-year cooperative agreement. Work in 2001–2002 focused on providing remote sensing observational support for buoy deployment in the Beaufort Sea.

Finally, three of the projects address the Tsunami research theme. Two of these projects are continuations of work begun under CIFAR’s last cooperative agreement. A new project entitled “Tsunami Warning and Environmental Observatory for Alaska” is designed to create an integrated observatory for tsunami research aimed toward reducing the hazards in Alaska presented by tsunamis from large earthquakes and undersea landslides, and to provide near-real-time oceanographic fisheries and weather data.

Publications and Presentations

At this early stage of the new cooperative agreement, one workshop proceedings volume has been published and five papers from projects receiving their funding through CIFAR are in press:

DeMaster, D., and S. Atkinson, Eds. (2002) *Steller Sea Lion Decline: Is It Food II*, University of Alaska Sea Grant, AK-SG-02-02, 80 pp.

McNutt, S.L. and J.E. Overland (In press) Understanding the spatial hierarchy in Arctic sea ice dynamics. *Tellus*.

Richter-Menge, J.A., S.L. McNutt, J.E. Overland, and R. Kwok (In press) Relating Arctic pack ice stress and deformation under winter conditions. *Journal of Geophysical Research*.

Serreze, M.C., D. Bromwich, M.P. Clark, A.J. Etringer, T. Zhang, and R. Lammers (In press) The large-scale hydroclimatology of the terrestrial Arctic drainage system. *Journal of Geophysical Research*.

Yang, D., D. Kane, L. Hinzman, X. Zhang, T. Zhang, and H. Ye (In press) Siberian Lena river hydrologic regime and recent change. *Journal of Geophysical Research*.

Ye, H. (In press) Observed regional and climatological associations between spring and summer precipitation over northern central Eurasia. *Water Resource Research*.

In addition, eight papers have been reported as submitted or in preparation, and eight presentations have been made at national and international meetings.

These numbers do not include presentations or publications from Arctic Research Initiative and Steller's sea lion projects funded at NOAA laboratories, other federal agencies, or through other joint institutes.

Project Reports:
Arctic Research Initiative

***Progress Report*: Ocean Fronts of the Bering, Chukchi and Beaufort Seas**

***Principal Investigator*: Igor M. Belkin, Graduate School of Oceanography, University of Rhode Island**

Objectives

The main goal of the project is to produce an up-to-date climatology of all major fronts of the study area and explore the seasonal and interannual variability of the frontal pattern and individual fronts as well as their relations to environmental parameters. Both satellite and in situ data have to be used. The main objectives of the project are summarized as follows:

1. Surface thermal fronts detection and mapping from satellite SST data.
2. Long-term seasonal climatology of SST fronts from satellite data.
3. Assembling a dataset of cross-frontal hydrographic sections.
4. Determination of fronts from the hydrographic sectional database.
5. Tracking major fronts of the Bering Sea in the alongshelf direction from Bristol Bay toward the Bering Strait and into the Chukchi Sea.
6. Interannual variability studies of major fronts; detection of possible climatic trends.
7. Elucidation of relations between fronts and environmental parameters (bottom topography, sea ice cover, air temperature, river runoff, Bering Strait transport, and wind stress) on a variety of scales, from seasonal to interannual to decadal.

Methods

Satellite SST data from AVHRR sensors flown on NOAA satellites have been processed using the front detection and cloud screening algorithms developed at the University of Rhode Island [*Cayula and Cornillon*, 1995, 1996; *Ullman and Cornillon*, 2000]. The front detection algorithm uses a histogram approach at three levels (window, image and a sequence of overlapping images). For each window or image that contains a front (a relatively narrow zone of enhanced SST gradient), the corresponding SST histogram would have a minimum identified with the front. Two types of maps are used in the analysis: long-term frontal *frequency maps* and quasi-synoptic frontal *composite maps*. The long-term frontal *frequency maps* show the pixel-based frequency F of fronts normalized on cloudiness: For each pixel, F=N/C, where N is the number of times the given pixel contained a front, and C is the number of times the pixel was cloud-free. Thus, the frequency maps are best suited for displaying the most stable fronts. Some fronts, however, meander and shift, thus defying their presentation with frequency maps, in which case quasi-synoptic frontal *composite maps* are most helpful because they portray all the fronts detected in synoptic SST fields within a given time period.

Main Results

Mapping SST fronts from Pathfinder data in the Bering, Chukchi and Beaufort Seas. Surface thermal fronts have been detected from individual twice-daily SST images with 9-km resolution, then composed into monthly frontal maps. For each of the three seas, Bering, Chukchi and Beaufort Sea, a set of 144 monthly frontal composite maps, 1985–1996, has been produced and analyzed, as well as a set of 12 long-term monthly frontal frequency maps.

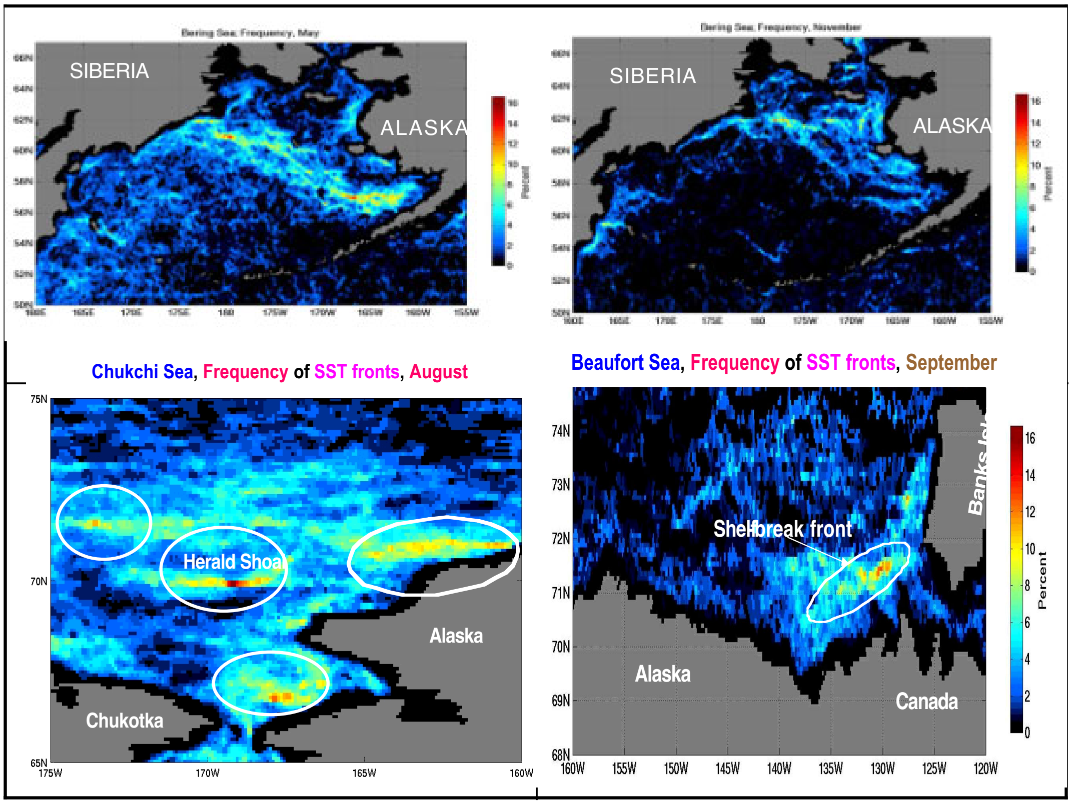
Long-term seasonal climatology of SST fronts. The Bering Sea in May (Figure, upper left panel) features a well-defined front from Bristol Bay to Cape Navarin. The front is not isobathic: it is located over shallow depths (~50 m) in Bristol Bay but continues over the outer shelf (100–200 m depth) farther west. The front does not correspond to any of the major known fronts (inner, middle, or outer) since these fronts are believed to be isobathic [e.g. *Coachman*, 1986]. The front is located about 1° of latitude south of the edge of sea ice cover and therefore appears to be related to the marginal ice zone processes. We suggest that the front represents an imprint left in the ocean by the receding sea ice cover. In November, several fronts extend SE–NW over the shelfbreak, outer shelf and inner shelf (Figure, upper right panel). The shallow fronts inshore of the 50-m isobath seem unrelated to the tidal mixed front associated with the 50-m isobath [e.g. *Coachman*, 1986]. Two fronts in the northwest correspond to the northward Anadyr Current and southward Kamchatka Current, both being branches of the Bering Slope Current.

The Chukchi Sea in August (Figure, bottom left panel) has several fronts. The Bering Strait inflow front makes a cyclonic incursion into Kotzebue Sound. Farther north, a front extends zonally toward Point Barrow. Another front hugs the steep southern flank of Herald Shoal. Other fronts are associated with the Chukotkan segment of the Siberian Coastal Current and its northeastern extension that veers offshore around Wrangel Island to pass through Herald Valley, then continues eastward at ~72°N north of Herald Shoal.

The Beaufort Sea in September features a robust shelf-break front (Figure, bottom right panel). The front is the most stable where the slope is the steepest, off Cape Bathurst, suggesting a strong topographic control.

Future work. The satellite-derived frontal locations will be used for selection of cross-frontal hydrographic sections from the World Ocean Database 2001 and other sources.

Surface thermal fronts from the Pathfinder SST data



References

Cayula, J.-F. and P. Cornillon (1995) Multi-image edge detection for SST images. *J. Atmos. Oceanic Tech.*, **12**(4), 821–829.

Cayula, J.-F. and P. Cornillon (1996) Cloud detection from a sequence of SST images. *Remote Sensing of Environment*, **55**(1), 80–88.

Coachman, L.K. (1986) Circulation, water masses, and fluxes on the southeastern Bering Sea shelf, *Cont. Shelf Res.*, **5**(1/2), 23–108.

Ullman, D.S. and P.C. Cornillon (2000) Evaluation of front detection methods for satellite-derived SST data using in situ observations, *J. Atmos. Oceanic Tech.*, 17(12), 1667–1675.

Publications and Presentations

Belkin, I.M. (2002) Fronts of the Arctic/Subarctic Seas from Pathfinder satellite SST data, presented at the Arctic Ocean Circulation Workshop, June 17–20, 2002, Lamont-Doherty Earth Observatory, Palisades, NY.

Belkin, I.M. (2002) Fronts of the Bering, Chukchi, and Beaufort Seas: a review. In preparation.

***Progress Report*: Interactions of Laterally Advected Heat and Moisture with Arctic Cloud Properties**

Principal Investigator: Jeffrey R. Key, Office of Research and Applications, NOAA/NESDIS, Madison, Wisconsin

Other Participating Researchers: Jennifer Francis, Rutgers University; Steven A. Ackerman, Cooperative Institute for Meteorological Satellite Studies (CIMSS), University of Wisconsin-Madison

Purpose

This report serves as summary of progress for the first year of this SEARCH (Study of Environmental Arctic Change) project. It covers work done at the Cooperative Institute for Meteorological Satellite Studies (CIMSS), University of Wisconsin-Madison (UW) only. The project PI at Rutgers University, Jennifer Francis, will provide a separate progress report for activities at that institution. Rutgers is the lead institution on this project. [Ed. note: Due to a delay in funding, the Rutgers report will appear in the next CIFAR Annual Report.]

Objectives

Our overriding hypothesis is that the patterns of heat and moisture transport into and within the Arctic basin have changed significantly during the past 20 years, and that they are strongly linked to changes in cloud properties and the Arctic Oscillation (AO). The specific objectives of the study are:

1. Compute the advection of sensible heat and moisture over the Arctic basin from 20 years of TOVS Polar Pathfinder soundings of temperature and moisture. Poleward and zonal components of transport will be computed for each season and in three thick layers of the atmosphere. *This work is being done at Rutgers.*
2. Perform spatial and time-series analyses on fields of advective heat and moisture transport to identify statistically significant regional changes during the 20-year data record, particularly comparing the pre- and post-1989 periods when other parameters appear to exhibit a significant shift in regime. *This work is being done at Rutgers*.
3. Compute cloud fractions and bulk microphysical cloud properties in selected regions and time periods with the largest advective changes. For comparison, we will also investigate selected locations where little or no change is apparent. *This work is being done at CIMSS*.
4. Investigate the extent to which observed spatial and temporal variability in advective fluxes and cloud characteristics are related to variations in the AO. *This work is being done at CIMSS and Rutgers*.
5. Examine cloud properties in areas of large advective change to identify likely linkages with heat and moisture transport. Compare these relationships to those in areas where advective fluxes exhibit no significant trends. *This work is being done at CIMSS and Rutgers*.
6. Determine the source(s) of observed changes. Are observed trends or discontinuities in the heat (moisture) advection patterns caused by changes in the thickness (water vapor) gradients and/or changes in the wind field, and do these factors differ with region, season, and/or height? Can differences in cloud properties be attributed to changes in moisture convergence? *This work is being done at CIMSS and Rutgers*.

The division of tasks between UW/CIMSS and Rutgers is such that CIMSS is primarily responsible for cloud properties from the AVHRR, while Rutgers is responsible for the analysis of advection from TOVS. Linkages between clouds and advective processes will be investigated by scientists at both institutions.

Personnel

The project manager and lead scientist at UW/CIMSS is Jeff Key. Key is a NOAA/NESDIS employee co-located at UW's Cooperative Institute for Meteorological Satellite Studies. Xuanji Wang, a Ph.D. student in the Atmospheric and Oceanic Sciences department, performs most of the data analysis.

Summary of Accomplishments

Our accomplishments for the first project year include:

1. Satellite retrieval techniques for use with the AVHRR Polar Pathfinder (APP) dataset have been refined and validated. Retrieved parameters are surface temperature, surface albedo, cloud properties (particle phase, effective radius, optical depth, temperature, and pressure), and radiative fluxes. Data from the SHEBA experiment and two Antarctic meteorological stations have been used for validation.
2. 18 years of APP data have been acquired and processed. The twice daily data cover the period 1989–1999 at a spatial resolution of 25 x 25 km. Monthly and seasonally averaged products were also created and archived.
3. The spatial and temporal distributions of surface, cloud and radiation properties have been examined.
4. Trends in surface and cloud properties, as well as their statistical significance, have been investigated. The area north of 60° latitude has been cooling at the surface during the winter, but warming at other times of the year. The surface albedo has decreased, particularly during the autumn months. Cloud amount has been decreasing during the winter but increasing in spring and summer. Interestingly, although there are trends in the shortwave (cooling) and longwave (warming) cloud radiative effects, the net (all-wave) cloud

radiative effect shows no trend. This is a result of the fact that the shortwave and longwave effects are similar in magnitude over bright surfaces with low sun angles, and effectively cancel each other.

5. Time series of surface temperature and cloud amount have been compared to the Arctic Oscillation (AO) and North Atlantic Oscillation (NAO) monthly indices through a cross correlation analysis. As expected, the satellite data show that when the AO and NAO are in their high phases, Greenland is colder than normal and northern Europe is warmer than normal.

Data Products

A dataset consisting of retrieved surface properties, cloud properties and radiative fluxes for the area north of 60^{o}N was generated. Products in this dataset include twice daily and monthly parameter images and means. The data and read routines will be made available to the public in the near future.

Plans for the Next Project Year

During the second project year the individual cloud and advection datasets (AVHRR and TOVS, respectively), will be examined jointly. Relationships between cloud properties and heat and moisture advection will be investigated. Specifically we will

- Collocate Path-P and APP data in space and time
- Begin cross-correlation of advection fields and cloud properties
- Select regions and time periods for in-depth analysis
- Complete analysis of spatial/temporal relationships between advection and clouds
- Perform regression analyses to relate advection and clouds to AO
- Prepare manuscript(s) presenting results of analyses
- Prepare dataset documentation and ancillary information
- Deliver datasets to NSIDC

Publications

Wang, X., and J. Key (2002) The Arctic climate and its change revealed by surface and cloud properties and radiation fluxes based on the AVHRR Polar Pathfinder dataset, to be published in *Proceedings of the SPIE 47th Annual Meeting*, Seattle, WA, 7–11 July 2002.

Wang, X. and J. Key (2002) Arctic climate characteristics and recent trends based on the AVHRR Polar Pathfinder dataset, to be published in *IGARSS'02 Proceedings*, Toronto, 24–28 June 2002.

Wang, X., and J. Key. Recent trends in Arctic climate based on the AVHRR Polar Pathfinder dataset. In preparation for submission to *Journal of Climate*.

Wang, X., and J. Key. A warmer but cloudier Arctic: Recent trends in satellite data. In preparation for submission to *Nature*.

***Progress Report*: Do Recent Changes in Sea Ice and Snow Cover Impact the Arctic Oscillation?**

***Principal Investigator*:** Lyn McNutt, Geophysical Institute, University of Alaska Fairbanks

***Other Participating Researchers*:** James Overland (project PI), PMEL/NOAA, Seattle, Washington

Methods and Main Results

This fiscal year has focused on collection, analysis and verification of sea ice data for the Western Arctic Ocean (Beaufort and Chukchi Seas) in support of the project PI, Dr. James Overland, NOAA, PMEL. These data activities include:

- Identification of NOAA Advanced Very High Resolution Radiometer data for 1989–1998 and 1980–1988,
- Collection of Polar Pathfinder data sets for TOVS, SSM/I and AVHRR, and
- Assembling a detailed dataset of Synthetic Aperture Radar (SAR) data for1997–1998 during the SHEBA field experiment.

The Co-I, Lyn McNutt, worked on validation of the snow and ice data, and contributed to discussions of the case selections, compositing methodology, and interpretation of the results.

For details on the further analyses, please see the report submitted by the Project PI, Dr. James Overland.

***Progress Report*:** **Do Recent Changes in Sea Ice and Snow Cover Impact the Arctic Oscillation?**

***Principal Investigator*:** James E. Overland, Pacific Marine Environmental Laboratory/NOAA, Seattle, Washington

***Other Participating Researchers*:** N.A. Bond, JISAO, University of Washington; S.L. McNutt, University of Alaska Fairbanks

Objectives

i) How do low-level anomalous radiative and temperature fields in late spring relate to large-scale climate variability, especially in association with the AO?
ii) To what degree do surface conditions feed back onto atmospheric structure in summer and early fall?

Methods

We make use of gridded fields: NCEP reanalysis for vertical profiles of winds, temperature, radiation, and moisture; TOVs for temperature fields, and SSM/I data for ice and snow cover. These are analyzed by various compositing and analytical techniques using atmospheric metrics such as vorticity. We strongly rely on visual inspection and semi-quantitative analysis of weather events.

Main Results

In the previous year, we emphasized that the springtime warming in northwestern North America in the 1990s relative to the 1980s was associated with anomalous atmospheric circulation related to the Arctic Oscillation (AO). However, the relation is indirect. The local temperature anomalies are related to an increase of short warm air advection events. The warm anomalies thus lag the main AO circulation changes in the lower stratosphere.

Early Summer: Our chief result in the present year is to note the influence of the moisture field in establishing Arctic climate anomalies over the summer. In years with warm spring temperature anomalies, there is an early snow melt and ice retreat in the western Arctic. Although summer temperatures are constrained over sea ice to be near the freezing point, there are increased moisture anomalies throughout the summer. Our hypothesis is that these anomalies carry the memory of springtime anomalies into the fall. Our data shows that in high humidity years, there are warm temperature anomalies in September, after sea ice no longer operates as an ice/water bath.

Heat Budgets: In support of these qualitative results, we have quantified the role of diabolic processes, in particular, the radiative and turbulent heat fluxes, and water phase changes, on the heat budget at low levels. The principal result is that these effects in the net, act to cool the lower troposphere in the Western Arctic at the rate of about 22 Wm^{-2} more in the 1990s than the 1980s. This implies a new importance of dynamic processes (anomalous horizontal advection) over thermodynamic processes. Thus, while the lower troposphere and lower stratosphere are decoupled in summer, surface conditions do play a role in lower level atmospheric anomalies. Thus, there is a complicated interaction over the year, with summer surface conditions contributing to the troposphere while the winter troposphere is dominated by stratospheric influences.

Publications and Presentations

Overland, J.E., M. Wang, and N.A. Bond (2002) Recent temperature changes in the western Arctic during spring. *Journal of Climate* 15: 1702–1716.

Stabeno, P.J., and J.E. Overland (2001) The Bering Sea shifts toward an earlier spring transition. *EOS Transactions, AGU* 82: 317–321.

Wang, M., J.E. Overland, and N.A. Bond (2002) The climate change in the western Arctic during the last two decades. *13th Symposium on Global Change and Climate Variations*, American Meteorological Society. pp. 40–41.

J.E. Overland gave invited presentations at the 2001 and 2002 Arctic Forums.

***Progress Report*:** **Variability of Thermohaline Circulation and Freshwater Storage in the Arctic Ocean**

***Principal Investigator*:** Andrey Proshutinsky, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts

The major goal of this project is to investigate the variability of the thermohaline circulation and freshwater storage in the Arctic Basin under the influence of different climate regimes based on analysis of existing data and numerical modeling.

Project objectives are to:

- Determine and document the variability of fresh water storage and thermohaline circulation of the Arctic Ocean;
- Identify the ocean response (freshwater storage and thermohaline circulation) to the seasonal, interannual and the apparent 10–15-year cycle of atmospheric circulation modes (Proshutinsky and Johnson, 1997) in the Arctic.

Project scientific questions are:

- What is the mechanism for accumulation of fresh water in the center of the Beaufort Gyre?
- Is this fresh water transported to the North Atlantic and what are the conditions that influence its rate of transport?
- What is the primary driver of the Arctic Ocean circulation, thermohaline or wind-driven forcing?
- How does the wind-driven circulation change the thermohaline structure and resultant circulation seasonally, annually, and decadally?

The present state of the Arctic Ocean and its influence on the global climate system strongly depend on the Arctic Ocean freshwater budget (*Aagaard and Carmack*, 1989, hereinafter *A&C*) because fluctuations in the freshwater export can significantly influence the depth and volume of deep water formation in the North Atlantic (NA) and ultimately the strength of the global thermohaline circulation. The traditional approach for investigations of the freshwater budget of the Arctic Ocean has been to perform a detailed analysis of its major components including river runoff, the inflow of waters from the Atlantic and Pacific Oceans, the outflows through Fram Strait and the Canadian Archipelago, the atmospheric moisture flux and the annual cycle of ice formation and melt (see *Lewis* [2000]). Significantly less attention has been paid to the processes involved in the storage of FW in the Arctic Ocean and its temporal variability. The regional differences in this storage (e.g., in sea ice thickness and in ocean salinity) are substantial (*A&C*; *Steele et al*., 1996). For instance, the Canadian Basin of the Arctic Ocean contains about 45,000 km^3 of fresh water (calculated relative to the salinity 34.80 by *A&C*). This is 10–15 times larger than the total annual river runoff to the Arctic Ocean, and at least two times larger than the amount of fresh water (FW) stored in the sea ice. A release of only 5% of this FW is enough to cause a salinity anomaly in the North Atlantic comparable in magnitude to the Great Salinity Anomaly of the 1970s. The largest of the anomalies is located in the Beaufort Gyre (BG), identified by a salinity minimum at depths 5–400 m (Fig. 1A–C.). This anomaly drives the BG geostrophic circulation anticyclonically (Fig. 1D). We propose that the freshwater budget of the BG and the freshwater flux to the NA depend significantly on the intensity of this salinity anomaly and climatic conditions conducive to the transport of FW from the BG to the NA.

The origin of the salinity minimum in the BG can be inferred by a comparison of the seasonal change in wind and sea ice motion. Fig. 2 shows the wind and ice drift patterns seasonally averaged for the period 1979–1997. In winter (September–May), the wind (Fig. 2A) drives the ice and ocean anticyclonically (Fig. 2C) and the ocean accumulates potential energy through a deformation of the salinity field (Ekman convergence and subsequent downwelling, see Fig. 1C). The strength of the horizontal salinity gradient and resultant geostrophic circulation depend on the intensity and duration of the anticyclonic winds. During the winter season the wind-driven and geostrophic currents coincide to set up a strong anticyclonic ice rotation (Fig. 2C).

In summer (June–August), the wind is weaker or it may even be cyclonic (Fig. 2B) but in the mean the ice still rotates anticyclonically (Fig. 2D). An obvious conclusion is that in summer the ocean geostrophic circulation prevails and drives the ice against the wind motion. The salinity anomaly and freshwater content (FC) in the BG (Fig. 1B) must decrease in summer, because without wind support, the ocean loses potential energy, i.e., Ekman pumping is reduced. During the following winter the ocean again accumulates potential energy. Hence, the climatic structure of the salinity and dynamic height distribution remain rather persistent (not shown) although exhibiting

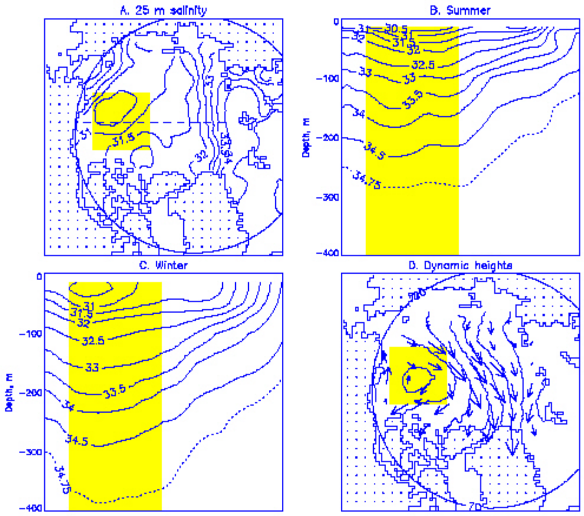


Figure 1. **(A)** The salinity distribution at 25m. **(B), (C)** Salinity distribution along dashed line in summer and winter. **(D)** Dynamic heights relative to 200 db and direction of geostrophic currents.

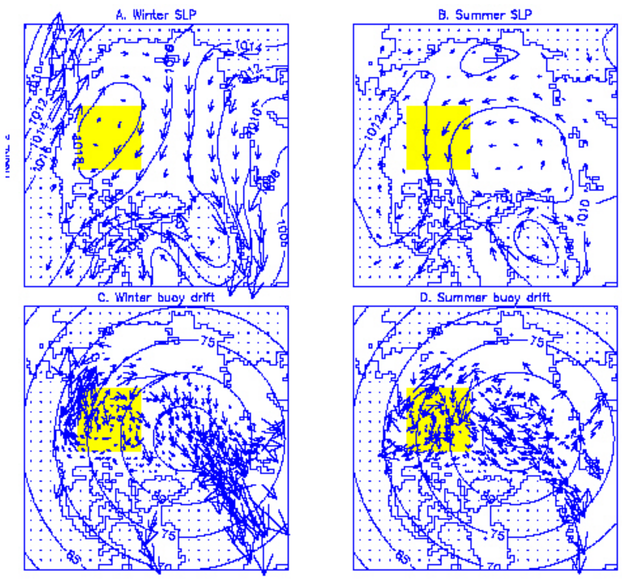


Figure 2: Winter **(A)** summer **(B)** sea level pressure (SLP, hPa) and geostrophic wind. **(C), (D)** Season sea ice drift.

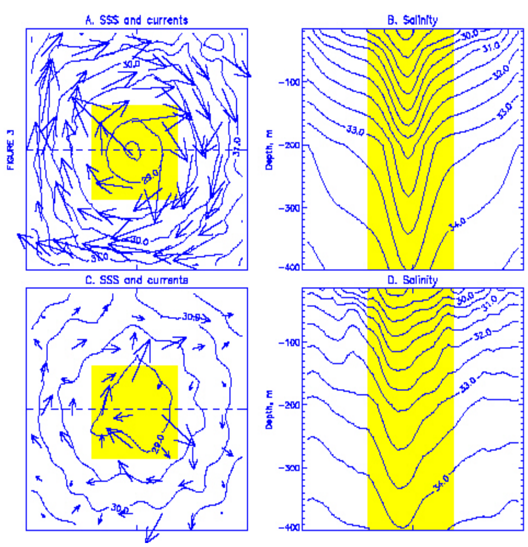


Figure 3. Results of numerical experiments in the ideal basin. **(A)** Sea surface salinity (SSS) and surface currents. **(B)** Salinity section along dashed line. Both figures show results after 9 months of anticyclonic symmetric wind forcing. **(C), (D)** The same characteristics as in (A) and (B), respectively, but after an additional 3 months of symmetric cyclonic wind forcing.

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some seasonal and interannual variability. When viewed on a seasonal scale, the BG salinity anomaly stabilizes the circulation, remaining essentially anticyclonic throughout the year, thus permitting the BG geostrophic circulation cell to serve as a flywheel for the Arctic Ocean circulation.

Some modeling results confirming this mechanism are shown in Fig. 3. An idealized situation has been tested using a 3-D *Blumberg and Mellor* [1987] numerical model in a 2000x2000 km basin with 1500 m depth. The basin was initially horizontally uniform but vertically stratified, then it was forced for 9 months by symmetric anticyclonic winds followed by 3 months of cyclonic symmetric winds. The anticyclonic winds generate downwelling in the central basin and upwelling along the boundaries (Figs. 3A–B). The results after anticyclonic forcing only are similar to the winter Arctic conditions, and the salinity structure in Fig. 3B resembles that in Fig. 1C. The addition of cyclonic winds leads to upwelling in the central basin and downwelling along the boundaries and to a reduction in the anomaly in the salinity field generated by anticyclonic winds. The distribution of salinity and currents after 3 months of cyclonic wind forcing are shown in Figs. 3C–D. The circulation pattern in Fig. 3C is similar to the ice drift pattern in Fig. 2D, i.e., it is still anticyclonic but is weaker than in winter. The salinity distribution in Fig. 3D resembles the summer salinity distribution in Fig. 1B when the cyclonic wind forcing leads to the release of FW from deep to upper layers. The seasonal variability of FW content in the central part of the basin is about 10% (not shown).

Hypothesis

A hypothetical chain of relationships among atmosphere, ice and ocean in the Arctic at the decadal time scale has been proposed by *Mysak and Venegas* [1998], *Proshutinsky et al.* [1999] (hereinafter *P99*) and others but it is important to know what causes the variability. In order to explain the relationship between the wind-driven and geostrophic circulation and their influence on the accumulation and release of FW we examine the interplay between the atmosphere, ice and ocean in terms of the two circulation regimes identified by *Proshutinsky and Johnson* [1997] (hereinafter *P&J*) and *P99*.

ACCR

During the anticyclonic circulation regime (ACCR), when high atmospheric pressure prevails in the Arctic, the Arctic Ocean accumulates FW through the increase of FW volume in the BG (Ekman convergence and subsequent downwelling, see Fig. 1C) and through the increase of ice thickness and area due to enhanced ice growth (the Arctic is colder during an ACCR than a cyclonic circulation regime (CCR) as shown in *P99*). Ice is additionally accumulated in the BG during an ACCR due to convergence and ridging under anticyclonic wind forcing. River runoff is increased (trajectories of cyclones are shifted toward land) (*P&J*; *Johnson et al*., 1999) and more FW accumulates in the surface waters. When anticyclonic winds are prevalent, the flow of Arctic waters towards Fram Strait is reduced (*P&J*; *Trembley and Mysak*, 1998). Consequently, the ice and water flux from the Arctic Ocean to the Greenland Sea and the transport of Atlantic Water into the Arctic Ocean (as a compensation of outflow) are weaker than usual. Deep convection in the Greenland Sea is then enhanced because the vertical stratification is reduced (less FW in the surface waters). This decoupling of the Greenland, Iceland, and Norwegian Seas (GIN Sea) from the Arctic leads to their eventual warming.

Transition to a CCR

All of the above processes lead (with some time lag) to an increase in the gradient of dynamic height between the BG and the NA. The resultant geostrophic circulation increases, as does the outflow of FW and ice from the Arctic. During warming of the GIN Sea, the Icelandic Low intensifies and moves to the north, leading to an intensification of the transport of Atlantic waters into the Arctic Ocean. This increase in warm water flux to higher latitudes enhances the penetration of atmospheric cyclones into the Arctic, and ultimately decreases the atmospheric pressure in the Arctic. Warming of the Arctic establishes the CCR.

CCR

During the cyclonic circulation regime, when low atmospheric pressure prevails in the Arctic (see table characterizing different environmental features of CCR and ACCR in *P99*), the Arctic Ocean releases FW to the NA through the passages in the Canadian Archipelago and Fram Strait. Warming in the Arctic during the CCR increases ice melting and releases additional FW to the central basin. The accumulation and storage of FW in the BG is not favored by the CCR (even though the cyclonic regime leads to increased ice melt, the FW is not accumulated in the

BG because of Ekman divergence and upwelling causing a decrease of freshwater volume in the BG), and hence more FW is available for transport to the NA. River runoff is lower during the CCR than during the ACCR but precipitation over the ocean is increased and hence more fresh water is available for immediate release to the NA from sea ice and surface waters during the CCR.

The stronger surface winds of the CCR in the Fram Strait area (*P99*) increase the transport of thick ice, and hence FW, to the GIN Sea. At the peak of these processes, when all of them coincide, we observe low salinity anomalies in the GIN Sea.

Transition to ACCR

After several years of increased release of ice and FW to the GIN Sea, the surface layer becomes cooler and fresher, and the sea-ice extent increases in the Greenland Sea. Freshening associated with melting of the increased ice volume and increased flux of fresher surface waters leads to an increase in stratification and a decrease in the interaction between the deep ocean and the atmosphere; deep-water convection is consequently suppressed. After several years the dynamic height gradient between the BG and the NA (and consequently the geostrophic circulation) decreases, the Icelandic Low moves to the south and the interactions between the GIN Sea and the Arctic Ocean become weaker, reestablishing the anticyclonic circulation regime.

It is important to note that in this sequence of processes the accumulation and release of FW and ice plays a fundamental role in the interaction between the Arctic Basin and the GIN Sea.

Project Results

During the first year of research we have reprocessed all available data collected in the archives of the Arctic and Antarctic Research Institute, St. Petersburg, Russia. Gridded water temperature and salinity fields were averaged for the years of cyclonic (1953–1957, 1964–1971, 1980–1983) and anticyclonic (1946–1952, 1958–1963, 1972–1979, and 1984–1988) circulation regimes. These data are available for the scientific community at the Woods Hole Oceanographic Institution web site (http://www.whoi.edu/science/PO/arcticgroup).

Maps of freshwater storage in the ocean corresponding to the anticyclonic and cyclonic climate regimes (based on observations) and maps of freshwater storage in the sea ice for different climate regimes based on simulated results were also prepared and posted at the web site.

A conceptual model (described above) of the freshwater accumulation and release during a seasonal cycle and for cyclonic and anticyclonic climate regimes was formulated as the first order approach. This is a new hypothesis along with supporting evidence that the BG plays a significant role in regulating the arctic climate variability. We propose and demonstrate that the BG accumulates a significant amount of fresh water during one climate regime (anticyclonic) and releases this water to the North Atlantic during another climate regime (cyclonic). This hypothesis can explain the origin of the salinity anomaly periodically found in the North Atlantic as well as its role in the decadal variability in the Arctic region.

A substantial release of the BG fresh water to the NA in response to changing climate conditions can be a source for a catastrophic salinity anomaly in the NA and consequently, a source for an abrupt global cooling. The above perspectives lead us to the conclusion that it is extremely important to understand the structure of the BG water properties, its currents, and their variability in space and time. Specially designed "Beaufort Gyre Exploration Program" (http://www.whoi.edu/science/PO/arcticgroup) was proposed in response to the NOAA's 2001 Ocean Exploration Program announcement of opportunity in order to support project's goals and hypotheses and to explore one of the most hostile and inaccessible areas of the globe. The proposal was evaluated by two reviewers and both recommended to fund the proposal, but cost of the project was too high and NOAA declined this proposal. We resubmitted the proposal to the NSF's program "Arctic Freshwater Cycle: Land/Upper-Ocean Linkages. A contribution to the Study of Environmental Arctic Change (SEARCH)" in June 2002.

A paper with the first project results was submitted to the *Geophysical Research Letters* (*GRL*) journal in February but it was declined by one of the reviewers. This paper was revised and resubmitted to *GRL* in July 2002. The manuscript is posted at the arctic group web site. Now we are working with a paper for the *Journal of Geophysical Research*.

In this paper our major hypothesis will be described with much more detail and a direct link between the Beaufort Sea anticyclonic Gyre and the Greenland Sea cyclonic Gyre as the two major circulation features of the Arctic Ocean will be described.

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Papers

Proshutinsky, A., and R.H. Bourke. The role of the Beaufort Gyre in Arctic climate variability: seasonal to decadal climate scales, *GRL* (submitted, declined, resubmitted).

Proshutinsky, A., L. Timokhov, and R.H. Bourke. Variability of freshwater storage in the Arctic Ocean (in preparation for *JGR*).

Presentations

Proshutinsky, A., Once again: Two circulation regimes of the Arctic Ocean circulation. Beaufort Gyre case study. Workshop on Measurement and Modelling of the Arctic Ocean Circulation, 17–20 June 2002, Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY, USA, invited talk.

Proshutinsky, A., R.H. Bourke, and T. Proshutinsky, Variability of freshwater storage and thermohaline circulation of the Arctic Ocean, IAPSO meeting, October 2001, Mar Del Plata, Argentina.

Proshutinsky, A., Decadal variability of the Arctic climate: past, present, and future studies, Arctic and Antarctic Research Institute, St. Petersburg, Russia, invited talk (January 4, 2002).

Proshutinsky, A., Beaufort Gyre as a flywheel of the Arctic Ocean Circulation: seasonal, interannual and decadal time scales, McGill University, invited talk (March 22, 2002).

Proshutinsky, A., Arctic climate variability. Marine Biological Laboratory, Woods Hole, MA, invited talk (March 22, 2002).

Progress Report**:** **Observation and Modelling of the Fresh-water Dynamics Connecting the Arctic and Atlantic: A Feasibility Study**

Principal Investigator**:** Peter B. Rhines, School of Oceanography, University of Washington, Seattle

Other Participating Researchers**:** Mr. Jerome Cuny, Dr. Jonathan Lilly, Dr. David Bailey, Dr. Wei Cheng. Cuny is a Ph.D. student funded jointly by National Science Foundation and this grant, working on Baffin Bay and Labrador Sea fresh-water dynamics and climate change. Dr. Lilly is a just-completed Ph.D. who has done extensive research on Labrador Sea dynamics funded by NSF and this project; he is now working on Labrador Sea altimetric observations, for a short time, funded by this grant. Drs. Cheng and Bailey are primarily funded by The G.U. Vetlesen Foundation but parts of their research are funded by this grant, and their modeling studies of Arctic-Atlantic ocean fluxes contribute to the PI's research in this grant.

Objectives

This project involves one of the most striking elements of ocean-related climate change in the past few decades: the 30-year decline of subpolar salinity in the northern Atlantic and Nordic Seas. One of the key elements of this change is the communication between the Arctic and Atlantic Oceans. The objective of this project is to develop observations in key oceanic regions at high latitude, which can give us a multi-year picture of the evolution of water masses; the object also is to analyze the important hydrographic and mooring observations made in the subpolar Atlantic during the 1990s (some under NOAA sponsorship).

Methods

1. *Programmatic.* During the 1990s there was an intense period of observations in the Labrador Sea, with Rhines involved through NOAA and ONR grants. That region is of great importance to global circulation and climate (see Lazier et al. 2000). To further the objectives above, an international program known as ASOF (Arctic Subarctic Ocean Flux) has been initiated, involving US, Canadian, European, and Japanese climate scientists and oceanographers. Dr. Robert Dickson has been the driving force behind the international effort. In the US, ASOF is a component of the SEARCH program. Rhines is chairman of the ASOF-West group, which with the parallel leadership of Dr. John Calder of NOAA, has organized North American activities and led efforts to develop funding for observations in the western subpolar Atlantic, Canadian Arctic Archipelago, and the near regions of the Arctic Basin. Included in this activity, and funded in part by this project, have been a series of meetings to develop US-Canadian research in the subArctic (at IOS and BIO), the International SSG meeting in Washington, November 2001.

2. Analysis of archived observations. We have analyzed Canadian observations from the Davis Strait/Baffin Bay/northwest Labrador Sea region, from a 3-year program ending in 1990. These data give a picture of the seasonality and mean transports connecting the Atlantic with the Arctic, west of Greenland. We have constructed volume flux diagrams as a function of potential temperature, θ, salinity, S, and time, which summarize the workings of this system. In the future, time series of these fluxes will be key observations in the ASOF program, and of importance to global climate. We have also analyzed hydrographic observations made during our NOAA funded collaborations with BIO Canada, in the 1990s. These give a detailed picture of the role of freshwater in the Labrador Sea convection cycle. More than one-half of the wintertime cooling by the atmosphere is used up in breaking through the low-salinity waters in the upper few hundred meters. Climate-related changes in freshwater availability (of either sign) will have strong impact on the ability of a warmer world to drive the global overturning circulation of the oceans.

3. Initiation of new observations. We have collaborated with Prof. C. Eriksen to develop an observational program for hydrography of the passages connecting Arctic with Atlantic oceans, and for formation regions of the Labrador Sea/Baffin Bay. This will be carried out with newly designed autonomous undersea vehicles, known as Seagliders. The Seaglider is buoyancy driven, gliding up and down across the ocean with a slope of 3:1 to 5:1. It gives high-resolution measurements of temperature, salinity, dissolved oxygen, fluorescence, and particle scattering. As soon as the gliders are ready we will launch them into the subpolar Atlantic. Planning has been carried out under this grant; deployment costs by another NOAA grant, and grants from the Office of Naval Research.

We have also collaborated with Dr. Simon Prinsenberg of BIO, Canada to increase the observational array for Barrow Strait, in the Northwest Passage. Coordination of various planned ASOF programs west of Greenland can produce a comprehensive, time-evolving picture of freshwater and volume transport between Arctic and Atlantic.

Main Results

The charts of flux of water through high-latitude straits and passages (with its seasonal variability) give a benchmark for observations in the near future. The distribution of Arctic/Atlantic flux in density classes (and θ-S classes), eventually through each of the major passages observed by ASOF, is a key 'answer' that we seek, together with its behavior in the future and impact on climate. Calculations of the strength of the low-salinity cap on the Labrador Sea have been made which should stimulate quantitative understanding of the retarding effect of freshwater on the meridional overturning of the oceans. Comparison with climate models is ongoing, and has already shown the contrast between the vertical structure of observed oceanic water masses and the numerically modeled structures that dominate current thinking about high-latitude climate change. A key issue in models is, as with observations, the relative balance of the various Arctic outflows: those west of Greenland, near the surface, and the deep overflows east of Greenland. When models cannot represent downslope flow of dense waters, they tend to exaggerate the role of intermediate depth sinking from the Labrador Sea.

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Papers are in preparation by Cuny, Lilly, Bailey and Rhines on the recent analysis of northern Atlantic hydrographic and mooring data. In addition, some key documents have been produced in support of ASOF, such as brochures and summaries of scientific objectives.

Progress Report: **Temporal and Spatial Variability of Alaskan Clouds Studied with a Ground-Based Infrared Cloud Imager**

***Principal Investigator*:** Joseph A. Shaw, Electrical and Computer Engineering Department, Montana State University, Bozeman, Montana

Objectives

This is a report of progress in the first year of a two-year research project to study the spatial and temporal variability of Alaskan clouds using a ground-based infrared cloud imaging system. The instrument employed in this study, called the "Infrared Cloud Imager" (ICI), was developed recently to record images of atmospheric emission from which clouds can be identified and classified according to their radiometric brightness.

The two primary objectives of this study are to:

1. Measure spatial-temporal cloud statistics at Barrow, Alaska that can lead to improved cloud parameterizations in Arctic climate models and begin to provide data for determining the relationship between the Arctic Oscillation and Arctic cloudiness;
2. Compare cloud statistics derived from multiple-pixel and single-pixel sensors to identify statistical biases that may occur in cloud statistics derived from zenith-viewing sensors such as cloud lidars and radars, which depend on advection of the cloud field overhead to provide a representative cloud sample over time.

Methods

The principal tool in this study is the Infrared Cloud Imager (ICI), which records radiometrically calibrated images of atmospheric emission in the 8–14 μm wavelength range without liquid nitrogen or other detector coolants. Each pixel in the images is classified as clear or cloudy, and classified further according to cloud type, based on its radiometric brightness. The ICI is a recently developed sensor in which an infrared camera alternately views the sky and a blackbody calibration target to generate radiometric sky images.

The ICI data are calibrated with a combination of laboratory and field calibrations. In the laboratory prior to deployment, a calibration curve is generated with the system viewing a blackbody cone that can be cooled from ambient down to approximately –70°C. The instrument gain (change in voltage for a change in radiance) found from this laboratory calibration has been found to be reasonably stable over time, so in the field we only view one calibration target to derive an updated offset term (radiance detected from self emission). This scheme appears to work well, but is being refined continually through comparison with data from other radiometric sensors, such as the Atmospheric Emitted Radiance Interferometer (AERI), and with radiative transfer models using radiosonde profiles as input.

Results

We started work on this project with an analysis of the ICI calibration using ICI data collected at Poker Flat Research Range (PFRR) near Fairbanks, Alaska, during the 2000–2001 winter. This analysis focused on uniformly clear or cloudy sky periods, during which radiosondes launched at Fairbanks were expected to be at least somewhat representative of the atmosphere over PFRR. We also used infrared and visible AVHRR imagery to verify the uniform clear or cloudy conditions, and to provide a cloud-top temperature to be included in the comparison during cloudy periods. This analysis showed that the cloud-base temperature from ICI agreed with the radiosonde cloud-base temperature to within 2°C, while the ICI clear-sky brightness temperature during the clear-sky period differed by 4°C from radiative transfer calculations using the Fairbanks radiosonde as input. The clear-sky comparison is quite promising, considering the potential for large differences caused by separation in space and time of the ICI and radiosonde measurements, and considering the great challenge of calibrating uncooled infrared detector arrays at such low radiance levels. Even without the calibration improvements that are presently underway, this level of radiometric performance is sufficient for the cloud identification and classification task of the ICI instrument.

The most significant accomplishment during the first year of this project was successful deployment at the NSA (North Slope of Alaska) site in Barrow, Alaska during February–May 2002 (following test deployments in Boulder, Colorado during December 2001 and Bozeman, Montana during January–February 2002). The Barrow deployment turned out to be approximately twice as long as the originally proposed field deployment duration, which was made possible by robust operation of the ICI system and by generous facilities support contributed by the DOE/ARM program and NSA site personnel.

For processing ICI images, we are working first on developing algorithms to separate the atmospheric and cloud emission signatures. In this wavelength range, downwelling emission from a cloudy sky comprises primarily cloud and water vapor radiance. We have developed algorithms that use microwave radiometer measurements of integrated atmospheric water vapor to quickly estimate and remove the infrared water vapor emission, leaving only the cloud emission so that we can perform robust and geographically independent cloud identification and classification. We are also studying methods for determining which portion of the integrated water vapor emission is contributed by the atmosphere below the cloud. At the NSA ARM site, this kind of analysis is enhanced by the ubiquity of sensors that can give critical data such as cloud height and water vapor profiles.

During this coming year, we will refine and test various algorithms for correcting ICI images for water vapor emission and for calculating spatial-temporal cloud statistics from ICI images. We will apply these algorithms to the entire NSA data set and also begin comparing cloud statistics derived from vertically viewing and spatially resolving sensors. Much of this work is awaiting a recalibration of microwave radiometer water vapor data available through the ARM data archive. An additional deployment of the ICI at the NSA site in Barrow will occur in February–March 2003, as part of a project funded by the DoE/ARM program, providing additional data that will add to the results of the present project.

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***Progress Report*:** **Trophic Pathways on the Chukchi-Beaufort Shelf: Where Do the Ice Algae Go?**

***Principal Investigator*:** Alan M. Springer, Institute of Marine Science, University of Alaska Fairbanks

Other Participating Researchers: C. Peter McRoy, University of Alaska Fairbanks; Sara J. Iverson, Dalhousie University, Halifax, Nova Scotia; Suzanne Budge, Dalhousie University, Halifax, Nova Scotia

Objectives

The goal of this project is to identify trophic pathways of ice algae on the Chukchi-Beaufort continental shelf using fatty acid biomarkers to trace carbon flow through the Arctic food web. Fatty acid biomarkers are used to differentiate between the two types of primary production, ice algae and spring bloom phytoplankton, that are the base of food webs leading to organisms at higher trophic levels, specifically, arctic cod, black guillemots, bearded and ringed seals, bowhead whales, polar bears, and humans. This, in turn, will allow us to evaluate the importance of sea ice algae, relative to phytoplankton, to food web production in the Arctic.

Methods

The first field season for this research began in May 2002. We collected samples over a four-day period from May 28–31 off Barrow, Alaska. Ice algae were obtained from cores. Large volumes of water from under the ice were filtered to obtain phytoplankton from the water column, which also included some sedimenting ice algae. Fauna, including copepods, amphipods, and benthic and pelagic worms, were collected with traps and nets deployed under the ice. Ice algae were also collected at a separate site in Bering Strait for comparison. Samples of ice algae and phytoplankton were preserved in 5% buffered formalin for taxonomy.

Numerous marine mammal blubber samples were obtained from subsistence hunters in both regions in spring. We have approximately 60 samples of ringed, bearded, spotted, and ribbon seals and walrus. Bowhead whales will also be sampled. Arctic cod and adipose samples of black guillemots are being collected from the area around Cooper Island.

Analyses were begun in June 2002. Lipid extraction was performed on all samples using a modified Folch et al. (1957) method (Parrish, 1999) using chloroform and methanol, followed by fatty acid methyl ester formation with BF_3. Individual fatty acids were determined using temperature-programmed gas liquid chromatography according to Iverson et al. (1997) on a Perkin Elmer Autosystem II Capillary FID gas chromatograph fitted with a 30 m x 0.25 mm id. column coated with 50% cyanopropyl polysiloxane (0.25µ film thickness; J & W DB-23; Folsom, CA).

Preliminary Results

Fatty acid analyses of samples collected in Barrow in May indicate some key differences between ice algae and water column phytoplankton. In ice algae, there was a clear predominance of fatty acids with 16 carbon atoms over fatty acids with 18 carbon atoms, so the ratio of $\sum C16/\sum C18$ was consistently greater in the ice algae than in phytoplankton. Also, levels of the fatty acid 16:1n-7 were much greater in ice algae than in water column phytoplankton. In contrast, amounts of other specific fatty acids, such as 20:5n-3, 18:4n-3, 18:2n-6 and 18:1n-9, were higher in the water column phytoplankton.

On May 30, a distinct shift in the along shore current from southerly to northerly occurred and an increase in small zooplankton and phytoplankton cells in the seawater samples was obvious. Clear differences were apparent in the taxonomic composition of water column phytoplankton after this change in current. Also, the fatty acid signature of that phytoplankton began to more closely resemble that of the ice algae with increases in $\sum C16/\sum C18$ and levels of 16:1n-7. This suggests that, in addition to the water column phytoplankton, these samples contained numerous free-floating ice algae cells and are perhaps not wholly representative of typical water column phytoplankton.

The fatty acid signatures of zooplankton sampled under the ice at Barrow are similar to zooplankton collected in other areas with large amounts of 18:4n-3, 20:5n-3 and 22:5n-3. However, unusually elevated levels of n-7 fatty acids were encountered, particularly 18:1n-7, 20:1n-7 and 22:1n-7. These fatty acids are likely formed by chain elongation of 16:1n-7 and, along with the presence of 16:4n-1, indicate extensive feeding of the zooplankton on ice algae. There is also some evidence of a change in zooplankton fatty acid signatures after the current shift, with an increase in 14:0 and a decrease in 22:6n-3.

These data demonstrate that we may use fatty acid signatures to differentiate between the two types of primary production, ice algae and spring bloom phytoplankton. In addition, the fatty acid composition of the zooplankton contains several ice algae biomarkers and indicates that ice algae are important dietary items of herbivores. These data represent the first step towards the eventual quantitative use of fatty acids to delineate trophic pathways in higher order consumers, including planktivorous sea birds, fish and marine mammals, and they suggest that we can expect to recognize fatty acid signatures of ice algae in higher trophic levels.

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***Progress Report*: An Arctic Archive of Model Output and Application to SEARCH**

***Principal Investigator*:** John E. Walsh, University of Illinois

***Other Participating Researchers*:** William L. Chapman and Michael S. Timlin, University of Illinois

Report

The primary objective of the project is a synthesis of global climate model output for uses in ACIA (Arctic Climate Impact Assessment) and SEARCH (the Study of Environmental Arctic Change). The need for such a synthesis arises from the widely varying formats, archival locations and access procedures for the output of global models. In addition, there is a general need for information from these models by Arctic scientists who are not familiar with global models nor with archival procedures. The most immediate need for such information has arisen in ACIA, for which a scenario working group identified five models and a common forcing scenario to be utilized by an interdisciplinary group of authors charged with assessing Arctic climate changes and their impacts over the next century. Under the present project, we have coordinated the archival of the model output for ACIA and we have performed diagnostic analyses of several subsets of the archived data.

The ACIA archive consists of B2 scenario output from five state-of-the-art global models: the Canadian Climate Center (CCCma) model, the European Center/Hamburg model (ECHAM), the model of the Geophysical Fluid Dynamics Laboratory (GFDL), the Hadley Centre's HadCM3, and the National Center for Atmospheric Research's Climate System Model (CSM). The CCCma archive consists of output from an ensemble of three 21st-century simulations, differing only in their initial conditions. The primary collection of output from each model consists of monthly grids of 20–30 variables, while daily grids of 58 variables (including surface air temperature and precipitation) are also archived for each model.

The information provided to ACIA has consisted of two types: (1) background information in the form of menu-driven images available at the ACIA scenario website, http://zubov.atmos.uiuc.edu/ACIA/ and (2) digital and graphical information tailored to specific needs of authors of individual ACIA chapters, provided on an "as requested" basis. The background information at the website includes time-series plots of key quantities from all models, including side-by-side comparisons of 21st-century temperature projections from the five models. The website also includes a clickable matrix for plots of temperature and precipitation maps for any ACIA time slice from any model.

The user-specified information has been provided in response to 20–25 requests from ACIA authors. These requests have generally been for regional values of variables such as snowfall, winds, growing-season quantities, and seasonality of changes.

A research focus of our activity during the first project year has been the compilation and analysis of scenarios of sea ice from the various models. We have extracted grids of monthly sea ice coverage for all models for the period 1980–2100. The control-climate sea ice coverage of every model shows some bias, at least on a regional basis. The control climate's sea ice cover ranges from a generally under-simulated sea ice cover (in CCCma) to a generally over-simulated sea ice cover (in the NCAR CSM). In the other models, the total hemispheric coverage is similar to the observed. In order to optimize the scenarios, we have used the present-day biases to introduce adjustments to the ice coverages projected for the future. In all cases, the bias-adjustments are functions of longitude, calendar month and model. After such adjustments are made, the greenhouse-driven (B2 scenario) retreat of sea ice ranges from about 12% in the NCAR CSM to about 40% in the CCCma model. The retreat is more rapid in the warmer models, which also have the least ice in the control climate. One model, the CCCma, becomes ice-free in the summer by about 2050 without bias-adjustment and by about 2090 after bias-adjustment. Several other models have very little ice at the summer minimum in 2100. Interestingly, the decrease of wintertime sea ice is relatively small—only 10–20% by the late 21st century in most of the models. The results of this study are described in more detail in a paper by Timlin and Walsh (2002).

A second diagnostic application of the application has been targeted at the needs of SEARCH as well as ACIA. We are using the daily output from the models to examine the frequency of extreme events in the Arctic: temperature exceeding high and low thresholds, precipitation exceeding various thresholds over various periods (daily, 5-day, monthly), and dry periods of varying lengths. This type of information requires daily output because the extremes are lost in the averages over the commonly used monthly periods. The preliminary findings are that most models show increasing frequencies of heavy precipitation events during the summer, and increasing frequencies of high temperature occurrences. The frequencies of extremely low temperatures during the winter generally decrease. Very preliminary results concerning storm events point to a varied picture among models: some of the models show stronger low pressure centers over the Arctic under the greenhouse scenario, while others depict decreasing frequencies of intense cyclonic systems. The reasons for these differences will be a focus of research in the coming year, as will a more complete documentation of the projected changes in the frequency and duration of extreme events in the Arctic.

Publications

Timlin, M.S., and J.E. Walsh (2002) Simulation of present-day and future Arctic sea ice cover by a suite of global climate models. *Polar Research*, submitted.

Progress Report: **Connections between Arctic-Subarctic Ocean Fluxes and the Arctic Oscillation**

***Principal Investigator*:** John W. Weatherly, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire

Objectives

The overall goal of this proposed project is to investigate the impacts of the Arctic Oscillation on the ice, water, heat, and salt fluxes between the Arctic Ocean, the subarctic GIN (Greenland, Iceland and Norwegian) Seas, and the Atlantic thermohaline circulation. Three main questions will be addressed:

1. How does the Arctic Oscillation (and associated climate variability) affect the heat, salt, ice, and water mass exchanges between the Arctic and subarctic oceans?
2. How does the strength of the Atlantic thermohaline circulation and the related ocean transports affect these exchanges?
3. How does the AO and the resulting variability in ice export affect the thermohaline circulation?

Methods

A global, coupled atmosphere-ocean-ice general circulation model (GCM) will be the primary tool used for investigating the connections between climate variability and Arctic-global ocean exchanges. This approach provides a method for diagnosing the interactions between atmosphere, ocean, and sea ice, and for testing hypotheses about the climate system using a variety of model simulations.

The global climate models being used for this study are the two models that have been developed and run at the National Center for Atmospheric Research (NCAR), the Community Climate System Model (CCSM), and the Parallel Climate Model (PCM). These two models consist of mostly similar model components for the atmosphere, ocean, and sea ice, though have been coupled in different ways. The first step is to diagnose the relationships between the AO and ocean fluxes from existing and ongoing climate simulations performed by the Climate Change Research group at NCAR, using both the PCM and CCSM models. Correlations will be computed between variables such as the AO index, the Fram Strait ice volume export, the heat and water mass fluxes through the Barents Sea, West Spitsbergen Current, northward heat and water transport in the subarctic seas, and the strength of meridional ocean circulation in the North Atlantic. Spatial correlation maps can also be computed between the AO index and Arctic ice velocities, ice concentrations, and sea surface temperatures.

Project Status and Progress

This project is awaiting the initial funding distribution from NOAA for FY 2002. The specific tasks for this project will begin when funding is available. Nonetheless, climate model development and simulations with the NCAR PCM and CCSM are proceeding, and are providing better model results for analysis in this project.

Development of a higher resolution version of the Community Atmospheric Model (CAM) by NCAR has improved the Arctic sea-level pressure results. The T85 resolution (approximately 1.4º degrees) shows better intrusion of lower pressures from the Norwegian Sea into the Eurasian Basin, and less dominance of the central Arctic high pressure. The summer SLP pattern is also more uniform (flat), similar to observations, and improved over the T42 version (approximately 2.8º).

The PCM modeling group at NCAR has completed new coupled climate simulations with both the new version of the PCM-2 and the new CCSM-2. These models both include the complete ice-thickness distribution model with the elastic-visco-plastic ice dynamics, and global ocean model resolution of 1º (and in the Arctic of 50–70 km). The

CCSM-2 ocean and sea ice components will be used in this study for the ocean-ice simulations of the years 1950–2000.

Publications and Presentations

No publications, as the specific study tasks are awaiting funding.

Workshop presentation: "Climate change modeling and the impacts of simulated Arctic variables," CAMP workshop, University of Wisconsin, Madison, sponsored by IARC.

***Progress Report*:** **Hydrologic Response of Siberian Major Rivers to Climate Change and Variation**

***Principal Investigator*:** Daqing Yang, Water and Environmental Center, University of Alaska Fairbanks

Other Participating Researchers: Tingjun Zhang (Co-PI), National Snow and Ice Data Center, University of Colorado, Boulder; Xuebin Zhang (Co-PI), Climate Research Branch, Meteorological Service of Canada, Downsview, Ontario; Hengchun Ye (Co-PI), Department of Geography and Urban Analysis, California State University, Los Angeles

Objectives

Climate over Siberia has experienced significant changes during the past few decades, such as considerable winter warming, winter and fall precipitation increase, winter snow depth increase, and ground temperature rising and permafrost thawing. Climate models predict a 1–4°C surface air temperature increase over the earth in the 21st century, with even greater increase in the Arctic regions. This warming trend will impact the structure, function, and stability of both terrestrial and aquatic ecosystems and alter the land-ocean interaction in the Arctic.

River freshwater inflow, contributing as much as 10% to the upper 100 meters of water column of the entire Arctic Ocean, critically affects the salinity and sea ice formation, and may also exert significant control over global ocean circulation. Arctic hydrologic systems exhibit large temporal variability due to large-scale changes in atmospheric circulation. This variation significantly influences the cross-shelf movement of water, nutrients and sediments. Thus, examination of streamflow changes and variations in the major northern river basins and their relations to surface climate and atmosphere are critical to better understand and quantify the atmosphere-land-ocean interactions in the Arctic and consequent global impacts.

The primary objective of this project is to investigate the hydrologic response of major Siberian rivers to climate change and variation. We have constructed and analyzed long-term records of temperature, precipitation, snowcover, active layer depth, soil temperature, river streamflow, ice thickness, and Arctic oscillation (AO) index to focus our research on the following three key aspects:

- *Investigating regional hydrologic change*. This includes a) quantifying the annual and seasonal freshwater fluxes to the Arctic Ocean from Lena, Ob and Yenisey rivers and their inter-annual variation and long-term trends; b) developing river ice thickness climatology and examining its relation to winter low-flow for the river basins.
- *Identifying regional climate variation and trends.* This includes a) defining climatologies, trends and variability of monthly and yearly temperature, precipitation, snowcover, soil moisture, active layer depth, shallow ground water storage; b) applying comprehensive statistical methods to selected key variables to identify the major spatial variation patters and their temporal changes at different time scales.
- *Examining atmosphere-land interaction*s. This includes a) multiple-correlation analysis of river runoff and ice thickness with key atmospheric circulation index (e.g. AO), temperature, precipitation, soil moisture, snow cover, active layer depth, shallow ground water storage; b) identifying important climatic and atmospheric control factors to regional hydrological changes; and c) quantifying lengths of memory of different variables (temperature, precipitation, snowcover, etc.) and their impact on inter-annual variation of river discharge.

Methods

During the first year, we focus our effort on data set developments and analyses. Up to June 2002, we have acquired long-term monthly records for temperature, precipitation, snow cover, ground temperature, active layer depth, river streamflow, and river ice thickness for the three large watersheds. We also obtained AO index and SST data for northern Atlantic and Pacific oceans. We used statistical approaches to examine the observational evidence of associations between river discharge and atmospheric and terrestrial variables, such as air temperature, precipitation, snowcover, soil moisture, timing and duration of the active layer depth, river ice thickness, and Arctic oscillation (AO) index.

Main Results

Hydrology Component

We identified remarkable changes in hydrologic regime of the Lena, Yenisey and Ob rivers. A significant increase in fall and winter discharge at the outlet of the watersheds has been found during recent decades for all the three rivers, particularly for the Yenisey basin. An early start of snowmelt period toward mid May was found in the Lena basin, with an increase of streamflow in May and a decrease in June. A decrease of river ice thickness has also been detected for the Lena River. A shift of the Ob River's maximum monthly discharge from spring snowmelt period towards summer season (July, August and even September) has also been discovered. Our analyses of influences of atmospheric and climatic variables on seasonal and annual discharge changes and variations suggest that changes in river streamflow of large Siberian rivers are the consequence of recent climate warming and are also related to changes in permafrost conditions.

Human activities, such as changing land surface and building large dams, influence the hydrologic regime and its change. Efforts are currently underway to document the dams in the northern river basins, including their size, year of completion, and ways of operations. Our preliminary examinations of reservoir regulation on river discharge in the Lena River show that peak discharge has been reduced by 20–30% and low flow has been significantly increased by 50–60%. As a result, the discharge trend derived from the observed records has been underestimated in summer and overestimated in winter. Winter discharge increase may also impact river ice condition. These results suggest more research attention to the human dimension of arctic environment changes.

Climate Component

Temperature. Based on long-term global climatic data sets, our initial analysis of climate trend shows that annual mean temperature has increased since the mid-1930s in almost all parts of the three basins, although some northern regions of the basins are stable. Statistically significant trends are observed in most parts of the Ob basin, the eastern Yenisey basin and the eastern Lena basin. The spatial patterns of the trends differ from season to season. Among the four seasons, the greatest increase was found in winter. Warming during winter is over 4°C for 1936–1995 in the southern Ob and Yenisey basins, as well as in the eastern Lena basin, and the trends are significant. The spatial pattern in winter is similar to the annual one, except that winter warming is stronger. The greatest warming during spring is over 3°C for 1936–1995 in the northwestern Ob basin, the southeastern Yenisey basin and eastern Lena basin, and the trends are significant in these areas. Summer shows significant warming trends in a small area of the eastern Ob basin, northeastern Yenisey basin, and eastern Lena basin. Some significant negative trends are found in the center of the Yenisey and Lena basins. Fall shows significant positive trends in most southern areas of the Ob basin and southeastern Yenisey basin and there are some negative trends found in the north of the three basins, but the trends are significant only in the northern Ob basin. It is apparent that warming in winter temperature contributed the most to the positive trend in the annual mean of daily temperature.

Precipitation. Annual precipitation in the Lena Basin significantly decreased by about 20% during 1936–1995 in a small area in the northeast, and no significant increasing trends are found. The spatial patterns of the trends differ from season to season. Winter shows significant increasing trends in the north; spring shows no significant trends; summer shows significant negative trends in the north; and fall shows significant positive trends in a very small area in the north. Yenisey River annual precipitation significantly decreased by 20%–30% during 1936–1995 in part of the south. Seasonally, winter and fall show some significant positive trends in the north, and spring shows positive trends in the east. Summer has significant negative trends in north and center, winter and fall also have a very small area in the south with the same trends. Ob basin annual precipitation increased in the west by 10%–30% during 1936–1995. Among the four seasons, the significant positive trends are only found in winter, and the greatest increase, which is found in the south, is about 70%–90%. Spring shows no significant changes. In summer, some significant negative trends are found in the northeast. Fall shows insignificant positive trends in most parts of the basin.

Permafrost Component

Permafrost Distribution. Based on data from the International Permafrost Association *Circum-Arctic Map of Permafrost and Ground Ice Conditions,* we conducted statistics on permafrost distribution over major Arctic River basins. Results indicate that the permafrost fraction increases from the western Russian Arctic region to the eastern Russian Arctic region. The Ob River basin has the smallest permafrost fraction, with approximately 4–10% of the basin underlain by permafrost. The Yenisey River basin has about 36–55% of the area under permafrost. The Lena River basin has the largest permafrost fraction, 78–93%. Existence of permafrost has significant impact on the surface water budget. For example, mean runoff ratios (runoff vs. precipitation) in the colder and permafrost dominated Yenisey and Lena River basins (0.41–0.55) are higher than for the warmer and largely permafrost-free Ob River basin (0.26).

Soil Temperature Increase. Soil temperature at 40 cm depth over the Russian Arctic and Subarctic has increased approximately 0.9–1.1^{o}C over the past few decades. The increase is particularly pronounced during the winter months, probably due to the increase both in air temperature and snow thickness. Increase in soil temperature implies thawing and degradation of permafrost over the study area. Further work is needed to understand the thermal status of soils and permafrost over each river basin scale.

*Active Layer Thickness***.** Based on ground-based measurements from 11 stations over the Lena River basin, maximum thickness of the active layer increased by about 30 cm from the late 1960s to the mid-1980s. An increase in maximum active layer thickness increases water storage capacity, thus partitioning the surface water budget. Further work will be needed to better understand changes in active layer thickness over the entire basin and other major river basins. This information helps to understand the changes in river runoffs during the past few decades.

Presentations

Yang, D., and T Ohata (2001) Lena river ice regime and recent change. Presented at the AGU 2001 fall Meeting, Dec. 10–14, 2001, San Francisco. Supplement to Eos, Transaction, AGU, 82(47) Nov. 20, 2001.

Yang, D., T. Zhang, X. Zhang, and H. Ye (2002) Hydrologic response of Siberian major rivers to climate change and variation. Presented at the NSF ARCSS All-hands Workshop, 20–22 February 2002.

Oelke, C., T. Zhang, M. Serreze, and R.L. Armstrong (2001) Regional-scale modeling of soil seasonal freeze/thaw over the Arctic drainage basin. Presented at the AGU 2001 fall Meeting, Dec. 10–14, 2001, San Francisco. Supplement to Eos, Transaction, AGU, 82(47) Nov. 20, 2001.

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Publications

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Yang, D., D. Kane, L. Hinzman, X. Zhang, T. Zhang, and H. Ye (In press) Siberian Lena river hydrologic regime and recent change. *Journal of Geophysical Research*.

Ye, H. (In press) Observed regional and climatological associations between spring and summer precipitation over northern central Eurasia. *Water Resource Research*.

Ye, H., D. Yang, T. Zhang, X. Zhang, S. Ladochy, and M. Ellison (In review) The impact of climatic conditions on seasonal river discharges in Siberia. *Journal of Hydrometeorology*.

Zhang, T., R.G. Barry, K. Knowles, F. Ling, and R.L. Armstrong, Distribution of seasonally and perennially frozen ground in the Northern Hemisphere, *Proceedings of the 8th International Conference on Permafrost*, Zurich, Switzerland, July 21–25, 2003 (submitted).

Project Reports:
Steller's Sea Lion Projects

Progress Report: **North Pacific Climate Variability and Steller Sea Lion Ecology: A Retrospective and Modeling Analysis**

***Principal Investigators*:** Steven J. Bograd, Pacific Fisheries Environmental Laboratory (PFEL), NOAA/NMFS, Pacific Grove, California; Michael J. Alexander, Climate Diagnostics Center (CDC), NOAA/CIRES, Boulder, Colorado; Roy Mendelssohn, PFEL; Arthur J. Miller, Joint Institute for Marine Observations (JIMO), Scripps Institution of Oceanography, University of California, San Diego, California; Franklin B. Schwing, PFEL

***Other Participating Researchers*:** Antonietta Capotondi, CDC; Douglas J. Neilson, JIMO

Objectives

The principal objectives of this project are to hypothesize and examine specific physical-biological processes, on a number of space and time scales, that could translate observed North Pacific climate variability into region-specific changes in Steller sea lion populations. This will be accomplished through three separate but integrated avenues of research. The group at the Pacific Fisheries Environmental Laboratory (PFEL) seeks to describe North Pacific climate variability over the past half-century through retrospective analyses of relevant oceanographic and atmospheric data sets. The Climate Diagnostics Center (CDC) group is examining, via modeling studies, large-scale environmental changes in the Gulf of Alaska (GOA) on interannual and decadal time scales. In addition to local forcing, CDC will also explore how the atmosphere and ocean in the North Pacific responds to conditions in the tropical Pacific (e.g. ENSO events). The group at Scripps Institution of Oceanography (SIO) is using a coupled physical-biological model to investigate whether changes in atmospheric forcing can alter plankton community structure by changing circulation patterns and nutrient availability. Integrating the work of PFEL, CDC and SIO, a specific hypothesis to be tested is that a change in community structure triggered by climate-induced variability along the perimeter of the GOA has reduced the diet diversity of the western stock of Steller sea lions relative to the eastern stock.

Methods

PFEL is using state-space modeling techniques to look retrospectively at historical oceanographic and atmospheric data sets from the Steller environment. An advantage of the state-space approach is its ability to separate seasonal and long-term contributions to the variability observed in environmental time series. Both contributions are ecologically important, as many marine organisms respond strongly to environmental changes on both seasonal and decadal time scales. The following three data sources were chosen for analysis due to their long record, easy access, and relevance to the Steller habitat: (1) Sea level pressure (SLP) fields for the dominant centers of action in the northeast Pacific (the nominal positions of the Aleutian Low and North Pacific High), from the National Center for Environmental Prediction (NCEP) reanalysis, for the period 1948–2000; (2) Sea surface temperature (SST) and surface wind data for 1° boxes in the eastern, central and western Gulf of Alaska, from the COADS data set, for the period 1950–1997; and (3) Mixed layer depth and upper ocean heat content throughout the coastal northeast Pacific from several dynamical models, including those that are part of this project.

In order to isolate the influence of ENSO on the atmospheric changes in the northeast Pacific, CDC is executing a large ensemble of experiments with the GFDL Atmospheric General Circulation Model (AGCM) coupled to a gridded 1-D mixed layer ocean model, with observed SSTs specified in the tropical Pacific. CDC is also working with NCAR's ocean GCM (OGCM) driven by observed surface fluxes over the period 1958–1997.

SIO is using the Regional Ocean Modeling System (ROMS) on an ETOPO-V based, 10-km grid covering the GOA north of 50°N and east of 170°W. The model is forced by NCEP-derived climatologies from the 6 years before and after the 1976–1977 regime shift. The biological model that is coupled to ROMS is a nitrogen currency, eight-component ecosystem model consisting of parallel paths representing old and new production. Each path consists of a single phytoplankton compartment, associated zooplankton grazer, and feed into a common detrital pool.

Results

PFEL's decomposition of the SLP series documented significant changes in the phase and amplitude of the seasonal cycle in the Aleutian Low and North Pacific High. The Aleutian Low seasonal amplitude nearly doubled over the study period, mostly due to wintertime deepening. Changes in the amplitude and phase of both the annual and semi-annual components contributed to a strongly time-varying structure of the North Pacific High. In particular, spring arrived earlier in the California Current System through the 1990s compared to the 1950s. These changes in seasonality can impact lower trophic levels by affecting local Ekman processes and disrupting the timing of seasonal events. Changes at lower trophic levels, in turn, may impact the diet of higher trophic level organisms, including marine mammals in the northern GOA. This study demonstrated the importance of considering a non-stationary and non-deterministic seasonal cycle when looking for the effects of environmental variability on marine ecosystems. Results from this analysis have been published in *Geophysical Research Letters* (Bograd et al., 2002). Analyses of the other two primary data sources, focused on looking at long-term trends and climate-driven change points, are continuing.

Ocean conditions in the GOA are sensitive to changes in the tropical Pacific on interannual and decadal time scales. For example, the 1997–1999 El Niño–La Niña cycle had a substantial impact on the northeastern Pacific. The CDC group, using simulated SSTs, achieved 1°C warmer SSTs and a 40m shallowing of the January–February mixed layer in 1998 versus 1999. On longer time scales, wintertime SSTs were also warmer in the central GOA in the decade after the 1976 regime shift compared to the decade before. This result was also mirrored in the OGCM model runs (using surface fluxes over the period 1958–1997), which indicated a large scale warming of 0.5–0.75°C in the GOA beginning in the mid-1970s. The warming was mainly a surface phenomenon, however, especially in coastal regions where temperatures at 100m depth were actually colder after 1976.

Based on analysis of the NCAR OGCM, CDC has found reduced Ekman pumping the northern part of the GOA in 1977–97 as compared with 1958–75. This resulted in decreased upwelling and a deepening of isopycnal surfaces between 40m and 200m along the northern rim of the gyre. The decrease in upwelling occurred between 125°W and 155°W and within 500 km of the coast. The CDC group is now investigating the processes responsible for these ocean changes.

The SIO group is currently validating the physical accuracy of the GOA ROMS output. The model adequately reproduces the general circulation patterns of the GOA, in particular the Alaskan Stream and Alaska Coastal Current. Runs have been made with both pre- and post-regime shift wind sets. Once validation of the physical model is complete, SIO will repeat the current runs and make longer, decadal-scale runs with active biology. Analyses will concentrate on differences in biological response between the eastern and western GOA.

Our initial results suggest at least two ways by which environmental changes can affect the GOA ecosystem: (1) by changing the intensity of Ekman processes, as demonstrated by the CDC results, and (2) by changing the seasonal timing of Ekman processes, as shown by the atmospheric changes revealed in the PFEL retrospective. These processes are likely responses at different time scales of the same atmospheric phenomenon. In the former case, changes in upwelling could lead to substantially different nutrient concentrations in the surface waters. In the latter case, shifting seasonality could alter not only the health of primary producers dependent on nutrient availability but also the interaction between adjacent trophic levels. The hypotheses generated by these analyses are being fully tested in the SIO coupled physical-biological model runs.

Publications

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Bograd, S.J., F.B. Schwing, R. Mendelssohn, and P. Green-Jessen (2002) On the changing seasonality over the North Pacific. *Geophysical Research Letters* 29(9): 10.1029/2001GL013790.

Progress Report: **The Role of Physiological Constraint in the Acquisition of Foraging Ability: Development of Diving Capacity in Juvenile Steller Sea Lions**

Principal Investigator: Jennifer M. Burns, Department of Biological Sciences, University of Alaska Anchorage

Co-Principal Investigator: C. David Pfeiffer, Department of Biological Sciences, University of Alaska Anchorage

Objectives

By studying the development of sea lion physiological status, and then linking it with diving behavior (determined by NMFS and ADFG), this project will advance our understanding of how physiological limitations imposed by age and body size might affect activity patterns and foraging strategies. In addition, this research will reveal whether rates of physiological and behavioral development are tailored to meet specific life history patterns or instead limit them. Data obtained from sea lions will be compared with that from other pinnipeds in an attempt to determine when sea lion juveniles are physiologically ready to become independent. Ultimately, this research may offer insight into those factors that influence juvenile survival and recruitment.

Methods

To determine the physiological diving capacity of sea lion juveniles, we will measure blood and muscle oxygen stores and compare them across age classes. Second, we will examine the metabolic characteristics of muscle, and determine what changes are occurring at the biochemical and histochemical level. Animals will be captured during cruises with Alaska Department of Fish and Game and the National Marine Mammal Laboratory.

Body oxygen stores will be determined by measuring blood oxygen carrying capacity (HCT, Hb, and volume) (ICSH 1973; Foldager and Blomqvist 1991; El-Sayed et al. 1995; Kooyman et al. 1980; Ponganis et al. 1993) and muscle mass and myoglobin load (Kanatous 1997). In order to understand what factors are most responsible for changes in blood volume and red blood cell characteristics, we will examine changes in red blood cell size and number by microscopy. In addition, we will measure circulating levels of the hormone erythropoietin (EPO) which stimulates red blood cell production, and is increased when tissues experience hypoxia (Brunner et al. 1992; MacDonald et al. 1995). We will also examine factors that influence muscle structure and function. These include enzyme activity (citrate synthase, ß-hydroxyacyl CoA dehydrogenase, and lactate dehydrogenase), and fiber type analyses (Castellini and Somero 1981; Reed et al. 1994; Noren 1997; Kanatous 1997).

Main Results

To date, our sampling has been limited by the ongoing delay in obtaining a research permit from the Office of Protected Resources at NMFS. Our sampling protocols are amendments to the Steller Sea Lion Research Permits submitted by Alaska Department of Fish and Game and the National Marine Mammal Laboratory, and as such we are dependent on their permits being authorized. We expect such authorization to happen in early fall 2002, more than a year later than originally expected.

Since the permit has been on hold, our research has been limited to activities that were previously permitted by NMFS, and to developing analytical techniques. In these areas we have been very successful. We have determined the HCT and Hb values for 232 animals, and have shown that both increase until approximately 10 months of age, by which time they have reached adult values. We have also worked with researchers at the Alaska Sea Life Center to develop and validate the hormone assay for erythropoietin. We have now validated the assay on phocids plasma (which is in ample supply), but the sea lion samples have not yet been run. Blood volume measurements await permit authorization, but the graduate student working on the project has been trained in the techniques at The Marine Mammal Center in California, where she practiced on live California sea lions.

Permitting difficulties have also limited our ability to measure muscle oxygen stores and metabolic status. While we have not been able to collect samples from live animals as yet, we have collected muscle samples from 10 recently deceased pups during ADFG and NMML capture / branding trips. Samples were also obtained from a single dead adult male. These samples have been analyzed for myoglobin content, and we have found that pup myoglobin load is significantly lower than that of adult ($p=0.000$). In addition, while adult swimming muscle showed significant elevation in myoglobin loads compared to non-swimming muscle, pups showed no difference in myoglobin concentration between muscle groups ($p>0.05$). Muscle mass in Steller pups is approximately 30.8% of the total body mass; adult values are still to be determined. Biochemical assays are recently underway, and preliminary data from these analyses will be presented at the American Physiological Society meetings in late August (Richmond et al. 2002). Histochemical assays have not yet begun on sea lion tissue, but methods have been trialed and refined on tissues from species for which we have excess sample volume. Since we have been unable to collect samples from older pups or juveniles (due to permit issues) it remains to be seen when juvenile muscles begin to develop.

Since permits have been considerably delayed, we have started to reach out to other sources of otariid tissues. We have initiated contact with the Native communities on the Pribilof Islands, and hope to obtain muscle samples from Steller sea lions killed as part of the subsistence hunt there. Samples from these animals (primarily juvenile males) would provide tissue from subadults with which we can compare the newborn data, but would likely not provide information on juvenile age classes. These samples will only come once permits are issued. However, we have also initiated contact with the Marine Mammal Center in California, from which we will obtain multiple muscle samples from animals that die under rehabilitation. These samples will be used for comparative purposes (with the SSL samples obtained) and to examine variation across different muscles in the body.

In combination, our findings indicate that newborn Steller sea lions have significantly lower oxygen stores than do adults, but without samples from animals between 1 week and adulthood, interpreting these finding is as yet difficult. However, the reduced oxygen storage capacity in young sea lions does conform to our previous finding in other pinnipeds, and suggests that the ontogeny of such stores plays a critical role in the transition to nutritional independence in sea lions, as it likely does in other species. To bolster these conclusions we await permits, but have also begun to pursue other ways in which to obtain necessary tissues.

While not part of this project *per se*, our SSLRI-funded project that examines the diving patterns of juvenile SSL has shown that SSLs younger than 10 months perform only limited behaviors suggestive of foraging, while animals older than that make longer and deeper dives, longer trips away from the rookeries, and further movements. These findings suggest that physiological changes necessary for diving and foraging are likely complete within the first year of life. It will be interesting to see if the physiological measurements to be carried out under CIFAR complement observed behavioral patterns.

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Publications and Presentations

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Progress Report: Investigation of the Foraging Behavior of Steller Sea Lions in the Vicinity of Kodiak Island, Alaska

***Principal Investigator*:** James Churnside, NOAA ETL, Boulder, Colorado

***Other Participating Researchers*:** Dick Thorne and Gary Thomas, Prince William Sound Science Center, Cordova, Alaska

Objectives

The primary objective of this work was to test the feasibility of using airborne remote sensors as part of a study of the foraging behavior of Steller sea lions near Kodiak Island. This study was particularly interested in the relationship between sea lions and herring in the winter.

Methods

Two primary instruments were mounted on a small fixed wing aircraft. These were the NOAA fish lidar and a multispectral imager that included three bands in the visible and one band in the thermal infrared. In addition, an infrared radiometer was installed to provide sea-surface temperature. Night and day surveys were made in two regions where herring were known to be wintering—the South Arm of Uganik Bay and Ugak Bay. Processing of the lidar data is by the normal methods to obtain profiles of schools of fish and of fish layers and plankton layers. The imager data are inspected for images of near-surface schools of fish, marine mammals, and birds. Also, the visible imager data are used to estimate distributions of primary productivity.

The original proposal involved use of a U.S. Coast Guard helicopter. In the aftermath of September 11, 2001, the Coast Guard was not able to provide this service, and the fixed-wing aircraft was chartered. The areas of interest are surrounded by mountains, and flight altitude had to be increased to 5000 feet in several flights because of safety concerns. This meant that better weather was required than if the helicopter had been used. Also, the charter costs were not covered in the original proposal, and this limited the available flight time. Table 1 summarizes the date, location, time of day, and altitude of each flight.

Main Results

The data collected by the multispectral imager are still being analyzed. Preliminary analysis of the lidar data has been completed. These data will be compared with acoustic data and samples collected by the surface survey.

During the two flights over Ugak Bay, fish were only detected along the north shore. Most were in fairly shallow water. The day flight was about 2 weeks before the night flight. In this flight, the observed schools were farther up in the bay. The nighttime observations were closer to the mouth of the bay. At night, the fish were in larger layers with less internal structure.

During the day, no fish were observed in the lidar signal in South Arm. There was a very distinctive change in the absorption of the laser beam in this area, probably caused by a high level of dissolved organic material. It is tempting to speculate that this organic material was produced by the herring that were known to be in this area. Distinct schools of fish were seen near East Point, and birds and sea lions were observed visually in this same area. The schools were located between 5 and 15 m in depth.

At night, the same region of strong laser attenuation was seen. There was also a strong scattering layer near the surface within South Arm. A diffuse scattering layer was observed in the area near East Point extending from about 5 to 30 m in depth. There is structure within the layer, but it is much larger and more diffuse than the school structure seen during the day.

Table 1. Flight summary

Date	Location	Day or Night	Altitude (feet)
3/14/02	Ugak Bay	Day	1000
3/18/02	Uganik Bay	Day	5000
3/28/02	Uganik Bay	Day	1000
3/28/02	Uganik Bay	Night	5000
3/28/02	Ugak Bay	Night	5000

Publications

Final data report in progress.

***Progress Report*:** **Climate-driven Bottom-up Processes and Killer Whale Abundance as Factors in Steller Sea Lion Population Trends in the Aleutian Islands**

***Final Report*:** **Zooplankton and Acoustic Sample Collection and Ship Charter**

***Principal Investigator*:** Kenneth O. Coyle, Institute of Marine Science, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks

***Other Participating Researchers*:** George L. Hunt (bird biology, project coordination), Department of Ecology and Environmental Biology, University of California Irvine; Sue Moore (marine mammal studies), National Marine Mammal Laboratory, NOAA, Seattle, Washington; Steve Zeeman (phytoplankton abundance and composition, primary production), University of New England; Phyllis Stabeno (physical oceanography), Pacific Marine Environmental Laboratory, NOAA, Seattle, Washington

The principal investigators listed above were funded under separate contracts from various agencies. They will therefore submit individual reports as required by their organizations and funding sources. However, since this research is a cooperative effort, parts of their contributions to the overall project appear in this report.

Background

Steller sea lions are large pinnipeds that breed along the west coast of North America from California to the Pribilof Islands in the north and westward along the Aleutian Archipelago. The western population, extending from Kodiak Island through the western Aleutian Islands, has undergone a steady decline since the mid 1970s. Due to the decline, the western population has been listed as an endangered species and the new listing has required severe restrictions on the groundfish fishery in regions where the sea lions breed and forage. The potential negative impact of these restrictions on the fishery has generated an immediate need to clarify the potential causes for the Steller sea lion population declines. The current working hypotheses for the declines are the following:

Hypotheses

1. Commercial fisheries are out-competing the Steller sea lions for the supply of available forage fish in the western part of the range.
2. Predation by killer whales on sea lions has increased mortality and lowered the survival of sea lion pups and juveniles.
3. Climate cycles in the North Pacific and southern Bering Sea have resulted in substantial declines in ecosystem productivity, thus lowering the overall food base for the Steller sea lions.

Recent studies of the population biology of Steller sea lions in the western portion of their range suggest that the population trajectories of sea lions may vary with rookery location. In the vicinity of Unimak Pass and the eastern Aleutian Islands, populations are holding their own or increasing slowly, whereas in the central Aleutians, population trends are still strongly downward. This spatial variation in the population trends of sea lions provides the opportunity to compare a variety of environmental variables in the two regions, and provides the possibility of identifying the factors responsible for the differences in these trends. This research tests the second and third hypotheses by measuring production indices and whale populations in the Akutan–Unimak area, where sea lion populations are steady or increasing, and in the Seguam–Amukta area, where the populations are in rapid decline. The research objectives are as follows:

Objectives

1. Measure the current flow and water column structure in the Akutan-Unimak and Seguam-Amukta regions.
2. Determine the location and intensity of frontal systems associated with the passes.
3. Measure primary production in and around the above two regions.
4. Measure zooplankton abundance and distribution in both regions relative to the frontal structure and distribution of water masses.
5. Generate acoustic measures of the distribution of forage fish and micronekton in both regions relative to frontal structure and water masses.
6. Estimate the abundance of apex predators (birds and mammals) in both regions.
7. Estimate the abundance of killer whales in both regions.
8. Obtain lipid samples from killer whales to determine their primary prey in both regions.
9. Compare the results of the above measurements in each region to identify consistent differences that would indicate climate and/or killer whale effects on the Steller populations.

Methods

Since this report deals mainly with the zooplankton and acoustic components, I will restrict my presentation of the methods to that portion of the project.

Two cruises have been completed. During year 1, June 4 to June 24 2001, samples were collected in Unimak, Akutan and Seguam passes. During year 2, May 16 – June 19 2002, samples were collected in Unimak, Akutan, Umnak, Samalga, Amukta, Seguam and Tananga passes. During year 1 a total of 128 MOCNESS samples and 78 CalVET samples were collected. During year 2, 230 MOCNESS and 82 CalVET samples were collected. Sample processing and data entry for all year 1 samples is complete. Year 2 samples will remain on the vessel till mid July, when it returns to Seward and is unloaded. The methods for zooplankton sample collection and processing are outlined below.

Large zooplankton and micronekton were collected with a 1-m^2 MOCNESS equipped with 500 µm mesh nets. The MOCNESS has eight nets, which can be opened at discrete depths to provide information on the abundance and species composition of organisms in specific scattering layers identified by the acoustic equipment. Samples were collected in 20 m depth increments from 100 m to the surface. The MOCNESS simultaneously collected data on salinity, temperature, fluorescence, depth, net angle, volume sampled, time and GPS position.

Small zooplankton were collected with a 9 cm diameter CalVET net system. The CalVET was equipped with 150 µm mesh nets towed vertically from the bottom to the surface. Samples were taken from 100 m to the surface at stations deeper than 110 m depth. The CalVET system was equipped with General Oceanics digital flowmeters to record volume filtered.

The samples were preserved in a 10% formalin seawater solution. The zooplankton samples were processed as follows: Each sample was poured into a sorting tray and large organisms, primarily shrimp and jellyfish, were removed and enumerated. The sample was then sequentially split using a Folsom splitter until the smallest subsample contained about 100 specimens of the most abundant taxa. The individual taxa were identified, staged, enumerated and weighed. Each larger subsample was examined to identify, enumerate and weigh the larger, less abundant taxa. The CalVET samples were subsampled with a Stempel pipet to produce subsamples with about 100 specimens of the most abundant taxa. Blotted wet weights of all specimens of each taxa and stage were taken for each sample and the coefficient of variation in average wet weight was computed. If the coefficient of variation for any given taxa and stage changed by less than 5% when additional weights were taken from subsequent samples, wet weights were no longer measured for that taxa for that cruise and the wet weight biomass was estimated by multiplying the specimen count by the mean wet weight. In practice, only calanoid copepods had consistent wet weights after weighing each taxa and stage in about 10–15 samples. Therefore, wet weights on euphausiids, shrimp and other larger taxa were measured and recorded for each sample individually. Wet weight measurements were done on a Cahn Electrobalance or Mettler top loading balance, depending on the size of the animal. All animals in the samples were identified to the lowest taxonomic category possible. Copepodid stages were identified and recorded. The data were uploaded to a Microsoft Access database for sorting and analysis. Analysis will be done with standard statistics software.

Acoustic surveys were done through each pass to document large scale distributional patterns of zooplankton and micronekton. Acoustic data were collected with a Hydroacoustic Technology Inc. (HTI) model 244 split-beam digital system. In year 1, the system included the following transducers: 43 kHz 6^o split beam, 120 kHz 6^o split beam, 200 kHz 3^o split beam, 420 kHz 6^o single beam. In year 2 the 43 kHz transducer was replaced with a 38 kHz transducer and the 420 kHz single beam transducer was replaced with a 420 kHz split beam transducer. The system multiplexes through each transducer collecting simultaneous 20 and 40 log R data for both integration and target strength determination. The transducer array was towed beside the vessel 3 m below the surface at about 6 knots. The data were integrated at 15-second time intervals and 1 m depth intervals. GPS time and position from the ship's navigation system were appended to each record before writing the data to disk. During year 2 the 38 kHz transducer failed. This failure compromised our ability to discriminate fish targets from zooplankton targets. However, during year 2, in addition to the HTI equipment, we were deploying a SciFish broadband acoustic system, which was multiplexed with the HTI system. The broadband system measured the frequency response between 110 and 190 kHz for all detected targets in the upper 200 m. The broadband data may permit us to discriminate between fish and zooplankton targets, despite the failure of the 38 kHz transducer.

The acoustic system was also deployed during each MOCNESS tow. The simultaneous collection of acoustic and net data will aid in the interpretation and scaling of the acoustic transect data.

Results

Preliminary results are currently available for year 1 only. A detailed cruise report on our year 2 effort is available from Hunt (the chief scientist for the cruise) on request. His e-mail address is glhunt@uci.edu.

The study area in the eastern Aleutian archipelago included Unimak, Akutan and Seguam passes (Fig. 1). The MOCNESS and acoustic transect through Seguam pass ran from the Pacific to the Bering Sea side. Flow through the pass generated distinct frontal regions, particularly on the north side of the pass. The frontal region was characterized by a sharp change in surface temperature from colder unstratified water in the pass to warmer stratified conditions north of the pass. Changes in temperature at the front were accompanied by distinct changes in salinity and density associated with the frontal region. The higher salinity and colder temperatures observed in the pass indicate upwelling generated by flow through the pass. Higher water column stability in the frontal regions relative to the pass was characterized by elevated water column fluorescence, indicating higher phytoplankton concentrations in the front relative to water in the pass to the south.

Highest abundances of the major copepod and fish taxa occurred primarily in the frontal region at the north end of the pass. Lower densities of the copepods *Neocalanus plumchrus*, *N. flemingeri* and *Eucalanus bungii,* and Pollock larvae, *Theragra chalcogramma*, were observed in the high density, upwelled water in the pass. Elevated volume scattering at 420 kHz was observed north of the pass in the frontal region. High-frequency volume scattering is generally associated with elevated concentrations of zooplankton, including copepods. Somewhat lower scattering in the front was observed in subsurface layers at 200, 120 and 43 kHz. The above pattern suggests the presence of high biomass of small zooplankton associated with the front at the north end of the pass. The pattern of elevated abundance of copepods in the front is particularly clear when examining water-column averages from MOCNESS tows. Zooplankton biomass of over 1.4 g m^{-3} at the front near the north end of Seguam pass was dominated by copepods (*N. plumchrus, N. flemingeri, N. cristatus, E. bungii* and *Calanus marshallae*). Marine mammal sightings occurred primarily on the north side of the pass, in proximity to the region of elevated zooplankton biomass associated with the front. The above observations suggest that physical mechanisms transporting upwelled water through the pass were generating elevated production in the transition zone between unstratified and stratified water, and the resulting production was being transferred through the food web to apex predators.

The MOCNESS and acoustic transect through Akutan Pass ran from the south Aleutian shelf northward through the pass and beyond the shelf break. A well-developed seasonal thermocline over the south Aleutian shelf was characterized by elevated surface temperatures and lower salinity. High water column salinity and density on the north side of the pass indicated intrusion of Bering Sea basin water onto the shelf. Elevated fluorescence was observed above the thermocline south of the pass and in regions of elevated salinity over the shelf break on the north end of the pass. Dense sound scattering near the bottom on the north Aleutian shelf was due to fish, possibly pollock. A scattering layer near the bottom south of the pass was apparently due to euphausiids. A scattering layer observed north of the pass was higher in the water column, probably due to diurnal vertical migration of euphausiids. The vertical sound-scattering features to the south and north of the pass were suggestive of eddies generated by flow through the pass. Abundance and biomass of the major zooplankton taxa was dominated by copepods. In contrast to Seguam Pass, a substantial amount of the zooplankton biomass also consisted of euphausiids. Euphausiids are indicated in the acoustic record by elevated scattering in the upper frequencies with little or no scattering at 43 kHz.

MOCNESS sampling in Unimak Pass was done only on the north side of the pass. Sampling to the south was suspended due to an electrical fire in the computer lab. The acoustic line was run clear through the pass and onto the south Aleutian shelf. As at Akutan Pass, the southern shelf region had a stratified water column with a sharp pycnocline at about 25 m depth. The high salinity dense water characteristic of the Bering Sea basin extended in a subsurface layer southward across the shelf to a distance of about 40 km from the shelf break. The above pattern of water mass distribution suggests substantial advection of nutrient-rich basin water onto the shelf near Unimak Pass. A scattering layer in the surface to the south of the pass was probably due to fish larvae. A scattering layer to the north of the pass was due to euphausiids and a scattering layer near the bottom on a ridge north of the pass was due to herring. Herring were observed in the regions in high numbers near the surface, where several specimens were taken with hook and line. The herring were foraging on dense swarms of euphausiids in the surface layer. Zooplankton abundance and biomass north of the pass were dominated by copepods, but substantial numbers of euphausiids were also present.

Although the results from all three passes suggest a similar overall species composition, the samples from the Akutan-Unimak region clustered together on a two dimensional multidimensional scaling plot (Fig. 2). Stations from the Seguam region were scattered throughout the plot, indicating an absence of a distinct species assemblage. The tighter clustering of Akutan-Unimak stations relative to Seguam Pass stations was probably due to the presence of shelf species associated with the broader shelf in the Akutan-Unimak regions. These species would include the euphausiid *Thysanoessa inermis* and the copepod *Calanus marshallae*. Seguam Pass and regions in the central Aleutians are essentially oceanic environments, as reflected by the dominance of *Neocalanus* and *Eucalanus* species in the copepod assemblage. Differences in the zooplankton community associated with the shelf and oceanic regimes will necessarily influence the species composition and abundance of forage fishes available to marine mammal predators.

Initial observations from the 2002 sampling effort suggest substantially lower overall production and zooplankton densities in the central Aleutians relative to the Akutan-Unimak regions. Definitive conclusions concerning the relative abundance and production of phytoplankton and zooplankton between the eastern and central Aleutian Islands will require statistical analysis of the results following sample processing of the 2002 collections. In addition, it is unclear whether the differences, if significant, represent a consistent trend or resulted from interannual anomalies in weather or hydrographic conditions. Consistently, lower production and abundance of forage species in the central Aleutians relative to the Unimak-Akutan region might indicate that substantial differences in environmental conditions in the central relative to the eastern region is impacting Steller sea lion populations in the two regions.

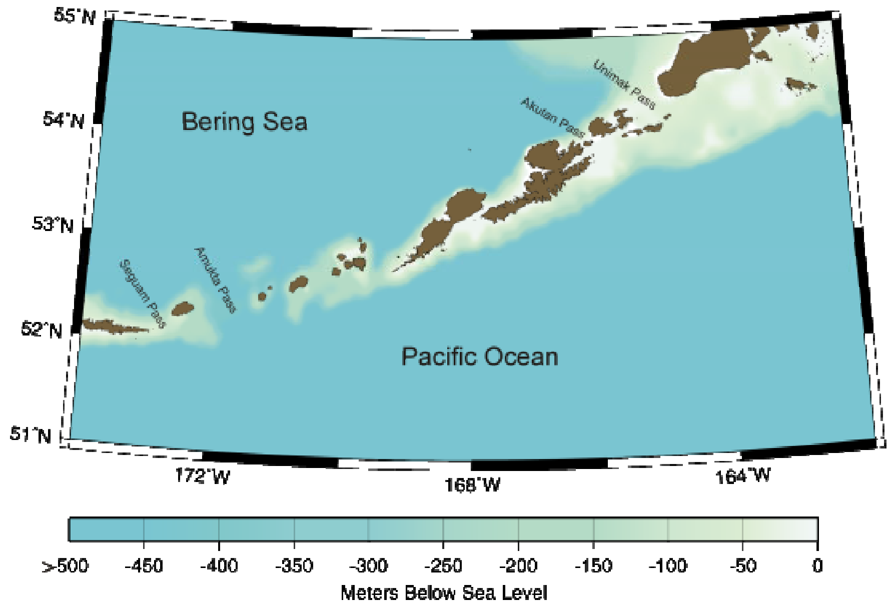

Fig. 1. Study area during year 1, eastern Aleutian Islands

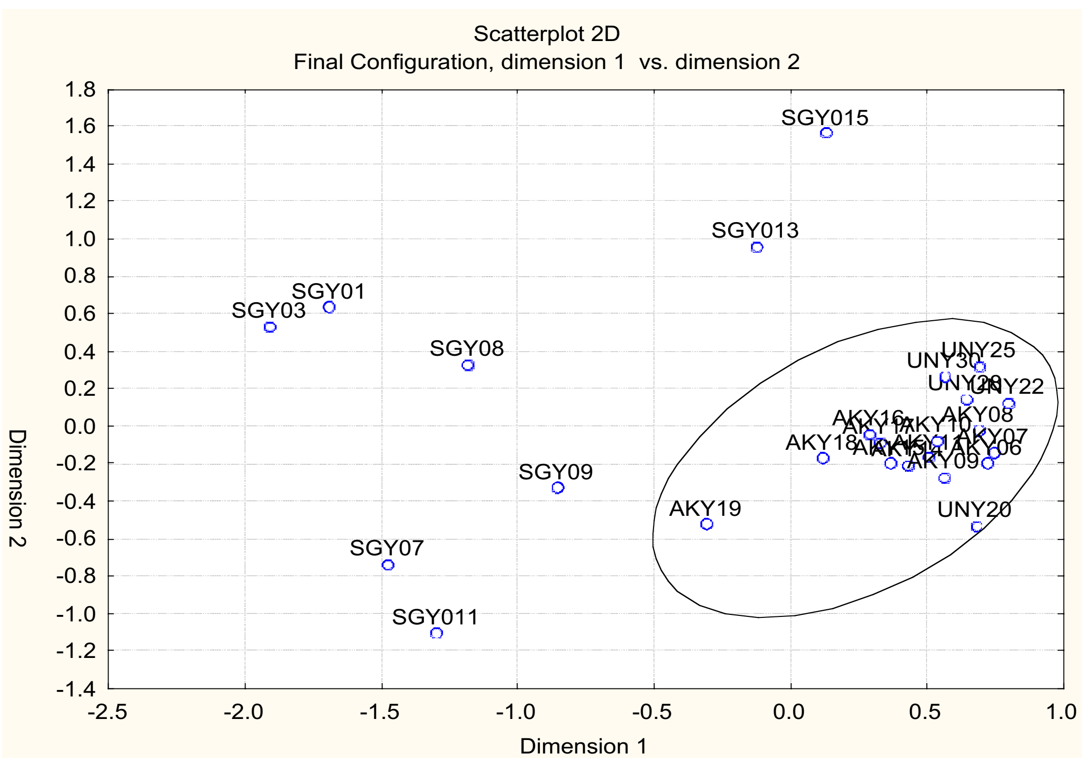

Fig. 2. Multidimensional scaling plot generated from abundance of the 10 most abundant taxa from each MOCNESS tow taken in the eastern Aleutians during June, 2001.

Final Report: Publication Support for "Is It Food II," A Workshop on Steller Sea Lion Declines

***Principal Investigator*:** Ronald K. Dearborn, Sea Grant College Program, University of Alaska Fairbanks

***Other Participating Researchers*:** Douglas DeMaster, NOAA/NMFS; Shannon Atkinson, Alaska Sealife Center, Seward, Alaska

Objectives, Methods and Main Results

The purpose of this project was to work with Dr. Douglas DeMaster of the National Marine Fisheries Service and Dr. Shannon Atkinson of the Alaska Sealife Center to document the findings of the workshop Steller Sea Lion Decline: Is It Food II. A workshop of 24 scientists was held May 30–31, 2001 at the Alaska Sealife Center in Seward, Alaska. Drs. DeMaster and Atkinson edited the publication "Steller Sea Lion Decline: Is It Food II." The report was then published by the University of Alaska Sea Grant College Program. Six hundred fifty copies were printed. Copies have been distributed to all participants. The workshop and publication have been publicized by Sea Grant and this has initiated a steady demand for the publication in the early weeks following its printing. Sea Grant issued an electronic media advisory to reporters across the state, notifying them of the publication's availability. Personalized emails were sent to selected reporters at Alaska Public Radio, the Associated Press, and Anchorage Daily News. Thus far, media results include mention of the publication in an Anchorage Daily News article about the role of the Steller sea lion in the May 19 edition, mention of the meeting in a forthcoming article in Alaska magazine, and general interest by reporters in the subject material as background.

The requirements of the project funding have been met. Distribution of the publication by Alaska Sea Grant will continue.

Publications

DeMaster, D., and S. Atkinson, Eds. (2002) *Steller Sea Lion Decline: Is It Food II*, University of Alaska Sea Grant, AK-SG-02-02, 80 pp.

Progress Report: Impacts of Climate Change on the Bering Sea Ecosystem over the Past 500 Years

***Principal Investigator*:** Bruce P. Finney, Institute of Marine Science, University of Alaska Fairbanks

***Other Participating Researchers*:** Amy C. Hirons, IMS/UAF; Alan M. Springer, IMS/UAF

Objectives

1) <u>To reconstruct changes in primary productivity of the Bering Sea at decadal or better resolution over the past approximately 500 years</u>. We will study cores from two locations to insure that regional changes are determined. We will also use multiple productivity proxies to develop a robust interpretation. We will also measure $\delta^{13}C$ on bone collagen from Steller sea lions to evaluate changes in marine primary production.
2) <u>To reconstruct relative changes in populations of forage fish at similar resolution to the records produced in objective 1.</u> Utilizing box and piston cores previously collected in Skan Bay, we are reconstructing high-resolution records of forage fish abundances through previous funding. Preliminary data from Skan Bay demonstrate the high potential for yielding excellent long-term data. To determine if the record from Skan Bay is representative of a larger region, we will also analyze sediment cores from one or more locations in the Aleutian Islands.
3) <u>To determine paleoceanographic changes in factors such as ocean temperature, salinity, and nitrate utilization for the cores discussed above.</u>
4) <u>To determine any changes in the trophic position of Steller sea lions.</u>
5) <u>To synthesize our results with available paleoclimatic, paleoceanographic and paleoecological data, and with retrospective and modern process studies in the North Pacific and Bering Sea.</u> Ultimately, we will develop a new understanding of natural variability of organisms at several levels of the food web (phytoplankton, zooplankton, forage fish, salmon, marine mammals) in this region, and their relationships to climatic and

oceanographic change. This long-term perspective is necessary to evaluate the recent changes, and to better understand the scales and processes of ecosystem change in this region.

Results

In an effort to reconstruct the paleocean productivity of the Bering Sea, we have collected and analyzed a 5-meter sediment core from Skan Bay, Unalaska Island. We have $\delta^{13}C$ data, carbon content and percent opal (from diatoms), all of which are proxies for primary productivity. Reconstruction of productivity from analysis of organic carbon mass accumulation rate and $\delta^{13}C$ ratio of organic matter is strongly controlled by photosynthetic rate. Diatoms are generally dominant primary producers in this region and the silica (opal) preserved in their tests give a good indication of their abundances through time. These data all indicate there were decadal and century-scale fluctuations in productivity taking place. Calibration of AMS and Pb-210 dating of the core indicates it represents almost 800 years.

Many recent studies have shown that the $\delta^{15}N$ ratio of marine organic matter is related to the $\delta^{15}N$ of the nutrient pool, which in turn is controlled by nitrate supply (e.g., Altabet and Francois, 1994). The $\delta^{15}N$ analysis is complete and the data for the Skan Bay core was more consistent than the $\delta^{13}C$ data over its length. However, the nitrogen data did have a few significant declines that may coincide with certain paleoclimatic events.

Fish scales have been removed from the Skan Bay core and are currently being identified in an effort to reconstruct forage fish abundances through time. These abundances are being linked chronologically with productivity and environmental changes throughout the core. Foraminifera are being removed individually from the small sediment fraction and being identified taxonomically. They will then be shipped this fall to a commercial lab for $\delta^{18}O$ and Ca/Mg analyses.

Cetacean and pinniped bones have been collected from archaeological sites on Unalaska Island and Kodiak Island through the time of occupation, generally the mid-19th century. The more modern samples of bone (~1850–1950 AD) have been collected from the Smithsonian and Carnegie Museums. The collagen extraction process has begun and the final isotope analyses are expected to be complete by the end of this summer. Trophic level reconstructions of these species will be taking place this winter.

Logistical difficulties have prevented us from accessing Shagak Bay, Adak Island and collecting a sediment core as originally proposed. However, we have made other provisions to collect sediment cores from equally, if not more, opportune locations. A NOAA cruise during September 2002 is taking place in the Bering Sea and we have been given the opportunity to collect sediment cores from the ship. We have isolated three sites along the Aleutian Arc that have the potential of providing us with cores meeting our earlier described criteria. We will deploy a gravity or piston corer from the vessel to collect the cores and, at the end of the cruise, ship the cores to our laboratory in Fairbanks where analyses, such as the ones conducted on the Skan Bay core, will take place this fall.

Cross-correlation and spectral analysis of the Skan Bay core has been, and continues to be, conducted. The relationship of climatic and oceanographic changes has had varied impact on organisms in the North Pacific Ocean. Sockeye salmon data has been compiled and their abundance differences have been introduced into the large-scale analysis. There appear to be periods of close correlation between productivity and abundance changes. Preliminary results of our data have been presented at an international stable isotope conference in Australia and at the PICES meeting in Canada last fall. These data were also presented at the Steller sea lion investigators meeting in Anchorage in March of this year.

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***Progress Report*: Seasonal Assessment of Prey Competition between Steller Sea Lions and Walleye Pollock**

***Principal Investigator*:** Robert J. Foy, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks

Objectives

The goal of this study is to assess the level of competitive interaction on a seasonal basis between walleye pollock and Steller sea lions within designated sea lion critical habitat. In particular the objectives are to:

1. Determine the seasonal diet composition of pollock from within Steller sea lion critical habitat.
2. Determine consumption and evacuation rates of pollock based on varied diets consistent with diets determined in situ, while taking into account pollock size and water temperature.
3. Calculate the potential removal (daily ration) of particular prey species by pollock given published pollock biomass and size frequency data.
4. Compare the removals of pollock prey to the diets of Steller sea lions to determine the extent of competitive interaction.
5. Address the efficacy and effects of restricting pollock harvests inside Steller sea lion critical habitat.

Methods/Analyses

Fifty pollock stomachs were collected from within the Long Island Steller sea lion critical habitat area in May, July, November 2001, and March, May and July 2002 in conjunction with the Gulf Apex Predator-prey study in Kodiak. In November 2002 fifty pollock stomachs will also be collected. One hundred fish were also collected from local processors that represent areas outside of sea lion critical habitat from which to compare the diets. A comparison of diets among localized groups of pollock will give some idea of small scale variability as has been found with local abundances of pollock subpopulations (Bailey et al. 1999).

Prior to stomach content analysis, each fish was blotted dry, weighed to the nearest 0.1 g, and measured (standard length) to the nearest 1.0 mm. To test for seasonal and spatial differences in fish size, analysis of variance comparisons will be made on log (x + 1) transformed length and weight values. Post hoc multiple comparisons of fish weights and lengths among sampling strata will be made by the Tukey post hoc method for unequal sample sizes (Spjotvoll and Stoline 1973).

To measure the relative amount of food in pollock stomachs, stomach content weight as % body weight (%BW) will be reported by dividing the stomach content weight by the total fish weight. Excised stomachs were weighed to the nearest 0.01 g, cleared and reweighed to determine stomach content weight. All empty stomachs were noted as well. %BW data will be arcsine transformed to satisfy the assumptions of normality by a Shapiro-Wilks W test of normality before inclusion in univariate regression models. Arcsine (%BW) will be regressed as a function of time of year and standard length of the fish. A stepwise function will be used to eliminate non-significant variables for the final regression. Post hoc multiple comparisons will be made by Tukey, Dunnett and Sidak methods.

Taxa from each stomach were enumerated and identified to the lowest possible taxonomic level. Life history stages were identified when possible. In some cases, due to digestion, it was only possible to identify prey to a broad taxonomic grouping.

Taxa composition of fish diets will be examined by ordination of dissimilarity indices. Bray-Curtis dissimilarities of pollock diets will be calculated on root-root transformed counts of taxa found in the stomach contents. The diversity of taxa in the pollock diets will be assessed by indices of richness and evenness.

One hundred pollock of multiple year classes were collect by jigging seining. Two 1150-gallon tanks were set up to acclimate and maintain the fish with running seawater at a rate to replenish seawater every hour. Fish feed was acquired from aquaculture sites in British Columbia, which have experience raising pollock. The condition of the pollock has been monitored to establish a daily regime. Feeding studies will not begin until fish have been held for 2–3 months (approximately September 2002). For consumption and evacuation rate experiments, three sets of feeding trials based on different temperatures will be performed on each size class of fish. Size classes will be determined by the availability from catches. The three temperatures will be representative of the range and mean temperatures encountered seasonally by pollock in the collection area around Kodiak. Mito et al. (1999) estimated lower daily rations during colder seasons (fall and winter). Light levels will be held constant at approximately 10 hours of light at a constant intensity.

Daily ration estimates of each prey species will then be collected from published literature on predator biomass, calculated consumption and evacuation rates (Elliott and Persson 1978). Size of fish before and after the study will be noted to relate feeding behavior to growth rates. This data will be compared to Steller sea lion diets from concurrent studies. Sea lion diet data is being collected from scat samples collected on Long Island and as such represents frequency of occurrence data. This data will be used to identify important prey species and will be compared to pollock diet frequency of occurrence using similarity indices.

Results

Five sampling cruises have taken place and 250 pollock have been sampled for diet analyses and proximate composition. Proximate composition analysis has been run on 150 pollock samples ranging from 8 cm to 60 cm from May to November 2001. Average protein content increased from 15.3 to 16.2 % for a 50 cm fish. Average lipid increased from 1.7 to 4.1 percent between May and November 2001. Adult pollock diets from 2001 were dominated by juvenile pollock, tanner crab, eulachon and euphausiids. Juvenile pollock diets are dominated by euphausiids and larval fishes. Fish collections will continue in 2002 for diet and proximate analysis. Pollock have been collected and are acclimatizing in captivity. Growth studies to determine growth rate, consumption and evacuation rates will commence in September 2002.

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Expected Publications

Competitive interactions between Steller sea lions and walleye pollock inside sea lion critical habitat: a diet comparison.

Seasonal lipid content and feeding habits of walleye pollock in Kodiak, AK.

Progress Report: **Interannual Variability of Biophysical Linkages Between the Basin and Shelf in the Bering Sea**

***Principal Investigators*:** Wieslaw Maslowski, Naval Postgraduate School, Monterey, California; Stephen R. Okkonen, Institute of Marine Science, University of Alaska Fairbanks

***Co-Principal Investigator*:** Terry E. Whitledge, Institute of Marine Science, University of Alaska Fairbanks

Objectives and Background

The general objective for this project is to investigate interannual and decadal variations in exchanges of properties and nutrients between the Bering Sea/North Pacific Ocean and Arctic Ocean, using a 9-km and 45-level, expanded version of the Naval Postgraduate School coupled ice-ocean model. In particular, our studies will include investigations of the dynamics and variability of the Bering Slope Current (BSC), their influence on the transport of nutrients from the deep basin of the Bering Sea to the continental shelf, the resulting phytoplankton production in the Anadyr and Chirikov Basins, and the export of phytodetritus to the Chukchi Sea. Ice-ocean interactions and their contribution to seasonal and interannual variability of the BSC will be addressed. In addition, we will also evaluate the role of upstream transport of mass and water properties, across the Aleutian Chain in the areas of main exchanges between the North Pacific and Bering Sea.

This research project addresses components of the research priorities of the Steller's sea lion research competition, as well as both the Climate Variability/Change in the Arctic and Bering Sea Productivity categories of the Arctic Research Initiative. Our large-scale study of interannual-to-decadal interactions between the Arctic Ocean and the Bering Sea/North Pacific will contribute to an understanding of cause/effect relationships between the two oceans. Global ocean models have commonly cut off the Arctic Ocean from their domains by prescribing some type of climatological lateral boundary conditions at the northern high latitudes. Regional Arctic Ocean models, on the other hand, usually have not included the Bering Sea or the North Pacific. Use of the Pan-Arctic model will allow for investigation of the two regions and their interactions over decadal time scales. This effort directly relates to the two major types of activities under the Study of Environmental Arctic Change (SEARCH) program. It addresses modeling of the Arctic environment and leads to possible predictions of its future variability, as it has been shown for the central Arctic Ocean by Maslowski et al. (2000, 2001 <www.oc.nps.navy.mil/sbi>). It also provides new ways to test hypotheses of critical feedback processes controlling variability of Arctic climate (e.g. exchanges through Bering Strait or through the Canadian Archipelago and their role in the Arctic/North Atlantic thermohaline circulation). The Pan-Arctic model including the North Pacific and North Atlantic will allow studies of the ice-ocean response to the large scale atmospheric weather patterns, such as the North Atlantic Oscillation (NAO), the Pacific Decadal Oscillation (PDO) and the Arctic Oscillation (AO). Model prediction of variable water and ice volume transports and fluxes of heat, fresh water and nutrients in and out of the Arctic Ocean will allow for synthesis and integration of various hydrographic sections, long term moorings and/or other monitoring data sets in support of the Arctic/Sub-Arctic Ocean Fluxes (ASOF) Initiative. The proposed research also provides a direct link to the Western Arctic Shelf Basin Interaction (SBI) program of the National Science Foundation (NSF), concentrated in the region of Bering Strait and the Chukchi/Beaufort Sea. The focus on biophysical linkages across the continental slopes of the Bering Sea and between the Bering Sea and Arctic Ocean will address the Bering Sea Productivity research priority. It will also complement studies from the recent Southeast Bering Sea Carrying Capacity (SEBSCC) program and the ongoing North Pacific Marine Research Initiative.

Progress to Date

Maslowski has completed a multi-decade integration and some analysis of model output with emphasis on the Gulf of Alaska and the Bering Sea circulation and variability. A 60-year integration of the coupled 9-km ice-ocean model has been completed, including a 45-year spinup and a 15-year interannual run. The model has been forced with daily-averaged realistic atmospheric fields from the European Centre for Medium-range Weather Forecasts (ECMWF) 1979–1993 reanalysis. The coupled model adapts the Los Alamos National Laboratory (LANL) Parallel Ocean Program (POP) ocean model with a free surface. The sea ice model uses a viscous-plastic rheology, the zero-layer approximation of heat conduction through ice and a simplified surface energy budget. Many improvements, such as the seasonal cycle of sea ice advancement and retreat, leads and polynyas, and the ice edge position in the Bering/Chukchi Seas, are shown to be a result of more realistic high resolution modeling of the upper ocean currents and hydrography. The regional model yields realistic predictions of the net northward transport through Bering Strait and consequently the oceanic circulation and variability upstream in the Bering Sea and the Gulf of Alaska. Large anticyclonic eddies (200–300 km in diameter) are simulated propagating to the west along the southern slopes of the Alaska Peninsula and the Aleutian Islands. Those eddies are shown to significantly influence water mass and property exchanges between the Gulf of Alaska and the Bering Sea as they slowly propagate (a few eddies per year) from the northeastern Gulf of Alaska westward towards the central North Pacific. More results from this experiment are available at <www.oc.nps.navy.mil/~pips3>.

To improve model representation of sea ice conditions in the Bering Sea and the proper Arctic Ocean, a state-of-the-art sea ice model has been developed to replace the existing ‘old’ sea ice model in the coupled 9-km ice-ocean model. A 20-year integration of the new sea ice model with a mixed ocean layer has been completed. This model uses the most recent version of sea ice model (CICE 3.0) developed at LANL. It contains an improved calculation of ice growth/decay based on work of Bitz and Lipscomb (1999). It has been configured to use five sea ice categories with 4 layers per category, a snow layer in each category, the EVP rheology (Hunke and Dukowicz, 1997), the remapping of sea ice transport (Lipscomb and Hunke, 2002) and ice thickness (Lipscomb, 2001). The realistic daily-averaged 1979–1988 ECMWF atmospheric data has been used to force the model. Results on model representation of leads, polynyas, and the ice edge in the Bering Sea suggest dramatic improvements due to more realistic model representation of sea ice concentration, drift, divergence, shear, and vorticity. Further model evaluations are planned as results from integration of the new sea ice model coupled to the pan-Arctic ocean model become available.

Okkonen has produced a preliminary comparison of modeled Bering Slope Current (BSC) eddy field topography and TOPEX altimeter observations of BSC eddy field topography. The character of the modeled eddy field exhibit resembles the observed eddy field in that it is characterized by ~100 km diameter eddies and that it exhibits annual period modulation and interannual variability. Model results also agree with observations that show that anticyclonic eddies adjacent to the shelf break in the central Bering Sea and the Alaska Peninsula draw surface shelf waters seaward (displacing the shelfbreak front seaward) and drive deeper waters onto the shelf. The biophysical effect is to ‘pump’ nutrients on to the shelf. Lateral velocity shear associated with anticyclonic eddies results in horizontal divergence which drives upwelling along the periphery of these eddies.

Whitledge has collected retrospective station location, hydrography and nutrient data from the PROBES project for comparison with the model output.

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Publications and Presentations

No manuscripts have yet been submitted for publication. The following presentations of research results have been made:

Maslowski, W., S.R. Okkonen, and W. Walczowski (2002) Towards an improved model representation of oceanic and sea ice conditions in the Bering and Chukchi Seas. 2002 Ocean Sciences Meeting, Honolulu, Hawaii, 11–15 February 2002.

Okkonen, S.R., W. Maslowski, W. Walczowksi, and T.E. Whitledge (2002) Eddy kinetic energy in the western Gulf of Alaska and Bering Sea: Comparative estimates from TOPEX altimeter data and coupled ice ocean model simulations. 2002 Ocean Sciences Meeting, Honolulu, Hawaii, 11–15 February 2002.

Maslowski, W. (2002) Are predicted changes in the Arctic System detectable? NSF/ARCSSS All-Hands Workshop, Seattle, Washington, 20–23 February, 2002.

Maslowski, W., Walczowski, W., and D.C. Marble (2002) Advanced ocean and sea ice modeling of the pan-Arctic region in support of the NSF/ARCSS program. NSF/ARCSSS All-Hands Workshop, Seattle, Washington, 20–23 February, 2002.

Maslowski, W., and S.R. Okkonen (2002) Interannual variability of biophysical linkages between the basin and shelf in the Bering Sea - Parts 1 and 2. Steller Sea Lion Principal Investigators' Orientation and Coordination Meeting, Hotel Captain Cook, Anchorage Alaska, 19–21 March, 2002.

***Progress Report*: Decision-Making under Uncertainty: Management of Commercial Fisheries and Marine Mammals**

***Principal Investigators*:** Jerry McBeath, Department of Political Science, University of Alaska Fairbanks; Matt Berman, Institute of Social and Economic Research, University of Alaska Anchorage

***Other Participating Researchers*:** Ronald "Burr" Neely, graduate assistant, University of Alaska Fairbanks; Darcy Dugan, research intern, ISER, University of Alaska Anchorage

Objectives and Methods

We proposed to CIFAR a two-year project, in the amount of $210,000, composed of four elements: a) An examination of the structure of the decision-making system—the relevant authorities, government managers, and affected interests; b) Analysis of the etiology of the SSL crisis including treatment of early warning signs, economic and political pressures to continue resource use, bureaucratic accommodation in the absence of certain data; c) Policy analysis of the scientific literature on SSL decline, focusing on existing knowledge that can guide decisions in the present (including hypothetical cost-benefit analysis comparing draconian to mild fisheries limitations, and their differentiated impact on SSL recovery); and d) Policy analysis of decision-making under conditions of uncertainty, including investigation of the political, socio-economic, and environmental risks of policy failures; estimates of the degree of certainty in scientific findings necessary before taking action. We proposed to use two primary data sources: files of government agencies and interviews with federal and state government officials, industry representatives, non-governmental organizations (Native, environmental, public interest), and scientists.

The project was funded, but at a reduced ($120,000) level, which necessitated changes in the scope of proposed work. Instead of eliminating any of the proposed project elements (quite difficult because they are interrelated), we determined to narrow our focus to specific aspects of each of the hypotheses and objectives. Further, we planned, insofar as possible, to reduce the amount of interviewing required and rely on secondary sources more strongly (particularly in analysis of the etiology and the scientific literature).

Main Results to Date

Because of the press of other projects with earlier deadlines, we started our work late, in January 2002. In the last six months, we have engaged in four activities:

a) Interviews with decision-makers and staff in the U.S. Congress (Office of Senator Ted Stevens, Washington, DC) and Office of Protected Resources of the National Marine Fisheries Service (Silver Spring, MD); b) preparation of a complete chronology of the Steller sea lion crisis (prepared by Burr Neely under the supervision of McBeath);

c) interviews with senior scientists and science managers directing SSL research efforts to ascertain their views on the certainty of the knowledge base and the quality of research data used to make policy decisions; and d) investigation of the most controversial aspect of the SSL crisis to the present: the decision of U.S. District Court Judge Thomas Zilly to enjoin all commercial groundfish trawl fishing in the waters of the Steller sea lion critical habitat within the Bering Sea/Aleutian Islands and the Gulf of Alaska region west of 144 degrees longitude in August 2000.

Because the case, *Greenpeace, American Oceans Campaign, and Sierra Club v. National Marine Fisheries Service* (C98-492Z), is still open and not yet logged on to the Pacer system, it was necessary to inspect and arrange for copying of documents in Seattle, which McBeath did in June. This included inspection of 552 court documents, in 19 large volumes and 25 expando files. These materials are currently being analyzed.

Planned Papers and Publications

Because of the late project start, and lifetime of only six months, no publications have issued from it yet. However, two conference papers are being prepared based on research. The first will be an analysis of the court case, focusing on those factors most influential in influencing Judge Zilly's decision. This will be presented to the Western Regional Science Association's annual conference, meeting in Arizona in late February 2003; it will be the basis of an article submitted to a professional journal.

The second paper asks how national politics and institutions influence the way sustainability knowledge is generated, distributed and used by actors, as well as how the distribution and utilization of scientific knowledge is influenced by political institutions and political and societal actors. This paper will use the SSL crisis as one case within the rubric of the Endangered Species Act, comparing it to the Spotted Owl and Pacific Salmon cases.

The paper will be presented to the December 2002 Berlin Conference on the Human Dimensions of Global Environmental Change, whose theme is "Knowledge for the Sustainability Transition: The Challenge for Social Science." The conference paper will be published in the conference proceedings; too, it will be the basis for an article submitted to a professional journal.

***Progress Report*:** **Retrospective Studies of Climate Impacts on Alaska Steller's Sea Lions**

***Principal Investigator*:** Edward Miles, University of Washington, JISAO/SMA Climate Impacts Group, Seattle, Washington

***Other Participating Researchers*:** Nathan Mantua, University of Washington, JISAO/SMA Climate Impacts Group; Steven Hare, International Pacific Halibut Commission, Seattle, Washington; Caren Marzban, National Research Center for Statistics and the Environment, University of Washington, Seattle, Washington

Objectives

To date, our research has focused on two main objectives. First, to develop and analyze an environmental and fishery database custom-tailored for retrospective studies of climate impacts on Alaska Steller's Sea Lions (SSLs). Second, to examine the potential for using elements of this database to statistically explain past time variability in the regional variations in SSL populations. This second objective is to identify the "best predictors" of regional SSL variability over the period 1970–2001 among the elements of our multi-variate database.

Methods

Objective 1: In developing our custom-tailored fishery and environmental database, we start with a subset of the time series compiled and examined by Hare and Mantua (2000). This subset corresponds with their fishery and local environmental data for locations along the coast of British Columbia north to the Bering Sea, as well as indices for large-scale climate variations over the Pacific and Arctic (data series 1–69 in their Table 1). Because the time series examined by Hare and Mantua (2000) only covered the period from 1965–1997, we have updated this database through 2001, and in some cases through 2002. In the near future, we will add several time series for Gulf of Alaska and Bering Sea herring recruitment and biomass that we have recently obtained from Alaska's Department of Fish and Game.

With this database we are doing the following analyses:

1. Computing trends in both the SSL and multivariate data series over the period 1970–2001 using Kendall's τ statistic. τ is capable of assessing nonlinear (but monotonic) trends. This analysis allows for a determination of statistically significant trends in all parameters, which can be compared and contrasted between the SSL and multivariate databases.
2. Computing linear and nonlinear principal components from the environmental and fishery data in the multivariate database. This part of the analysis is an extension of the analysis reported on by Hare and Mantua (2000) in three ways. First, the database represents a subset of that which was examined in their study. Second, these time series cover a longer period of record (1965–2001 versus 1965–1997); and third, this analysis will employ both linear and nonlinear Principal Component Analysis.
3. Identifying "best predictors" of SSL regional population variations via correlation analyses, first from the individual elements of multivariate database and second from the linear and nonlinear principal components that are developed in step 2. In this analysis, we examine correlations between the various indices at lead/lags of +/- 0 to 15 years with the SSL series. When examining correlations between climate or fishery data and the SSL data, it is quite possible that the most important correlations will occur at lags of a few to several years. This seems especially likely when comparing our database with adult SSL counts, as changes in the adult populations may arise from environmental or ecosystem processes that impact juvenile or adolescent animals more strongly than adults.

Main Results

To date, we have a draft manuscript describing the database, analysis methods, and preliminary results from our "trend" and "best predictor" analyses. A critical issue that we have struggled with over the past few months has involved attempting to "quality control" the SSL data series provided by NOAA. We believe that this problem has been solved with the help of John Sease at the National Marine Mammal Lab. Working with this revised SSL database requires us to redo our trend and best predictor analyses, now high priorities on our schedules. The results of this work will be reported in a manuscript that will be submitted for publication in a peer-reviewed journal.

Preliminary results of our linear principal component analysis of our own multivariate database identify two statistically significant patterns of variability. The leading mode clearly represents the well-known 1977 climate and ecosystem regime shift in the North Pacific, and the second mode represents state shifts in both 1977 and in 1989. These features have been reported on in several published articles. Additionally, the leading mode also identifies a state-shift between 1998 and 1999. There has been some speculation that the latest regime-shift in North Pacific climate and marine ecosystems took place in 1998/99, yet little solid evidence has been presented in the peer-reviewed literature (e.g. see Hare and Mantua 2000, and Schwing and Moore 2000). We are now closely examining the fishery and environmental time series that are consistent with such a shift, as well as those that are in disagreement. We plan to draft a manuscript reporting on the results of our linear and nonlinear principal component analyses and submit it for publication in a peer-reviewed journal.

References

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Schwing, F. and C. Moore, 2000: A year without a summer for California, or a harbinger of a climate shift? *Eos Trans.*, AGU, 81, 301, 304–305.

***Progress Report*: The Temporal and Spatial Nature of Regime Shifts and Their Impact on Steller Sea Lions**

***Principal Investigator*:** Donald B. Percival, Applied Physics Laboratory, University of Washington, Seattle

***Collaborative Investigators*:** James E. Overland and Harold O. Mofjeld, NOAA/Pacific Marine Environmental Laboratory, Seattle, Washington

Objectives

Steller sea lions (SSL) have declined from a population of about 250,000 in the Kodiak–Aleutian area in the 1960s to less than 50,000 in the late 1990s. One hypothesized factor in this population decline is the impact of ocean climate regime shifts. Our work has the following two objectives, both of which are directly relevant to the goal of investigating the impact of ocean climate regime shifts on SSL populations.

1. Provide understanding of the underlying character of North Pacific regime shifts. Loosely speaking, a regime is a stretch of time during which a time series remains predominantly either above or below its long term average value; however, in practice all ocean climate time series include a significant stochastic component due to interannual variability and other factors. In order to properly account for this inherent stochastic element, quantification and detection of regime shifts must be done within the context of particular time series models. The objective of this portion of our work is to compare and contrast different deterministic/stochastic models for time series exhibiting regime-like characteristics. The particular time series to be studied are a 100-year series of winter and spring average sea level pressures for the Aleutian low (termed the North Pacific Index (NPI)) and a 1829–1996 record (with gaps) of winter Sitka air temperature. Both series measure climate change for Western Alaska, the region of SSL impact.

2. Compare space-time variability of North Pacific climate indices with SSL declines. While the large SSL population in the Kodiak–Aleutian area has declined dramatically in the last thirty years, the considerably smaller population in Southeast Alaska has actually increased by 6%. Can the fact that the SSL population has fared better in the Southeast Alaska be attributed to differences in ocean climates or to different responses to regime shifts? Although the Kodiak–Aleutian region is dominated by the NPI, the Gulf of Alaska has a secondary mode of variability and also has an enhanced response to El Niño (Overland *et al.*, 2000). Both ocean and SSL variability show spatial differences in the timing of changes (Trites and Larkin, 1996; Overland *et al.*, 1999). Our goals here (to be addressed in the second year of our project) are (i) to use historical coastal Bakun upwelling indices to map space-time variability along the Alaskan coast on a season by season basis; (ii) to study the relationships between these spatially separated indices using a variety of statistical techniques that treat the series both in a bivariate manner (e.g., coherency analysis) and also in a multivariate manner that takes into account the spatial separation between the series; (iii) to subject these indices to a regime analysis; and (iv) to compare the spatially dependent upwelling indices and their associated regimes to *changes* in corresponding SSL populations (i.e., to recruitment series) using techniques that can account for the sparseness of relevant SSL recruitment data.

Methods

We considered three different models for the NPI and Sitka air temperature series. The first two models are purely stochastic and are based on (i) a Gaussian 'short memory' first order autoregressive (AR(1)) process and (ii) a Gaussian 'long memory' fractionally differenced (FD) process (Percival *et al.*, 2001). The third model is a 'signal plus white noise' model in which the 'signal' component was determined using a 'matching pursuit' procedure. This procedure consists of searching through a large set ('dictionary') of explanatory vectors to see which vector was the single best match for the time series under study. The vectors in the dictionary are associated with (i) sinusoidal oscillations dictated by the discrete Fourier transform, (ii) square wave oscillations with all possible periods and shifts and (iii) wavelet and scaling coefficients from a discretized version of the continuous Haar wavelet transform. While application of matching pursuit to the NPI series was straightforward, we had to adapt the procedure somewhat to handle the Sitka series due to the fact that this series has a significant number of gaps.

Each of the three models depends upon three parameters. We estimated the parameters for each model using a maximum likelihood procedure (again with adjustments to handle the gappy Sitka series). We validated the large sample theory behind these estimators using Monte Carlo techniques based upon simulation procedures that are capable of generating time series with exactly correct statistical properties.

Main Results

We used matching pursuit to investigate the notion that North Pacific climate time series exhibit regimelike shifts. In particular we explored a hypothesis by Minobe (1999) that there are penta- and bi-decadal oscillations in NPI, with sharp transitions between high and low states that cannot be easily modeled by sinusoidal oscillations. We found that matching pursuit preferentially selects square wave oscillations with periods and phases that agree closely with Minobe's analysis and penta-decadal hypothesis; however, our analysis calls into question the existence of an independent bi-decadal oscillation. For the Sitka winter air temperature measurements, we found that matching pursuit again picks out a square wave oscillation that is quite similar to the one identified for NPI, with zero crossings during 1840–1, 1867–8, 1894–5, 1921–2, 1948–9 and 1975–6. Details of this work are presented in Percival *et al.* (in press).

We also compared the 'signal plus white noise' model selected by matching pursuit with the AR(1) and FD models studied previously (Percival *et al.*, 2001). Statistically each model fits the NPI and Sitka series equally well. The fact that both series are quite short (100 data points for NPI and 146 data points spread out over 168 years for the Sitka series) makes it unrealistic to expect to be able to clearly prefer one model over the other. Although the models fit equally well, their implications for long term climate patterns can be quite different in terms of, e.g., generating regimes of characteristic lengths (i.e., stretches of years over which a climate variable is predominantly either above or below its long term average value). This fact is demonstrated in Figure 1, which indicates that (i) a regime of twenty years duration is about eight (fifty, respectively) times more likely to occur under the square wave oscillation model than under the FD model (AR(1) model, respectively) and (ii) regimes of thirty or more years duration are most likely to occur under the FD model. Because we cannot determine a preferred model statistically, we are faced with either entertaining multiple models when considering what the long-term behavior of the NP index is likely to be or using physical arguments to select one model. The latter approach would arguably favor the FD process because it has an interpretation as the synthesis of first order differential equations involving many different damping constants. Details of this work are presented in Percival *et al.* (submitted).

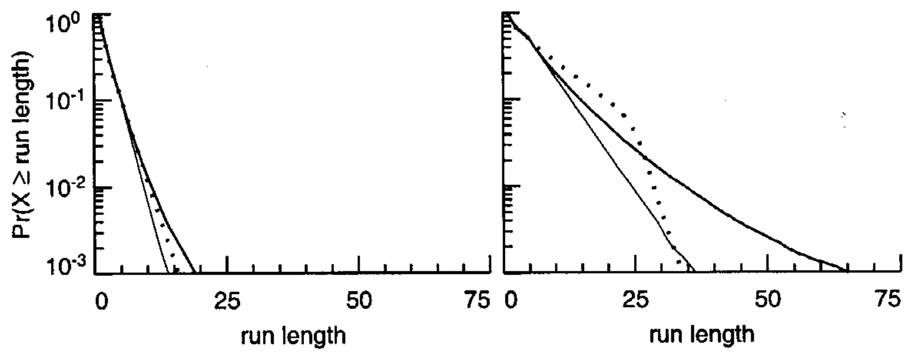

Figure 1. Probability of observing a regime ('run') greater than or equal to a specified regime length. The thin, thick and dotted curves are for, respectively, the AR(1), FD and 'square wave oscillation plus white noise' models. The left-hand plot is for runs determined from the processes themselves, whereas the right-hand plot is for runs after the processes have been subjected to a five-year running average.

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Percival, D.B., J.E. Overland, and H.O. Mofjeld (In press) Modeling north Pacific climate time series. In *Time Series Analysis and Applications to Geophysical Systems*. D.R. Brillinger, E.A. Robinson and F.P. Schoenberg, Eds., Springer–Verlag.

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Progress Report: **Ocean Climate Variability as a Potential Influence on Steller's Sea Lion Populations**

Principal Investigators**:** Thomas C. Royer and Chester E. Grosch, Center for Coastal Physical Oceanography, Department of Ocean, Earth and Atmospheric Sciences, Old Dominion University, Norfolk, Virginia

Objectives

We hypothesize that interdecadal changes in the ocean climate will influence the biological productivity in the North Pacific and Bering Sea. The combination of many of the oceanic-atmospheric forces with bidecadal cycles could lead to the regime shift in the North Pacific that occurred in the late 1970s (Francis et al. 1996). These low frequency fluctuations could influence the amount of biomass in the ecosystem and its trophic level distributions. In order to address this hypothesis, two important questions must be addressed: (1) How are the sea level slopes and ocean circulation related to the coastal freshwater discharge and coastal sea levels in the Gulf of Alaska? (2) Do coastal freshwater discharge and coastal sea level records contain information on interdecadal changes in the marine ecosystem in the North Pacific and Bering Sea?

Methods and Results

We have used spectral techniques and wavelet analysis to analyze the relation between the coastal freshwater discharge and the Pacific Decadal Oscillation. We found that they have a cross-correlation coefficient of 0.38, (>99 Confidence Level). Enhanced freshwater discharge favors the establishment of a positive phase of the PDO. Briefly, enhanced coastal precipitation along the eastern coast of the Gulf of Alaska enhances the buoyancy driven (Schumacher and Reed 1980; Royer 1981) coastal flow (northward) that then brings more heat from the south into the Gulf of Alaska. The increased heating will increase cyclogenesis here that will again increase the precipitation and buoyancy driven flow. Royer et al. (2001) found that fluctuations in the marine ecosystem have periodicities that are similar to those of the forcing functions of atmospheric pressure and freshwater discharge. Periodicities of zooplankton at Ocean Station P (50˚N, 145˚W) have similar periodicities to those found in the Alaskan coastal freshwater discharge.

We have analyzed historical data from National Data Buoy Center buoys in the Gulf of Alaska and the Bering Sea to see if there is evidence of increased cyclogenesis. The data are daily averages of sea level barometric pressure, wind speed and wind direction and the maximum gust speed occurring during the twenty-four-hour period. The criteria for the detection of a cyclonic event using sea level barometric pressure is that the daily average fall below a threshold, say 995 hPa. Counting the number of such events per month yields a cyclonic index (CI). The data from these buoys were used to construct time series of the CI. While there are gaps in the record due to the buoys being out of service, there are several multiyear continuous time series of the CI from 1975 to 2001. Preliminary analysis shows that there was a change in the structure of the CI signal and an increase of its amplitude beginning in 1988–1989. The mid 1990s had a relatively smaller signal. From the late 1990s to 2001 the CI signal has had a much larger mean (> 95 Confidence Level) and variance (> 90 Confidence Level) as compared to any other period since 1975. This may suggest that the feedback loop identified by Royer et al. (2001) is in fact operating as described above. Further analysis of the wind speed, wind direction and maximum gust speed is being used to test these conclusions.

We are also analyzing other data sets such as those available at ftp://climate.gi.alaska.edu/MonthlyT. These include, for example, air temperature measurements at a number of different locations. One such set that we have analyzed in some detail is that from Sitka from 1828 to the present and from St. Paul Island in the period 1916 to 1938 and from 1951 to the present. While such data are very valuable, they have some drawbacks such as gaps in the record and movement of the observation station. We have examined the possibility of using atmospheric reanalysis data in place of or as a supplement to the station data.

The National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) have reanalyzed fifty years of global atmospheric data using an analysis/forecast system (Kalnay et al. 1996; Kistler et al. 2001). The purpose of the NCEP-NCAR Reanalysis project (hereafter the NCEP reanalysis) was to produce an internally consistent fifty-year record of atmospheric data. The product of the reanalysis is a set of time series of variables on a 2.5-degree latitude by 2.5-degree longitude grid at seventeen levels in the atmosphere (Kalnay et al. 1996).

A hydrology model (Royer 1982) has been constructed to estimate the flux of freshwater into the Gulf of Alaska. The inputs for that model are the monthly mean National Weather Service (NWS) divisional averages of temperature and precipitation. The model treats the Southeast and South coast divisions separately and then combines the results for a total freshwater flux. Stream or river measurements are rare here and there are no major river networks formed because of the small drainage basins. However, the fluxes are significant because the precipitation rate typically exceeds 2.5 m per year with an extreme of more than 8 m per year. Another important facet of this region is the presence of glacial fields. It has been estimated that 20% of this coastal drainage area is covered with glaciers. These features complicate the annual freeze and thaw cycle and have the potential to contribute or store freshwater.

We are interested in better determining the hydrology cycle for this coastal region to address potential changes on the physics and biology. We investigated whether the NCEP data can be used as a replacement for the divisional averages used previously. Our approach was to make comparisons of surface temperature, barometric pressure and precipitation with National Weather Service (NWS) observations along the coast of Alaska and observations from a National Data Buoy Center (NDBC) buoy in the Gulf of Alaska.

We have examined the seasonal and interannual signals of both temperature and precipitation. We are also concerned about whether there has been a phase shift in the annual signal that could, in turn, affect the timing of the biological production, e.g., the spring bloom. Of interest, also, are the interannual changes in the temperature and precipitation, since they would affect long term changes in the density structure and ocean circulation in the region.

The analysis of the Southeast Alaska air temperature and precipitation indicates that, apart from an increase in the South Coast precipitation, neither the NWS data nor the NCEP data have long-term trends. This is surprising, since high latitudes have been identified as regions where the largest and most rapid climate changes are expected. Comparing the two data sets, we find that the mean temperature of the NCEP data is about 3˚C less than the mean of the NWS data. The variance of the NCEP temperature data is also less. The annual temperature signals are very similar, with the minimum in January and maximum in July in each record. The NWS temperatures have an increasing trend in late spring to early summer (April, May, June, July) whereas the NCEP temperatures have a decreasing trend in late summer (August, September and October). The NWS temperatures are 2–4˚C less than the NCEP temperatures. The variances of the two data sets are always different.

The mean and variance of the Southeast NWS precipitation data are also greater than those of the NCEP data. The mean difference is about 2 mm/day, or about 45% of the NCEP mean. The NWS variance is 0.56 (mm/day), about 3 times the NCEP variance. The amplitude of the annual NWS precipitation cycle is 1.9 times greater than that of the NCEP data, with the standard deviation of the annual NWS cycle being about 2.2 times that of the NCEP data. Clearly, the NWS data have more variability than the NCEP data.

Similar to the Southeast temperature record, the South coast Alaska air temperatures do not contain any significant trends. Once again, there are significant differences in the air temperature means, with NCEP data less than that of the NWS data. Addressing the trends in the individual monthly data, there is an increasing trend of about 0.03˚C/year for the April, June and July NWS air temperatures. Conversely, there is a decreasing tendency in the NECP air temperatures of 0.026–0.043˚C/year for July, August and September. The seasonal temperature cycle has its minimum in January for both data sets and that is the month with the highest variance. For the NWS air temperatures, the maximum is in July, accompanied with the least variance. The NCEP temperature maximum is in August though the minimum variance is in May. On the average, the NWS air temperatures are lower than the NCEP temperatures in winter (October–March) while the reverse is true in summer (April–September). Except for those months where the seasonal cycle differences switch from positive to negative (March and October), the two temperature time series are not equal. The variances of the NWS temperatures are greater than the NCEP temperatures except in July, August and September.

The South coast NWS precipitation has a long-term significant trend of 0.038 mm/day/year whereas the NCEP data have no significant trend. Once again, the variance of the NWS data set is greater than that of the NCEP data. The annual NWS mean is greater than 2 mm/day and that is about 60% greater than the NCEP mean. Moreover, the range and variance of the NWS precipitation are about 1.7 and 2 times those of the NCEP data, respectively. The NWS precipitation is always greater than the NCEP precipitation and the NWS precipitation has a significant increasing trend.

The NCEP temperature and precipitation data should be used with caution for the coastal Gulf of Alaska since they did not present well the available observations. This is especially critical since the sources of supplementary data are very limited. Point observations with long term ocean buoy measurements are helping to fill these data gaps and will provide data with synoptic time scales. The only significant trend in the Southeast or South coast data is in the South coast precipitation. Precipitation is increasing, which will have a tendency to accelerate the alongshore flow. The lack of any significant trend of temperature could be attributed to the presence of glacial fields. While significant increases in heating might be taking place, this heat would be used to melt the glacial field rather than raise the air temperature. This will continue until the ice fields are melted. At that time, a dramatic increase in the air temperature might occur, accompanied by a decrease in the coastal freshwater discharge. Also, the phasing of the seasonal freshwater discharge would be altered and the spring subpeak would disappear. This could have some serious ramifications on the spring plankton blooms and general biological productivity.

Finally, we have begun using ocean altimeter measurements (Topex/Poseidon) to provide spatial variations of sea level slopes to be used as an index of gyre scale circulation; the strength of the Alaska Gyre and Alaska Stream. These sea level slopes will be compared with the longer time series of coastal sea level to determine if historical circulation changes can be detected in the coastal observation. These coastal observations have a longer record than the 8 years of altimeter measurements. Regional spatial variabilities of the physical environment will be investigated since they could be very important. Important questions include: Do the Northeast Pacific and Bering Sea fluctuate in or out of phase? Evidence of out of phase ecosystems is demonstrated by the historical salmon catches along the British Columbia/Washington coast being out of phase with those in the Bering Sea (Bristol Bay).

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Publications

None to date.

***Progress Report*: Investigation of the Foraging Behavior of Steller Sea Lions in the Vicinity of Kodiak Island, Alaska**

***Principal Investigator*:** Richard E. Thorne and Gary L. Thomas, Prince William Sound Science Center, Cordova, Alaska

***Other Participating Researchers*:** Kevin Brennan and Matt Foster, Alaska Department of Fish and Game, Kodiak, Alaska

Objectives

The overall objective of this project is to investigate the role of Pacific herring (*Clupea pallasi*) as overwinter forage for Steller sea lions (*Eumetopias jubatus*) in the vicinity of Kodiak Island. The study is an extension of previous work conducted in Prince William Sound and intends to transfer the methodology used in Prince William Sound to the Kodiak region. Specific objectives include determination of the abundance and distribution of overwintering herring schools around Kodiak Island and assessment of Steller sea lion foraging activity on these schools.

Methods

The techniques that were developed in Prince William Sound are a combination of acoustic-net sampling, infrared and aerial surveys. Acoustic technology is used to locate and measure the biomass of overwintering herring schools. Net sampling, typically using purse seines, provides biological information on the fish. Infrared surveys are used in conjunction with the acoustic surveys to detect the association of marine mammals and birds with the fish schools. Aerial surveys are used to determine the numbers and distribution of marine mammals in association with the schools and are helpful in locating herring schools. All the Kodiak surveys used a 38 kHz BioSonics DT4000 digital transducer system for the acoustic data and a Raytheon Model 200 “Nightsight” (12º by 6º field of view) for the infrared. These techniques were used from the F/V *Captain Kidd*, a 56' Alaskan seine boat. Biological sampling was conducted using the F/V *Natalia***,** a purse seine vessel with a 150' fathom net, 1600 meshes deep. Aerial surveys were conducted by the Alaska Department of Fish and Game.

This project also coordinates with another CIFAR project that uses LIDAR to investigate fish and marine mammal distributions (Principal Investigator, James Churnside [see separate Progress Report]).

Main Results

Three surveys have been conducted. The first survey took place in late January 2002 and covered the northwestern quarter of Kodiak Island. The major overwintering concentration of herring was located in Uganik Inlet. Eight replicate acoustic series were conducted on this concentration. The estimated biomass ranged from 9,280 to 21,100 metric tons with a mean of 13,071 mt. Seventy Steller sea lions were enumerated around the school by the aerial surveys. Foraging activity was primarily at night, with rafting during daylight hours, a pattern similar to that observed in Prince William Sound and reported by the Principal Investigators in *Nature* 411:1013.

The second survey took place in March 2002 and was a repeat of the first survey, covering the northwestern quarter of Kodiak Island. Again, the major overwintering concentration of herring was found in Uganik Inlet. Again, eight replicate acoustic series were conducted with biomass estimates ranging from 5,010 to 18,000 metric tons with a mean of 8,179 mt. Foraging activity by Steller sea lions was more intense than during the January survey. Over 300 Steller sea lions were counted within Uganik South Arm where the herring were concentrated. Foraging activity was still primarily at night, but daytime foraging was also observed on shallower herring schools at the head of the inlet. In addition, while rafting activity was predominant during daytime, one transitional haulout was located on a rocky beach in South Arm. Over 100 Stellers were observed on the beach at this location on one occasion. The Stellers were a mixture of adult males, females and juveniles. Digital camera photographs were taken to document this occurrence. The existence of a transitional haulout provides an opportunity for other investigators to conduct scat analysis. Historically scat analyses have poorly documented the role of herring as forage for Steller sea lions because they have focused on traditional haulouts that are remote from the foraging activity.

The third survey also took place in March and centered on Ugak Bay on the eastern side of Kodiak Island. This is the site of some historic herring observations. A major concentration of fish was observed in this area, but the depth of the fish was greater than typically associated with herring. The fish were too deep (> 40m) to be sampled with the purse seine. Jigging attempts produced a single pollock. No Steller sea lions were associated with this concentration, which was estimated to be 4,700 mt. A few isolated herring schools were located near shore, but were too small and scattered for a good estimate. One small (< 10) foraging pack of Steller sea lions was observed in the nearshore area in the vicinity of the herring schools.

LIDAR surveys were conducted in conjunction with both the 2nd and 3rd surveys.

Overall, the abundance of herring that was located around Kodiak Island was smaller than anticipated and was limited to very few areas. However, Steller sea lions were clearly associated with these times and locations. An expanded search effort is planned for next year to try to locate and assess additional concentrations.

Publications

One manuscript has been completed and is currently under review.

***Progress Report*:** **Predator/Prey Investigations of Killer Whales and Steller Sea Lions in Alaska**

***Principal Investigator*:** Andrew Trites, North Pacific Marine Science Foundation, Seattle, Washington and Vancouver, British Columbia

***Other Participating Researchers*:** Craig O. Matkin, North Gulf Oceanic Society; Lance Barrett Lennard, UBC Marine Mammal Research Unit; Graeme Ellis, Department of Fisheries and Oceans; John Ford, Department of Fisheries and Oceans Canada; Jan Straley, University of Alaska Southeast; Dena Matkin

Objectives

This project is assessing the effect of killer whale predation on Steller sea lions by:

- Making initial estimates of numbers and distribution of killer whales in western Alaska using mariner surveys
- Initiating photocensus of killer whales in the Kodiak and eastern Aleutian region
- Initiating genetic studies examining population affiliations of killer whales in these regions
- Providing observational data to estimate the impact of killer whale predation on Steller sea lions
- Comparing data on killer whales and predation from the western Alaska region where Steller sea lions have declined with southeastern Alaska where sea lion stocks are stable or increasing.

Methods

The first of two Alaska Killer Whale Counts will occur over the weekend of July 19–21, 2002. Over the past six months, a web site was designed and launched advertising the count (www.AlaskaKillerWhales.org). Media were contacted to promote public involvement. Dr. Andrew Trites and Ms. Kerry Irish traveled to Juneau, Dutch Harbor, Anchorage, Cordova and Kodiak between May 13–17 to initiate media contacts and make public presentations about the study. Press releases and a poster have also been prepared for distribution in early July as follow-ups with media, businesses and organizations are undertaken. Participants can sign up via the web site and can obtain copies of the questionnaire from the web or by mail.

Field data collection in this study relies on methods developed over the past 25 years in work in British Columbia, Canada and Prince William Sound/Kenai Fjords, Alaska. A thorough description of research procedures is found in Matkin et al. (1998). The project relies on photo identification of individual animals, biopsy techniques for genetic analysis of population structure (Barrett-Lennard et al. in prep), acoustic recording for further investigation of population structure, observational techniques for assessment of killer whale predation. Searches for killer whales were not made on random transects, but based on current and historical sighting information in the Dutch Harbor and Kodiak region (Dahlheim 1997). In addition, whales were located by listening for killer whale calls with a directional hydrophone (calls can be heard up to 10 miles away), or by responding to VHF radio calls from other vessels reporting sightings of whales.

The primary vessels used to secure identification photographs during the Dutch Harbor/Unalaska based fieldwork in 2001 were a 36’ Mel Martin designed diesel inboard powered vessel and a 32’ Commercial Marine “Bristol Bay” design diesel inboard. Fieldwork in Kodiak was conducted from a 26’ diesel bow picker style vessel. In southeastern Alaska, small cabin skiffs, 18–22’ in length powered by outboard motors, were used on a day trip basis.

Sixty boat surveys were conducted in Sitka Sound, Alaska between 28 August 2001 and 17 June 2002. In addition, two aerial surveys were conducted in conjunction with Alaska Department of Fish and Game predator surveys to assess herring movements into Sitka Sound in the late winter and early spring. The boat survey tracklines totaled 960.5nm over 154.5 survey hours. Total time with all whales (humpback and killer whales) totaled 36.9 hours. Time with killer whales totaled 1.8 hours.

An extensive sighting network was established region wide (southeastern Alaska). This included a ‘killer whale hot line’ cell phone, notices at boat harbors throughout southeastern Alaska, VHF radio calls, public service radio announcements and newspaper advertising. The Coast Guard Air Station Sitka and Buoytender MAPLE participated by calling in sightings. Air taxis also called in sightings. Alaska Department of Fish and Game participated by calling in sightings and taking calls from fishermen without access to a cell phone. The fishing community of southeastern Alaska turned in sightings on a regular basis as did workers on the Alaska Marine Highway ferries and tugboats traveling between the smaller communities. University of Alaska graduate student, Jamie Womble, who flew on a monthly basis throughout the fall, winter and spring, reported any killer whales that were sighted near sea lion rookeries and haulouts.

Main Results

In the Eastern Aleutians, there were 15 encounters with killer whales during the 16 days of field effort. Although we have identified unique individuals from nearly every encounter, photographs of individuals are poor in some cases, but will be usable after additional encounters with these particular groups in future years. Whales in this region were generally more difficult to approach than in other regions we have worked. Because our enumeration of killer whale will depend on documenting matriline membership over the years, we have not enumerated or given permanent name/numbers to individuals at this time. 152 whales were estimated in these encounters, although at least 20 of these were resights. Additionally, an undetected shutter malfunction in a new camera caused the loss of photographic data from August 16 and 17.

Of the seven tissue samples we obtained in the eastern Aleutians, six were from biopsy and one was from a recently stranded whale. Two whales were tentatively classed as transients based on feeding habits and backed by our initial but incomplete genetic analysis. The other five whales were tentatively classed as residents based on feeding habits and incomplete genetic analysis. Positive classification will be made following completion of genetic work. We observed two instances of predation—probable transient whales were observed feeding on a northern fur seal, and probable resident whales were observed feeding on Pacific halibut. One stomach examined of a stranded probable transient whale (juvenile) contained harbor seal parts, feathers, and bones from a river otter.

In the eastern Aleutians, a total of 49 minutes and 37 seconds of recordings were separated into 11 recording sessions (5 on June 25th, 3 on June 26th, and 3 on June 30th). Analysis attempted to acoustically identify the type of killer whale (e.g. members of the resident, transient, or offshore killer whale populations) present during each recording session (Ford and Hubbard-Morton 1990). In all but three recording sessions (June 25—session #4 and #5, June 26—session #3) the vocalization patterns observed allowed the conclusion that the recorded whales were resident killer whales. Session #5 from June 25th contained only one clear call type and four whistles, and session #3 on June 26th contained only whistles. Both of those sessions could potentially have been recordings of transient killer whales because of low vocalization rates and no recorded echolocation clicks. In recording sessions #1 and 2 on June 26th, and #1,2,3 on June 30th, the same call type could be identified in all sessions. The call type was recognized as AKS 16, which is otherwise only used by AF and AG pods of AB clan within the Southern Alaska Resident community. Furthermore, one call type could be recognized as AKS 34 in recording sessions #1and 2 on June 25th. This call type is used primarily by AG pod of AB clan. Finally, one call type was identified as AKS 11 in recording sessions #1,2,3 on June 30th. All members of AB clan use this call type. However, the structural variant recorded on June 30th is similar to the variant used by AG and AF pods.

Our observations suggest a large population of fish-eating resident type killer whales in the eastern Aleutians and much smaller numbers of marine-mammal-eating transient types that maintain different diets. We estimate a ratio of about 10:1 ratio resident types:transient types from our very limited data photographic/encounter data.

In the Kodiak region, we operated for a total of seven days and had only two encounters with killer whales—one on 12 May and the other on 12 July. The encounter on 12 July was with the resident type AS pod photographed 6 days earlier on July 6 in Kenai Fjords. Acoustic recordings were obtained from the 12 July encounter and indicated the whales were of the resident type.

In the Glacier Bay/Icy Strait region of southeastern Alaska, we had 20 killer whale encounters during the 50 days of fieldwork. From previously compiled catalogues, we identified all individuals present in each encounter. Thirteen of the encounters were with known transient killer whales from the West Coast transient population, although during one of these encounters they were mixed with a Gulf of Alaska transient population known previously only from western Alaska (Prince William Sound/Kenai Fjords). Seven of the encounters were with resident whales from AF22, AF5, or AG pods. Harassment events by transient whales were observed on two occasions—one with killer whales attempting to prey on Steller sea lions and another of harassment of a humpback whale by killer whales. On three occasions, killer whales killed a marine mammal that could not be identified. Resident killer whales were observed feeding on fish on three occasions.

In Sitka Sound, the surveys resulted in two encounters with killer whales and 26 groups of killer whale sightings with one predation event observed. This sighting network resulted in 79 groups of killer whale reported from Dixon Entrance to the south to Lynn Canal to the north.

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Project Reports:
Research Themes

Contaminants
Fisheries Oceanography
Hydrographic and Sea Ice Studies
Tsunami Research

Research Themes: Contaminants

***Progress Report*:** **Persistent Organic and Trace Element Pollutants in the Alaskan and Eastern Russian Arctic**

***Principal Investigators*:** Greg Patton, Battelle Pacific Northwest Division, Richland, Washington; Catherine Cahill, Department of Chemistry and Biochemistry, University of Alaska Fairbanks

***Other Participating Researchers*:** L. Barrie, Global Atmospheric Watch Program, World Meteorological Organization, Geneva, Switzerland; P. Blanchard, Environment Canada, Toronto, Ontario, Canada; E. Crecelius, Battelle Sequim, Sequim, Washington; P. Fellin, AirZone One, Inc., Mississauga, Ontario, Canada; R. Schnell, NOAA/CMDL, Boulder, Colorado; G. Stern, Freshwater Institute of Canada, Winnipeg, Manitoba, Canada

Objectives

This project is part of the Study of Atmospheric Deposition of Contaminants in the Arctic: A Paired Study of a Site in Alaska and a Site in the Russian Far East by the National Oceanic and Atmospheric Administration's Arctic Research Initiative and the U.S. State Department's Environmental Diplomacy Fund for the U.S./Russian Atmospheric Contaminants Program. The project scientific objectives are: (i) to gain insight into the sources, occurrence, and environmental fate of persistent organic herbicides/pesticides and industrial chlorinated compounds (POPs) and aerosol trace elements in the atmosphere of the Alaskan and eastern Russian Arctic, (ii) to contrast the occurrence of POPs and trace elements in this region with other Arctic air sheds and (iii) to provide data in a form compatible with existing AMAP data to be used in assessing the potential risks to the environment and human inhabitants in the Arctic due to POPs.

Methods

For one year at the Barrow NOAA baseline air chemistry laboratory, the atmospheric concentrations of 90 polychlorinated biphenyl compounds, 40 organochlorine pesticides/herbicides or their metabolites and 14 polycyclic aromatic hydrocarbons (PAHs) will be measured. Suspended particles and gases are collected separately and chemically analyzed. The compositional signature of PAHs together with high time resolution size-segregated multi-elemental analyses, other Barrow baseline aerosol and gas observations and meteorological data will be used to identify the origin of air in which the POPs measurements are made. From January 2001 to September 2003, three stages of activity will take place: (i) preparation of site and measurement methodology, (ii) a one-year measurement period and (iii) a data analysis, interpretation and reporting step.

Observed POPs and trace aerosol concentrations will be used to estimate atmospheric inputs of these substances to the Arctic. Collaboration with Canadian laboratories in this research ensures access to a set of similar observations with current observations being made in the Canadian and Russian Arctic under the Arctic Monitoring and Assessment Program. It also standardizes protocols of sampling analysis and data archiving.

Main Results

Air sampling for POPs and metals was initiated at the Barrow, Alaska NOAA/CMDL station in March 2002. Continuous samples have been collected since March 2002 with minimal problems. C. Cahill is evaluating initial results for metals, initial POPs results are still pending.

March 2001–August 2001: The Barrow/CMDL staff expanded the existing sampling deck to allow for installation of the POPs high volume air sampling equipment. A sample change hut was also constructed on the sampling deck. Electrical power was installed for both the sampling deck and change hut.

August 2001–March 2002: Battelle received funding for this project as a grant from the Cooperative Institute for Arctic Research (CIFAR). POPs sampling equipment was purchased, fabricated, tested, and shipped (Feb. 2002) to the Barrow/CMDL station. Site-specific procedures were written for POPs sample collection.

C. Cahill and G. Patton installed equipment for POPs and metals sampling at Barrow/CMDL on March 13–15, 2002 with assistance from Barrow/CMDL staff. Metals sampling was initiated on March 14, 2002. POPs sampling was initiated on March 19, 2002.

April 2002 to June 2002: During the first weeks of POPs sampling an electrical power outage occurred at the NOAA/CMDL station. As originally planned, the running time meter supplied with the Wedding Inlet for the POPs air sampler was used to measure sampling time (this meter self-starts following a power outage). However, the 230VAC motor starter used with the air sampling pumps does not self-start following a power outage, thus it was not possible to determine the sampling time for this sample. To fix this problem, a 230VAC running time meter was procured and installed in line with the motor starter at the Barrow/CMDL station.

L. Barrie (co-principal investigator) left Battelle in May 2002 to take a position as Chief of the Environmental Division coordinating the Global Atmospheric Watch Program for the World Meteorological Organization in Geneva, Switzerland. L. Barrie has agreed to provide technical advice for this project and will be involved in the final data evaluation and as an author on future publications.

Publications

This project is still conducting the initial stage of sampling and analysis; therefore, no publications/presentations have been produced.

Research Themes: Fisheries Oceanography

***Progress Report*:** **Relationship Between Growth and Survival of Coho Salmon Utilizing the Coastal Gulf of Alaska**

***Principal Investigator*:** Milo Adkison, Juneau Center, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks

***Other Participating Researchers*:** Ryan Briscoe (graduate student), Alex Wertheimer (NOAA's Auke Bay Laboratory)

Objectives

Coho salmon in the northeast Pacific have had substantially different population trends in the Pacific Northwest compared to Alaska. Coho salmon in the Pacific Northwest have declined precipitously (Weitkamp et al. 1995), to the extent that most populations in the region have been listed as threatened or endangered under the federal Endangered Species Act. At the same time, coho salmon catches in Alaska in the 1990s have been at historically high levels (Byerly et al. 1999); while data on the status of individual populations is sparse, an analysis of available escapement data for coho salmon in southeast Alaska showed generally stable or increasing trends (Baker et al. 1996). Clearly, terrestrial habitat conditions have contributed to these dichotomous trends; much of Alaska habitat remains in pristine condition (Wertheimer 1996), while degradation and destruction of freshwater habitat has reduced the range and caused much of the decline of coho salmon in the Pacific Northwest (Weitkamp et al. 1995). However, during this same time period, conditions in the marine environment have contributed to the different population trends as well. For example, ocean survival of Oregon Production Index coho salmon has declined from an average of nearly 6% throughout the 1970s to 0.5% in recent years (Weitkamp et al. 1995). In contrast, ocean survival for coho salmon at Auke Creek in southeastern Alaska has averaged 19% over the same time period, ranging from 8 to 37% (Taylor and Lum 2000).

These regional differences in marine survival are consistent with the general inverse response of Pacific salmon in the two regions to changing environmental conditions (Hare et al. 1999). Climatic conditions have been strongly correlated with salmon abundance in the Gulf of Alaska (Downton and Miller 1998; Beamish et al. 1999), as well as with changes in zooplankton abundance and species composition in the Gulf of Alaska (Brodeur and Ware 1992; Anderson and Piatt 1999). While changes in temperature and other biophysical conditions in the Gulf of Alaska have obviously benefited Alaska salmon populations, our understanding of the mechanisms of this coupling and how they relate to growth and survival of salmon in the marine environment is poor. There is considerable evidence to indicate that growth rates during the first year of marine residency are a critical factor for surviving to adulthood (Beamish and Mahnken 1999; Mortensen et al. 2000). This relationship between growth and survival of salmon, and the phase of the marine life history at which it occurs, underlies the major hypotheses of the Global Ecosystem (GLOBEC) research program in the Gulf of Alaska.

This study will use archived scales from both adult and juvenile coho salmon to examine the relationships between growth during specific marine phases and subsequent survival to adult and size at maturity, and to evaluate how these parameters vary in relation to biophysical data sets. These studies will increase our understanding of the mechanisms by which processes in the Gulf of Alaska affect coho salmon population responses, and may lead to enhanced predictability of the response of the resource to changing climate conditions. Such information is important in developing robust management approaches that can respond to both times of high survival and abundance that has occurred recently in much of Alaska, as well as for conservation and maintenance of coho salmon populations when climatic conditions shift.

Methods

A. Digitizing and analysis of juvenile scale collections. Scales collected from juvenile coho salmon in coastal habitats of Southeast Alaska are being digitized and analyzed to identify the transition period from nearshore to GOA waters.

B. Digitizing and analysis of Auke Creek scale collections. Archived scales taken from adult and jack coho salmon returning to Auke Creek weir are being digitized and analyzed to determine interannual growth patterns. Marine growth will be evaluated for three phases: juvenile nearshore/coastal; juvenile Gulf of Alaska; and adult.

C. Data management, analysis, and reporting. A data base of scale data will be created and linked to biological data on Auke Creek coho salmon and environmental data for nearshore waters of southeast Alaska and for the GOA. Relationships between scale growth, marine survival, size at return, and environmental data sets will be analyzed using appropriate statistical methodology.

Main Results to Date

1. A graduate student, Ryan Briscoe, was appointed in summer 2001 and has been working on this project since.
2. Purchase and installation of a new scale digitizing and analysis system (using other funding) modeled after the systems chosen by Pete Hagen for ADF&G. Installation, set-up, and learning to use this system was a time-intensive endeavor.
3. Inventory of the available scales.
4. Digitizing of several hundred scales (analysis not complete).
5. A statistical power analysis. Adkison ran a set of simulations using Briscoe's empirical measurements of within- and among-year variation in early marine growth to determine how many scales needed to be measured each year to detect environmental variation of various magnitudes. Based on these simulations, we determined that the optimal allocation of sampling effort was to measure relatively few scales each year (~20) and concentrate instead on sampling more years, stocks, sexes, etc. (Table 1).

Table 1. The power to detect an environmental influence on the marine portion of scale width as a function of the number of scales measured each year (rows) and the fraction of the among-year variation in mean scale width (columns). Assumes 20 years of data.

# scales	0.2	0.3	0.4	0.5	0.6
5	0.1354	0.28	0.5065	0.7424	0.9144
10	0.151	0.3343	0.6093	0.8656	0.9749
15	0.1582	0.3565	0.6533	0.8979	0.9866
20	0.1639	0.3744	0.6755	0.9147	0.9905
25	0.1728	0.3814	0.689	0.9267	0.9926
30	0.1646	0.3862	0.7081	0.9311	0.994
40	0.1706	0.3952	0.7135	0.9391	0.9961
50	0.1764	0.401	0.724	0.9463	0.9964
70	0.1728	0.4094	0.7378	0.9507	0.9978
100	0.1776	0.4109	0.7419	0.9534	0.9977

6. Production of a rough draft thesis proposal based on these efforts. After examining the inventory of available scales, talking to experienced scale analysts at ADF&G, and considering the goals of the project and considerations of statistical power, we've prioritized the scales to digitize and analyze. The thesis supervisory committee consists of UAF professors Milo Adkison (chair), Nicola Hillgruber and Bill Smoker along with Alex Wertheimer of NOAA's Auke Bay Laboratory.

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Progress Report: Regional Impact of the Effect of Steller Sea Lion RPAs on the Fishing Economy of Kodiak, Alaska

***Principal Investigators*:** Mark Herrmann, Department of Economics, University of Alaska Fairbanks; Joshua Greenberg, Department of Resources Management, UAF; Charles Hamel, Department of Economics, UAF; Hans Geier, Department of Resources Management, UAF; Keith Criddle, Department of Economics, Utah State University

Objectives, Methods and Main Results

Specifically, we plan to make as much progress as possible on estimating a range of regional economic impacts from Steller sea lion regulations that alter groundfish harvest patterns; estimating a range of changes in groundfish landings to Kodiak reflective of Steller sea lion regulations (both in terms of volume and primary [exvessel] value); and estimate the economic impacts of proposed various management alternatives, to be developed in conjunction with the NPFMC. Primary cost (regional expenditure) data collection is our major concern and if successfully gathered we are poised to construct the various components of the impact model to simulate the effects of Steller sea lion regulations on fisheries and their subsequent economic impacts.

In our initial proposal we indicated that we would rely on the regional cost expenditure collected from an anticipated Alaska Sea Grant project that unfortunately was not funded. We were also hoping to rely on cost data collected by the National Marine Fisheries Service (NMFS), whose effort has now been combined with the Data Collection Committee made up of the North Pacific Fisheries Management Council (Council) and affiliated agencies and industry. We had hoped, and are still hoping, to have a regional model developed in which we could use the NMFS (or Council) survey data to complete our analysis.

Another possibility is to perform our own survey that would be similar to one that we developed for the Alaska Fish and Game (ADF&G) “Regional Economic Impact Assessment of the Alaska Snow Crab Fishery.” For the ADF&G study, harvester, processor, and catcher processor expenditure surveys are being, or have been, constructed. [A copy of the expenditure survey for harvesters is on file at CIFAR.] We are considering amending the harvester survey to create a groundfish equivalent instrument that would provide the necessary expenditure data for our regional Kodiak groundfish model should the Data Collection Committee be unsuccessful in obtaining independent survey results. We have paid selected expert harvesters $200 to participate in our ADF&G study (for 8 hours of time—an initial 4 hours to fill out the survey and another 4 hours for follow up information). It may be necessary to similarly reimburse groundfish fishermen for their time and to make another trip to Kodiak.

Besides the work on a survey we have nearly completed the groundtruthing of the IMPLAN Software and databases that are being used to create regional I/O models for Kodiak. A principal part of the IMPLAN I/O data verification procedure involved in-person visits by members of the research team to Kodiak in May 2002. Community experts were consulted during the Kodiak visits and the regional economic profiles created from the IMPLAN database were updated and verified. The Kodiak trip also involved a tour of groundfish processing plants. This allowed the research team to gain a better understanding of the types of processing facilities currently employed by the industry.

Historical groundfish processing and harvesting information will be obtained from the Alaska Department of Fish and Game and the Alaska Commercial Fisheries Entry Commission. The collected harvester data will include daily fish ticket files, permit files, and vessel license files. The Commercial Operators Annual Report (COAR) will be obtained to provide processing information. Data will be compiled to create profiles of harvest operations, and processing operations, and to summarize historical industry performance.

Because the development and coordination of the cost collection portion of this grant is so time consuming (including the very lengthy and tenuous process of earning the trust of processors), and because the uncertainties regarding this collection process are well known, the final report will be some time off. The success or failure of this grant will hinge on the cost collection, and as other similar efforts have been unsuccessful, we will take a slow and methodical approach to this portion of the grant. This problem of cost data collection currently plagues several economic studies and this work is no exception. At minimum, upon completion of this work, we will have a framework for incorporating cost collection survey data to complete the regional analysis when cost data is finally collected. We are hoping for more and are taking more time to continue to tackle the problem of collecting expenditure data.

***Progress Report*:** **Reproductive Potential of Pacific Cod**

***Principal Investigator*:** Brenda L. Norcross, Institute of Marine Science, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks

***Other Participating Researchers*:** Olav A. Ormseth, Ph.D. student, SFOS/UAF

Objectives

Pacific cod (*Gadus macrocephalus*) are an important ecological and economic resource in the North Pacific Ocean. The cod fishery in Alaska is the state's second largest groundfish fishery (NMFS 2000). Pacific cod are also a major component of North Pacific Ocean ecosystems, serving as predators of numerous species of invertebrates and smaller fish and as prey for other fish and marine mammals (NMFS 2000). Like most marine fishes, Pacific cod exhibit significant recruitment variability at interannual and decadal time scales (NPFMC 2001). This results in changes in cod abundance that affect both the human and non-human communities that depend on cod.

Recruitment success depends in part on the fate of offspring during egg and larval life stages, which generally experience high mortality (Chambers and Trippel 1997). Therefore, recruitment may benefit from factors that increase the number of eggs spawned and/or the likelihood that eggs will survive to older stages. In a number of species, individual female spawners differ substantially in the number of eggs they produce, the amount of energetic resources they provide each egg, and the timing and duration of the spawning season (Chambers and Trippel 1997). For example, in Atlantic cod (*Gadus morhua*), older spawners produce more and bigger eggs than young spawners, and spawn over a longer period of time (Trippel 1998). In addition, females possessing greater energy reserves are more likely to be successful spawners (Kjesbu et al. 1991).

In Pacific cod, little is known about the factors that influence female reproductive potential. Relative fecundity (fecundity per unit body weight) increases with length of fish (Hattori et al. 1995), and female cod appear to depend on energy stored in the liver to produce eggs and survive the spawning period (Smith et al. 1990). Thus variability in age, size, and energy stores of females may be an important source of variability in reproductive success and recruitment in Pacific cod.

To explore the influence of maternal attributes on reproductive potential in Pacific cod, we are conducting a study of female cod caught in the western Gulf of Alaska during the spawning season. We are investigating how the age, size, and energy reserves of these females relate to their fecundity and the quality of the eggs they produce.

Methods

Sample collection: Fish samples have been collected mainly through the assistance of the NMFS Groundfish Observer Program and six commercial fish processing plants in Kodiak, Alaska. From February 10 until May 3, 2002, NMFS Observers in these plants collected fish according to a schedule of length bins from 50–90cm in 5cm increments (a total of 10 bins). Observers were asked to collect one fish within each length bin per week per plant. According to this sample design, approximately 600 fish would have been collected. Unfortunately, fluctuations in fishery activity and observer availability limited the collection to a total of 201 fish. This was augmented by a previous collection of 24 female cod (over a similar size distribution; Fig. 1) by NMFS personnel on a survey cruise north of Kodiak Island in November 2001. Thus, we obtained a total of 225 female cod for the 2002 spawning season. Overall, lengths were distributed normally around a mean value of 69cm; however, the size distribution of the collections varied throughout the season (Fig. 1). In addition, the total number of samples collected each week was highly variable, with the most samples collected in mid to late February and late March (Fig. 1). The samples were stored frozen at a commercial facility in Kodiak, AK.

	length bin										
Date	**<50**	**50–55**	**55–60**	**60–65**	**65–70**	**70–75**	**75–80**	**80–85**	**85–90**	**>90**	**total**
Nov	0	0	5	5	5	5	3	0	1	0	24
2/10	1	1	1	1	1	1	1	1	0	0	8
2/17	5	5	5	5	5	5	5	5	5	3	48
2/24	2	3	3	3	3	3	3	2	2	2	26
3/3	2	2	3	3	3	3	3	3	3	1	26
3/10	0	0	0	2	2	2	2	1	1	0	10
3/17	1	1	2	3	3	3	2	1	1	1	18
3/24	0	3	2	3	4	4	3	3	0	0	22
3/31	1	1	2	2	2	2	2	1	1	1	15
4/7	0	0	1	2	0	2	2	2	1	0	10
4/14	0	1	1	1	1	1	1	1	0	0	7
4/21	0	1	1	1	1	1	1	0	0	0	6
4/28	0	0	0	1	1	1	1	1	0	0	5
total	12	18	26	32	31	33	29	21	15	8	225

Figure 1. Number of female Pacific cod throughout the spawning season per length bin, Nov. 2001–May 2002. Date refers to the first day of the week in which the fish were collected; November collections are indicated by "Nov".

Completed analyses: Preliminary sample analysis was conducted in June 2002 at the Fishery Industrial Technology Center in Kodiak, AK. Fish samples were thawed, and weight and length were measured. The liver and gonads were dissected from the sample, weighed and photographed. The liver and one ovary were refrozen; the remaining ovary was preserved in 10% formalin. Stomach contents were also removed and refrozen. Otoliths were extracted and dried. The remaining carcass was homogenized and approximately 300g of the homogenate was refrozen. All preserved tissues were transported to Fairbanks for further analysis.

Analyses in progress: The following analyses are currently being performed using the preserved tissues:

- Age: Age will be determined by NMFS personnel by identifying the number of annular rings in the collected otoliths.
- Size: Size will be determined using measurements of length and weight made by the observers on fresh fish.
- Energy reserves: We will utilize several techniques to estimate energy reserves, which will enhance our ability to compare the results of this work with other studies and to investigate how energy reserves are partitioned in these fish. We will calculate condition factor (weight/length^3) and hepatosomatic index (liver weight/body weight). In addition, we will estimate whole body energy content using bomb calorimetry; proximate composition of liver and whole body using solvent lipid extraction and a nitrogen analyzer; and liver vitellogenin (yolk protein) content using immunoblotting techniques.

Immunoblotting involves the separation of proteins from a known quantity of sample extract on an electrophoretic gel. A commercially available vitellogenin antibody will be used to identify the bands of vitellogenin in the gel, and measuring the density of those bands will allow us to quantify liver vitellogenin.

- Fecundity: Fecundity will be determined by gravimetry using the formalin-preserved ovaries.
- Egg quality: Egg quality will be estimated by determining egg diameter and weight, as well as a calculation of gonadosomatic index (gonad weight/ body weight). In addition, we will analyze energetic content of the eggs via bomb calorimetry, proximate composition, and vitellogenin content as described above. Because a number of factors can be used to describe egg quality (e.g. Brooks et al. 1997), these analyses may be modified as the study progresses.

Future Work

We plan to collect spawning females again during the 2002–2003 spawning season. The collection of samples by NMFS observers was an inexpensive means of obtaining fish over the course of the season, and will likely be repeated in some form. However there were several problems that limit the utility of this approach. These include a lack of reliability in the number and size distribution of fish collected at any given time; high variability in the handling of the samples from the time of actual catch to reaching the observer (i.e. length of time in fish holds and the conditions in those holds); variability in observer handling and packaging of samples; and the limitations of using frozen samples. Therefore, we plan to alter or expand our collection methodology by including at least three short cruises (pre-, mid-, and post-spawning). This will allow us to reduce variability in our data set and permit us to perform additional analyses, such as histological examination of ovaries and possibly measurement of reproductive hormones.

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***Progress Report*: Analysis of Genetic and Phenotypic Differentiation Between Wild and Hatchery-bred Chinook Salmon**

***Principal Investigator*:** William W. Smoker, Juneau Center, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks

***Other Participating Researchers*:** Maria Lang, graduate student

Introduction

One of the concerns surrounding the conservation of wild Pacific salmon in western North America is the potential for damaging interactions with salmon produced from hatcheries. Among the potential interactions, genetic interactions potentially result from interbreeding between genetically different hatchery salmon and wild salmon (Hindar et al. 1991; Utter et al. 1993). Genetic differences potentially arise from translocations of salmon from distant populations to hatcheries or from domestication of hatchery salmon. In Alaska translocations have been strictly limited by state policy (Davis et al. 1985).

Domestication as a source of genetic difference is not well understood; observed differences between hatchery-raised and wild salmon may derive from domestication or from environmental differences inherent in two groups

(Thompson 1966; Olla and Davis 1989; Donnelly and Whorisky 1991). For instance, in Alaska wild chinook salmon spawn in large rivers where they rear as parr, migrating as smolts age 1 (Meehan and Siniff 1961; Murphy et al. 1988). In hatcheries they are also released as age 1 smolts but are much larger (15–40 g vs 5 g) (Meehan and Siniff 1961; McGee et al. 1990). In hatcheries the nutritional environment is much richer, and requires no natural foraging. In hatcheries salmon are never exposed to predators. Therefore observed differences between fish from hatchery and wild populations, even at the same size or age, may relate either to genetic differences due to domestication (or translocation) or to differences resulting from the very different environments experienced by the two groups.

This research observes chinook salmon from hatchery and wild lineages that are both derived from the same ancestral population and derived from the same environmental history. Through observations of behavior and body morphology of fry and parr in laboratory experiments it augments research examining hatchery domestication in stocks of Alaska spring Chinook being conducted by US NOAA Fisheries at Little Port Walter (LPW). Researchers there (J.E. Joyce and others, Auke Bay Laboratory, Juneau, Alaska) have developed chinook salmon brood stocks for use in Southeast Alaska Hatchery programs. These broodstock development programs began in the late 1970s and now provide material to examine the effects of hatchery culture on the biology of chinook salmon. In 1996 and 1998, with the cooperation of the Alaska Dept. of Fish and Game (ADF&G), gametes were collected from chinook salmon spawning in the native, undisturbed river systems that these hatchery stocks were derived from. Second generation lines from these collections and from existing LPW broodstocks form the basis for these studies. The ability to compare hatchery stocks with wild fish from undisturbed populations provides a unique opportunity to conduct these types of studies.

Activities in the first year of this research have been to take part in the propagation and culture of the experimental lines at LPW and to design observational studies to be carried out in the laboratory in summer 2002. These designs are presented here.

Research Plan: Behavioral assay of domestication effects on hatchery bred salmon and their outcrosses with wild salmon

Domestication Effects. Behavior has been shown to be among the first traits affected by domestication (Ruzzante, 1994). Predator avoidance and agonistic behavior are two types of behavior that may be affected by the hatchery environment (Olla et al. 1998). In addition, behavior can have a direct effect on an animal's fitness or their ability to survive. For example, the decisions an animal makes when faced with a predator will ultimately determine whether it eats a meal or becomes a meal. Changes in morphological traits, such as body size and shape, have also been shown to occur relatively quickly during domestication. Body morphology can have a direct influence on an animal's ability to exploit its natural environment.

Agonistic Behavior and Ability to Dominate. Rosenau and McPhail (1987) demonstrated inherited differences between two spatially separated populations of juvenile coho in the durations and frequencies of agonistic acts performed. On a smaller spatial separation scale, Swain and Holtby (1989) found agonistic differences between juvenile coho rearing in a lake and its tributary stream; these differences persisted after 6 weeks of rearing in a common laboratory environment. This suggests that environmentally induced agonistic behavior develops early in life and is fixed, or is genetically based. Chinook salmon juveniles from stream-type populations have been shown to be more aggressive than juveniles from ocean-type populations (Taylor and Larkin, 1986b; Taylor, 1988). Levels of aggression in juvenile salmonids appear to be related to length of freshwater residence and then type of environment (lake, stream, slough), perhaps type of predators present.

Juvenile coho from hatchery populations were found to be significantly more aggressive than wild coho from nearby streams (Swain and Riddell, 1990). Cutthroat trout of hatchery origin were also shown to be more aggressive than their wild counterparts (Mesa, 1991). Berejikian et al. (1996) found that steelhead hatchery juveniles were less aggressive than wild juveniles at emergence, but that after 105 days in a natural stream, the hatchery fish were more aggressive than wild fish raised in either a natural stream or a hatchery tank.

Predator Avoidance Behavior. Johnsson and Abrahams (1991) found that juvenile hybrids of steelhead and domesticated rainbow trout were significantly more willing to risk exposure to a predator than were juvenile steelhead, even though they were shown to be equally susceptible to the predator. Berejikian (1995) also showed that juvenile steelhead of hatchery origin had a decreased ability to avoid a benthic predator when compared to steelhead of wild origin. Several studies have shown that exposure to a predator or a predator "alarm signal" (predator odor paired with injured conspecific odor) can increase the ability of juveniles of several species to avoid predators (Healy and Reinhardt, 1995; Berejikian et al., 1999).

Foraging Behavior. Starvation has been shown to be a primary cause of poor post-release survival in hatchery fish (Flagg et al., 2000). Hatchery reared parr of Atlantic salmon were found to forage less effectively than naturally reared parr (Sosiak et al., 1979). Wild parr fed primarily on benthic organisms, ate a greater diversity of organisms and consumed more food than hatchery reared fish, which concentrated on winged and terrestrial insects. Brook trout were also found to have innate differences in foraging behaviors between wild, hatchery, and hybrid strains (Mason et al., 1967). When raised in identical environments, wild fish fed only from the bottom while hatchery fish fed readily at the surface. Hybrid fish exhibited intermediate behavior. Mesa (1991) found no difference in the feeding rates of wild and hatchery cutthroat trout, although dominant hatchery fish rarely tolerated intrusions from subordinates while dominant wild fish were often observed feeding with subordinates.

Body Morphology. Body morphology can have an effect on the fitness of a fish in a particular environment. A streamlined body shape may enhance prolonged swimming ability, whereas a deeper body shape may improve burst-swimming performance (Taylor and McPhail, 1985). Taylor and Larkin (1986a) developed a model to discriminate between hatchery and naturally reared coho salmon parr based on morphology. Hatchery fish had a different shape and were less variable than wild fish.

Objective and Experimental Design

Our objective is to determine if there are behavioral and morphological differences between chinook salmon that have undergone five generations of domestication, the wild stock of chinook salmon from which they were derived, and how these differences are expressed in F1 and F2 hybrid crosses. Behavioral studies will be conducted in the behavioral lab at the Little Port Walter Research Station. This lab consists of two flumes approximately 1 meter wide by 3 meters long. Each flume contains ten 20-gallon aquaria, situated two wide by five long. Each aquarium has one water inflow and water flows out over the downstream end. The aquaria are graveled and equipped with an upstream mid-water feeder. A small refuge with overhead cover and a small aquatic plant refuge are also provided.

The hypotheses are divided into five distinct sets: levels of agonistic activity, ability to dominate, predator avoidance strategy, foraging behavior, and body morphology.

Agonistic Activity. The primary hypotheses for levels of agonistic activity are:

H_0: Levels of agonistic activity in juvenile chinook are not dependent on parentage

H_0: Levels of agonistic activity in juvenile chinook are not dependent on density

H_0: The effect of parentage on levels of agonistic activity does not depend on density

Agonism experiments will be conducted at two different densities, 2 fish per tank or 6 fish per tank, and each tank will contain only one type of fish. Fish will be given one day to acclimate and on the second day two ten-minute observational periods will take place. This will be repeated 10 times resulting in a total sample size of 15 for each fish type at each density (or 30 if analyzed using repeated measures). Data recorded will include frequencies and durations of agonistic acts. The effects of parentage and density on the observations will be estimated by two-way analysis of variance.

Ability to Dominate. The primary null hypothesis for dominance behavior is that the ability of juvenile chinook to establish dominance over wild juveniles does not depend on parentage. Experiments will be conducted by size-matching wild juveniles with each of the five other cross-types. Pairs will be placed in aquaria in the morning and the dominant fish will be determined in the evening. This will be repeated 5 times resulting in a sample size of 20 for each cross-type. Statistical analysis will be done with chi-square tests.

Predator Avoidance Strategy. The primary hypothesis for predator avoidance behavior is:

H_0: Reaction of juvenile chinook to chemical alarm signals (predator avoidance strategy) is not dependent on parentage

Predator avoidance experiments will be conducted by placing 4 juveniles in each aquarium. Each aquarium will contain only one type of fish. Fish behavior will be observed for 10 minutes. At the five-minute mark, predator odor paired with injured conspecific odor will be added to the tank. Differences between pre and post-stimulus observations will be compared between populations using one-way ANOVA or the Kruskal-Wallis test with parentage as the factor.

Foraging Behavior. The primary hypothesis for foraging behavior is:

H_0: Foraging behavior of juvenile chinook is not dependent on parentage

Foraging ethograms will be constructed by observing feeding behavior during the agonism experiments. Differences between the cross-types will be examined by two-way ANOVA with parentage and density as the factors.

Body Morphology. The primary hypothesis concerning body morphology is:

H_0: Body proportions and coloration of juvenile chinook are not dependent on parentage

Body morphology will be examined by taking measurements of standard length, maximum body depth, head depth, head length, maximum parr mark length, maximum parr mark width, dorsal fin height, length of longest dorsal fin ray, anal fin height, length of longest anal fin ray, caudal fin depth, total number of parr marks and number of major parr marks on the left-hand side. General coloration of the upper half of the body and of the dorsal, anal, caudal, and pelvic fins will also be recorded. A sample size of 25 fish from each population will be used. Body measurements will be adjusted to standard length using covariance analysis.

Future Plans

Participate in breeding experiments in 2002. Adult chinook salmon returning to LPW in 2002 will include progeny from Chickamin River wild and hatchery brood lines and their hybrids. These fish will be held to maturation and used in a breeding experiment to maintain wild and hatchery brood lines and generate F-2 hybrids.

Behavioral experiments with juvenile chinook salmon. In fall 2002 through winter 2003 collate and analyze results of behavioral experiments conducted in spring and summer 2002, contrasting responses of fish from different wild and hatchery lineages.

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***Progress Report*:** **Analysis of Genetic and Phenotypic Differentiation Between Inbred and Outbred Lines of Steelhead and Rainbow Trout**

***Principal Investigator*:** William W. Smoker, Juneau Center, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks

***Other Participating Researchers*:** Erika Ammann, graduate student

Introduction

Of ten Evolutionarily Significant Units (ESU) of steelhead trout in the western USA (the anadromous form of *Oncorhynchus mykiss*), six have been identified as threatened or endangered under the Endangered Species Act, a consequence of habitat degradation over the past century. Restoration plans for these ESUs focus on restoration of habitat and the steelhead populations, but some form of protective custody may be necessary if the ESUs decline to extremely small numbers. Captive rearing, multigenerational artificial culture until fish can be returned to healthy habitat, carries risks of domestication and consequent loss of genetic fitness in the natural habitat (Olla et al. 1994, Reisenbichler and Rubin 1999). An alternative to captive rearing may be to move the ESU into a protected natural habitat where domestication forces are absent (e.g., the desert pupfish, Dunham and Minckley 1998). For an anadromous salmon, however, it may be impractical to move an ESU to a habitat from which they have access to the sea and the normal completion of their life cycle.

Research by US NOAA Fisheries at the Little Port Walter (LPW) research station is investigating a model of custodial protection in which anadromous steelhead have been translocated into a lake isolated from the ocean where they reproduce naturally and from which anadromous steelhead may once again be produced. The research at LPW depends on a fortuitous translocation of juvenile steelhead in the 1920s from Sashin Creek above two impassable waterfalls into Sashin Lake, where they established an isolated population. Researchers (F.P. Thrower and others, Auke Bay Fisheries Laboratory, Juneau, AK) have cultured lines of *O. mykiss* derived from anadromous steelhead in Sashin Creek and resident trout in Sashin Lake as well as lines derived from intercrosses; they have observed growth and survival in hatchery culture and survival at sea of released smolts from these groups.

The research reported on here augments the study at LPW and focuses on observations of behavioral differences between trout from different genetic lineages. Behavioral differences may have arisen between the landlocked and anadromous trout at LPW from adaptive changes in the landlocked, resident, population. Behavioral observations can reveal adaptive differences between populations (reviewed by Keenleyside 1997).

Activities in the first year of this research have been to take part in the propagation and culture of the experimental lines at LPW and to design observational studies to be carried out in the laboratory in summer 2002. These designs are presented here.

Research Plan: Behavioral Assay of Differences Between Lake-Resident and Anadromous Steelhead Trout

Behavioral and development differences have been demonstrated between similarly related lineages of salmonids including mating behavior of hatchery and wild steelhead (Berejikian 1997, 2001, Chebanov and Riddell 1998), dominance and aggression in wild and hatchery salmonids (Berejikian 2000, 1995, 1998, Ruzzante 1994, Swain and Riddell 1990), feeding behavior (Fenderson et al. 1968, Mesa 1991), growth (Vincent 1960), and predator avoidance (Johnsson and Abrahams 1991, Berejikian 1995).

Such differences may have arisen between the Sashin Creek and Sashin Lake trout because the environment of the lake, the model here for a custodial environment, is different in many ways from the natural environment of the

Sashin Creek steelhead. Behavioral adaptations to the lake by the sequestered population may prove maladaptive in the natural habitat, suggesting limited utility of the technique for ESU conservation.

Lake environments are generally slower moving, if moving at all, and can have different vegetation, different prey and predator species than a stream. Also, lakes and streams differ in the amount and kind of usable habitat they can provide for salmonids. In streams, competition for optimal territory is important while in lake environments there may be a larger proportion of equally valued territory and territorial behavior may not be so necessary. Swain and Holtby (1987), for instance, found that stream-resident coho were more aggressive than lake-resident coho and hypothesized that the difference was due to less competitive stream coho being pushed out of stream territories into the lake.

Social dominance has been observed in the freshwater stage of several salmonid species. Intense agonistic behavior, and the size and health of an individual contribute to dominance (Berejikian et al. 1996). Advantages are earned by the dominant fish such as less frequent attacks or nips by other fish, optimal feeding station, growth (Fausch 1984) and mate choice (Berejikian 2001). Dominance in size-matched fish is established through physical encounters which include displays of size and actual aggressive attacks. Observations of these encounters have been well documented (Rosenau and McPhail 1987). Subordinate displays enable fish to avoid agonistic behavior from a dominant fish (Swain 1989). Dominant fish can be identified by position for feeding, the number of attacks issued and received (Vosyliene et al. 1993).

Agonistic behaviors in salmon are seen in intraspecific as well as interspecific interactions and usually illustrate competition for access to food, mates, or shelter from predation. The level of aggressive behavior varies between species and between situations. Swain and Holtby (1989) found that lake-reared and stream-reared Coho differed in their levels of agonism, while Rosenau and McPhail (1987) showed that separate stream populations of Coho had different levels of agonism, possibly related to different adaptive environments in the streams.

Fin condition, parr mark coloration, and general body coloration and shape have all been used as quantifiers of differences between fish populations. Fin nipping occurs in agonistic exchanges where actual contact is made. It occurs in the wild but is frequently characteristic of hatchery culture in high density (Soderberg and Meade 1987, Wagner 1996). Fin condition has been shown to be a useful tool for indirect assessment of aggression in a natural population (Siikavuopio et al. 1996). Parr mark coloration in rainbow trout is identified as a signal for dominance (Berejikian et al. 1996). The dominant individual will display darker parr marks than the subordinate individual as an elastic and changing feature.

The main purpose of this study is to determine if there is a difference in behavior of trout from Lake and Stream lineages. We are observing agonistic and dominance behaviors in year-old trout and, within lineages only, in age-0 trout, observing social dominance in trout from the lineages, and observing fin condition and parr mark coloration. This experiment will attempt to answer four main questions through laboratory experiments at LPW in summer 2002:

1. Is there any difference in agonistic behavior between year-old rainbow with Resident (Lake) parents or with Anadromous (Stream) parents?

2. Is there any difference in agonistic behavior between newly emerged rainbow with Resident (Lake) parents or with Anadromous (Stream) parents?

The collection of data for the agonistic behavior will be done through direct observation and event recording in laboratory aquaria. The total number of nips, charges, and lateral displays will be recorded for each fish. This will later be analyzed by looking at the total number of aggressive behaviors performed by each type of fish.

3. Is there any difference in establishment of dominance between 1 yr old rainbow with Resident (Lake) parents, Anadromous (Stream) parents, or F1 generation hybrids?

The collection of data for the establishment of dominance will be done through direct observation and ranking of dominant individuals. The dominant individuals will be removed after establishing dominance and given a rank of 0. The next trial will be the establishment of dominance between the fish that are remaining. After four days the last fish will be removed and given a rank of 4. Analysis will be done using a Kruskall-Wallace test for ranked groups.

Observations will also be made regarding parr mark coloration. The related darkness of the dominant to subdominant will be recorded (i.e. the dominant fish is darker than the subdominant true or false) and a scale of coloration to determine if any consistent range exists. Position in the tank will be recorded and used to assess optimal positions for feeding and maintenance of those positions.

4. Is there any difference in fin condition between 1 yr old rainbow with Lake parents, Stream parents, or F1 generation hybrids?

Morphological, as well as behavioral, observations are being made in the same experiments. Fin condition will be assessed using the equation: fin factor %=(fin length x 100)/(total length) (Kindschi 1987). Morphological measurements will also be taken regarding total length, depth, and general coloration.

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Research Themes: Hydrographic and Sea Ice Studies

***Progress Report*: Observation and Theoretical Foundation for the Dynamics in a High-Resolution Sea Ice Model**

***Principal Investigator*:** S. Lyn McNutt, Geophysical Institute, University of Alaska Fairbanks

***Other Participating Researchers*:** James Overland, NOAA/PMEL; Jacqueline Richter-Menge, CRREL

Methods and Main Results

Work in 2001–2002 focused on providing remote sensing observational support for the buoy deployment as part of the Beaufort Stress Program. Two papers were prepared and are now in press, and one presentation was made.

<u>The Beaufort Stress Program</u>. A total of 11 buoys with transmitters were placed on the ice, including a Mass Balance Buoy at the center of the array. The data collection focused on the period from November 2001 to March 2002. Table 1 indicates the weekly averaged location of the array through March 2002. There was a high casualty rate for the buoys, and as of March, six remained in service with the following no longer operational:

- Center site 3S (south) died 11/7
- Southern site 1 died 12/22 but was not working properly anyway

- Center stress site 3C died 1/3 (This coincides with the met station tilt sensor going to 50 degrees)
- Center (north) site 3N died on 2/27
- Center (east) site 3E died on 3/8

Table 1. Weekly Position for the Center of the array (Mass Balance Buoy) through March 2002.

Date	Latitude	Longitude
9/22/01 0:00	73.356309	141.986174
9/29/01 0:00	73.343844	142.428875
10/6/01 0:00	72.941713	142.035279
10/13/01 0:00	72.720906	143.405458
10/20/01 0:00	72.525147	144.744963
10/27/01 0:00	72.03155	146.610646
11/3/01 0:00	72.225649	149.213953
11/10/01 0:00	72.173829	150.092259
11/17/01 0:00	72.702253	153.795234
11/24/01 0:00	72.822909	156.279629
12/1/01 0:00	73.023658	157.251946
12/1/01 1:00	73.022575	157.259924
12/8/01 0:00	72.846206	157.570739
12/15/01 5:00	72.665798	159.352871
12/22/01 0:00	72.54676	158.973751
12/29/01 0:00	72.802003	160.485981
1/5/02 0:00	72.494946	160.079337
1/12/02 0:00	72.523918	160.728191
1/19/02 0:00	72.901159	163.112684
1/26/02 0:00	72.95835	164.573651
2/3/02 0:00	72.962	165.257418
2/10/02 5:00	73.253971	168.710668
2/17/02 0:00	72.998516	169.611384
2/24/02 0:00	73.168285	170.589678
3/1/02 0:00	73.353814	171.334557

The array crossed 170 degrees W in mid-March and it traveled along the 170 meridian until about the beginning of May, when it slowly started to drift westward. At the end of June, the only buoys still transmitting were site 4-09161 and the met station 22206. The others stopped reporting throughout the Spring. At this point, the two remaining buoys were still east of Wrangel Island and were traveling north to north-north-west, remaining east of 175 degrees W, as follows:

Date	Latitude	Longitude
6/28/02	76.46934N	172.74606W

Publications

Two publications are now in press based on research from this project. One presentation was made at the International Geoscience and Remote Sensing Symposium (IGARSS).

Publication summaries:

Richter-Menge et al. *(Journal of Geophysical Research)*

Together, thermodynamic and dynamic processes determine the thickness distribution of the ice cover, which governs the exchange of energy between the atmosphere and the ocean. Key to the dynamic processes is the mechanical behavior of the ice cover. During the SHEBA field experiment, we deployed sensors to measure the internal ice stress at several locations within a 15 km x 15 km area. These measurements are combined with satellite-derived ice motion and imagery products. The objective is to make a first step towards using these data sources as a direct means of evaluating sea ice dynamics models, by assessing whether the stress signal can be qualitatively linked to the regional-scale (10–100 km) deformation activity. Four case studies are presented, each with distinguishing characteristics: consolidation of the seasonal ice zone against the Alaskan coast (5–7 December 1997); advancement of the consolidation zone into the perennial ice pack (11–13 December); extreme divergence (14–17 January); and consolidation of the pack against Wrangel Island and the Siberian coast (20–23 February). The results of this analysis (1) demonstrate that stress measurements are related to the regional deformation behavior of the ice cover, (2) confirm that regional-scale ice dynamics is primarily a function of coastal geometry, and sustained, large-scale wind direction and magnitude, (3) provide continued evidence that the ice pack behaves as a granular hardening plastic, and (4) encourage pursuit of efforts to use direct measurements of ice stress and deformation in the formulation and development of sea ice dynamics models.

McNutt & Overland (*Tellus*)

This study defines a classification for Arctic Sea ice dynamics based on spatial and temporal scale: floe, multifloe, aggregate, coherent, sub-basin and seasonal. The classification is supported by remote sensing and *in situ* observations of sea ice motions as scales of 1–700 km, as found in the existing scientific literature. The first significant change in sea ice behavior appears as an "emergent" property of the sea ice at the transition from the multifloe scale (2–10 km/<1 day) to the aggregate scale (10–75 km/1–3 days). This emergent behavior establishes a statistical mechanical length where sea ice can be considered a plastic continuum. A second important "coherent" scale occurs primarily at 75–300 km and 3–7 days, where the spatial and temporal processes of sea ice dynamics best match the scales of wind forcing, i.e., winds of this duration and fetch are necessary to fully load the internal stress field of the sea ice. At scales smaller than the coherent scale, the spatial dimension is important because the sea ice motions on the coherent scale provide non-local forcing to the aggregate scale. At dimensions larger that the coherent scale, including the sub-basin and seasonal scales, spatial and temporal averaging occurs, which smoothes discontinuities.

This new classification of sea ice dynamics shows the importance of changes in sea ice dynamics from the multifloe (2–10 km) to the aggregate (10–75 km) scale. The 10 km multifloe scale is important in sea ice dynamics, as this is the point at which the ice exhibits emergent behavior, thereby providing the link between the dynamics associated with individual floes and the plastic continuum of motion based on statistical mechanics. The aggregate and coherent (75–300 km) scales both show velocity discontinuities and propagation of stress features through the ice field, demonstrating the plastic behavior of the ice cover. The coherent scale is important for modeling and observing sea ice because this is the spatiotemporal scale where ice dynamics couples most strongly with wind forcing.

The integrity of sea ice models at all scales requires that both the model resolution and the parameterization of the sea ice physics be appropriate to the model scale. Based on SAR data and in situ observations, we conclude that modeling and validating regional ice dynamics is most important at the coherent scale, requiring resolution of the sea ice at the aggregate scale. Modeling on the sub-basin scale must include parameterization on the coherent level, which is achieved in current generation viscous-plastic models. Initialization, data assimilation and validation of sea ice models requires data that correspond to the appropriate model scale, or data derived from observations taken at the next smaller scale.

McNutt et al. *(IGARSS presentation)*

In this paper, we discuss the use of three data analysis techniques for understanding sea ice dynamics at the regional scale during the Surface Heat Budget of the Arctic (SHEBA) Experiment in the winter of 1998. The satellite data consist of SAR and AVHRR, and the techniques used include: 1) Hue-Intensity Saturation (HIS); 2) RADARSAT Geophysical Processor System (RGPS) ice tracking; 3) measurements of sea ice deformation in the Seasonal Ice Zone (SIZ) and the Perennial Ice Zone (PIZ) of the Beaufort and Chukchi Seas. We then discuss the results of data analyses using these techniques and the importance of the observations in understanding the behavior of the SIZ and PIZ, and the implications these observations have for understanding and modeling ice dynamics in this region.

Publications/Presentations

Richter-Menge, J.A., S.L. McNutt, J.E. Overland, and R. Kwok (In press) Relating Arctic pack ice stress and deformation under winter conditions. *Journal of Geophysical Research*.

McNutt, S.L. and J.E. Overland (In press) Understanding the spatial hierarchy in Arctic sea ice dynamics. *Tellus*.

McNutt, S.L., N. LaBelle-Hamer, and J.E. Overland (2001) Combining SAR and AVHRR to understand sea ice dynamics in the seasonal and perennial ice zones of the Beaufort and Chukchi Seas. Presentation to IGARSS Symposium, Sydney, Australia, 9–14 July, 2001.

Research Themes: Tsunami Research

***Progress Report*:** **Alaska Earthquake Information Center Seismic Station Upgrade and Installation**

Principal Investigator: Roger Hansen, State Seismologist, Geophysical Institute, University of Alaska Fairbanks

Report

This continuing contract is to install a total of 18 new modern digital broadband seismic stations throughout Alaska and to maintain their operation and telemetry. Of the total, five stations have been funded through CIFAR. These five stations as listed in the original statement of work are given here with their operational status. (Note that original locations were tentative):

- Cold Bay, AK 55.19 -162.70 (approx): Station installed as a new site at False Pass and operational. Utilizing local school internet for communications
- Peninsula (Yakutat), AK 59.67 -139.40: Stations installed as an upgrade to PIN. Operational pending FTS phone communications.
- Cordova, AK 60.55 -145.75 (approx): Station installed as a new site near Cordova. Waiting for final connection to the FTS phone line in August 2002.
- Paxson, AK 62.97 -145.47 (approx): In the process of upgrading this existing station. Clean-out of the existing borehole is in progress. To be completed in August 2002.
- Dot Lake, AK 63.65 -144.06 (approx): This site was to be installed at either Dot Lake or Granite Mountain. The Granite Mountain site on the Seward Peninsula is more desirable, and is in the process of being permitted in cooperation with BLM. Installation schedule will depend on the timeliness of the permitting process.

The long-term operation, archiving and telemetry of the operational stations is progressing well with sharing of data to the tsunami warning centers, the USGS, and soon to the IRIS Data Management Center for further sharing of the data with the University community.

***Progress Report*:** **Alaska Tsunami Inundation Mapping Project**

***Principal Investigator*:** Roger Hansen, Geophysical Institute, University of Alaska Fairbanks

Overview

With CIFAR/NOAA/PMEL and leveraged Alaska Science and Technology Foundation (ASTF) funding, we established an Alaska Tsunami Mapping Team (ATMT) centered at the Geophysical Institute, University of Alaska Fairbanks. This team of university, state, and federal employees in seismology, oceanography, geographical mapping, and emergency response/hazard mitigation has taken an interdisciplinary approach to evaluating and mapping the inundation and flooding of Alaska coastlines following large coastal earthquakes and landslides that generate tsunamis. The ATMT has: (1) acquired/adapted, calibrated and tested a high resolution numerical computer code for tsunami propagation and runup from earthquake and landslide generated sources, (2) studied runup at selected Alaskan locations and produced tsunami inundation maps, and (3) transferred the results of the studies to the local communities, the Alaska Division of Emergency Services (ADES), the Alaska Tsunami Warning Center (ATWC) in Palmer, Alaska and other related federal agencies, the National Oceanic and Atmospheric Administration (NOAA) and the Federal Emergency Management Administration (FEMA).

Inundation studies at three communities on Kodiak Island were completed along with an extensive report and associated GIS-based maps of potentially flooded areas intended to provide guidance to local emergency managers in tsunami hazard assessment. The report represents the type of final product we are producing for the project. It is a joint publication of the State of Alaska, Department of Natural Resources, Division of Geological and Geophysical Surveys and the Geophysical Institute of the University of Alaska Fairbanks, and is available from ADGGS and over the Web. The title of the report is “Tsunami Hazard Maps of the Kodiak Area, Alaska” by E.N. Suleimani, R.A. Hansen, R.A. Combellick, G.A. Carver, R.A. Kamphaus, J.C. Newman, and A.J. Venturato. (See also web site: http://www.aeic.alaska.edu/tsunami/index.html and click on the link to Tsunami Hazard Maps of Kodiak, Alaska.) We have also begun work on several more communities, including Homer, Seward, and Sitka.

***Progress Report*:** **TWEAK: Tsunami Warning and Environmental Observatory for Alaska**

***Principal Investigator*:** Roger Hansen, Geophysical Institute, University of Alaska Fairbanks

TWEAK Element 1—Enhanced Observation and Modelling of Tsunami Waves

Element 1 is presented in two parts. Part A deals with the additional capabilities that TWEAK brings to the operational aspects of inundation mapping. Part B briefly describes the work of Dr. Zygmunt Kowalik on enhancements of the numerical modeling for landslide generated tsunami waves.

A. Observations and Inundation Mapping Work

Work on developing the necessary data grids for inundation mapping in Alaska coastal communities has made consistent progress despite numerous setbacks. Many of the communities of interest in Alaska are in relatively remote areas and have very little measured data available. Efforts to find any data available have included dialogs with local sources such as city, borough, and state officials, along with national sources such as the Army Corps of Engineers, USGS, and NOAA, and the use of new technology such as GPS and SAR interferometry. With utilization of all these sources, along with analysis of data using powerful software including Matlab and ArcView/ArcInfo GIS, the development of quality merged bathymetry-topography grids proceeds for the Alaskan communities of interest.

Kodiak. After successful modeling of the inundation from the 1964 event, along with seven other sources, the results were distributed to the local community for comment. A week before final publication of the Kodiak report we had to continue work on the Kodiak Inundation maps due to late feedback from the city engineer. Direct comparison between the inundation line on our maps and detailed ortho-photo maps of the city showed unexpected results of the inundation line steeply crossing contours of the ortho-photo plots. These ortho-photo plots were not used to produce or constrain the 1-second grids for Kodiak. We compared the Kodiak 1-second grid topography with the ortho-photo topography and noted large differences. Also many of the errors noted by the city engineer are smaller than the ~100 foot grid spacing, and so are finer then our resolution at the 1-second grid spacing. We described the limitation of our resolution and carefully made small adjustments to the inundation line to better match the ortho-photo topography without compromising the integrity of the modeling, and finished the report. In the current and future mapping efforts, we hope to include all such data in the grid production to ensure better matching with local maps and the most accurate results possible.

The full Kodiak report has been published through the Alaska Department of Geological and Geophysical Surveys. “Tsunami Hazard Maps of Kodiak, Alaska,” a joint publication of the Alaska Division of Geological & Geophysical Surveys (ADGGS) and the University of Alaska Geophysical Institute (UAGI), is posted on the ADGGS web site and is available in hard copy as ADGGS Report of Investigations 2002-1. The URL is http://www.dggs.dnr.state.ak.us. Click on Recently Published Maps and scroll down to Kodiak. The text is downloadable in pdf format and requires Acrobat Reader. The maps are downloadable in MrSid format, which maintains high resolution upon zooming in. The free MrSid reader is downloadable from LizardTech through a link on the Recently Published Maps page.

Homer/Seldovia. Grid development in the communities of Homer and Seldovia posed a significant challenge due to the lack of quality topographic data. The problem was most significant in the area of the Homer spit, which contains no elevations above 10 meters, which is the first contour of the most detailed USGS topo map for the area. The USGS DEM is made directly from the contours of the topo maps, and thus the entire spit was represented by interpolated data points, almost all having a uniform elevation of 5.2 meters. This lack of information was unacceptable in the important area.

Discussions with all local and national resources revealed that no other sources of digital data were available, but one set of paper ortho-photo maps including topography was found and acquired. Through discussions with the Alaska SAR Facility, plans were made to use Synthetic Aperture Radar to develop new DEMs for the area. The possibility of using the soon-to-be-released SRTM DEMs of the area was also discussed.

Despite many promises, ASF was unable to produce any DEMs for our area of interest. Also, the SRTM data release of data in the Homer/Seldovia area was delayed until the adjacent Asia continental data is ready, some time next year. These setbacks caused significant delay in grid development. We decided to digitize the paper ortho-photo maps to produce the high quality data needed.

There were 64 large format maps containing 1inch=100feet scale images with 2 foot contours. All maps were scanned using a large format scanner at full resolution into .tiff format images which support georeferencing for accurate digitization. All maps included georeferenced corners of the quarter section grid which were used at control points for georeferencing the digitized contours. Digitizing this quantity of contours is very time consuming, causing further delays, but producing a high quality grid. Additional information from the Army Corps of Engineers was used to constrain the new small boat harbor and staging area at the end of the spit, completing the Homer grid.

In the Seldovia area, no ortho-photo maps were available. The grids developed for Seldovia relied mostly on the USGS DEMs, along with some supplemental information from measured GPS points, and data from local sources about breakwater heights and elevations of some lakes and the airport landing strip. A vector of the coastline from the USGS map was used to constrain the coastline. After several draft versions, the Seldovia grid required only small manual adjustments of single errant points to produce a high quality final grid.

The Homer/Seldovia grids are now complete. Custom matlab scripts show that the edges between different grid scales are now very well matched, and will not produce any numerical instabilities. Development of appropriate source models has been concurrent with the grid development, and initial model runs have been performed. Development of the one potential source model, the Augustine Landslide, will require additional bathymetry resolution in the source region, and requires further development before it can be modeled. Inundation modeling should proceed smoothly from here.

Seward. Initially, Seward was of higher priority than Homer/Seldovia, but the necessary bathymetric data was not available for Seward, and was for Homer/Seldovia, and NOAA was planning to do a bathymetric survey of the Seward area. The preliminary grids covering the Seward area showed very poor data coverage. The new survey is finished, and one-half of the data is available for grid development. Hopefully soon the rest of the data will become available, and then the bathymetric coverage in this area will be some of the highest in any coastal community in Alaska.

The prospect for topographic grid development was initially very poor, similar to the Homer/Seldovia area, with only USGS DEMs developed from insufficient coverage of topo contours available. Subsequently, the SRTM data covering the Seward area has been released. This 30m DEM is based on interferometry, and so does not include interpolated grid points at low elevation levels. Although this data set may include noise in the water sections, and may include uncorrected tilts and offsets, the USGS DEMs may be used to constrain these errors while still preserving the valuable new data. With the combination of the SRTM data, the USGS DEMs, and local data, the prospect of quality topographic grids is now very good.

B. Code Development for Numerical Modeling of the Landslide-Generated Tsunamis

The goal of this research is construction of numerical code based on the landslide generated theory developed by Jiang and LeBlond (1993). The basic theory treats the landslide and overlying ocean as a two-layer system. The first numerical experiments show that landslides generate inside the domain a combination of traveling, reflective and standing waves on both free surface and discontinuity surface (internal wave). All these waves when reflected from the open boundary lead to the noise and instability. Therefore, the first problem to be solved was proper formulation of the radiating boundary conditions for the two-layered fluid. These boundary conditions were constructed using the method of characteristics (Durran, 1999). We have tested the open boundary formulation for two-layer and three-layer flow, and compared results with those of Pearson and Winter (1984). The comparison turned out to be satisfactory.

References

Durran, D.R. 1999. Numerical Methods for Wave Equations in Geophysical Fluid Dynamics. Springer, 465pp.

Jiang, L. and P. H. LeBlond. 1993. Numerical modeling of an underwater Bingham plastic mudslide and waves which it generates. J. Geophys. Res., v. 98, No. C6, 10,303–10,317.

Pearson, C.E. and D.F. Winter. 1984. On tidal motion in a stratified inlet, with particular reference to boundary conditions. J. Phys. Oceanogr., 14, 1307–1314.

TWEAK Element 2—Earthquake Characteristics and Finite Fault Processes: Diagnostics for Tsunamigenic Potential

(1) As a first step in our problem of setting up a procedure for moment tensor calculation, we evaluated velocity models used by the Alaska Earthquake Information Center (AEIC) for routine processing of the earthquakes. As a result of the evaluation, we recommended few corrections for the standard AEIC velocity models. Also, we set regions for use of each of the three regional models: northak - used north of the 62.5°N, scak - used south of 62.5°N,

including the Aleutian Islands, and gulfak - used for earthquakes that occur in the Gulf of Alaska, behind the Aleutian trench.

(2) Since the standard processing and the data archiving at the AEIC is based on relational databases, we worked on upgrades to the AEIC earthquake databases. As a part of this work, we compiled a catalog of focal mechanisms for Alaska, which became a part of the AEIC earthquake database. This compilation provides us reference information for the types of faulting characteristics in any part of Alaska.

(3) We have searched published literature for various velocity models based on the seismic reflection/refraction surveys in Alaska and the Aleutians. We have worked on adopting velocity models based on those profiles into 1D structures which have been tested for the Green's function calculations. In some cases, when the published data was not enough, we contacted authors of the papers and requested the velocity data from them. The Alaskan seismicity can be subdivided into two main categories: (1) seismicity in the overriding North American plate (depths above 30 km), present in the entire state, and (2) seismicity within the subducting Pacific plate that can be further subdivided into (2-1) the seismicity in the Gulf of Alaska before the Pacific plate comes into contact with the North American plate (depth less than 20 km) and (2-2) seismicity in the Wadati-Benioff zone (WBZ) (maximum depths of 220 km beneath Alaska and 250 km in the Aleutians), present in southcentral Alaska and the Aleutians. Therefore, it is not possible to use a single velocity model for calculating the Green's functions and synthetic seismograms in the entire state of Alaska. We subdivided the state of Alaska into five regions and identified the test velocity structures for each subregion: (1) southcentral Alaska - south of 62.5N, 140W–160W: (a) standard AEIC model SCAK, (b) averaged models from various land and marine seismic reflection/refraction surveys. (2) southeastern Alaska - east of 140W and south of 60N: (a) standard AEIC model SCAK, (b) PGS (Canadian) model for events in the Queen Charlotte Islands/Gulf of Alaska region. (3) central Alaska - 62.5N–66N: (a) standard AEIC model NORTHAK; (b) TACT model (from seismic reflection profiles); (c) Canadian model for events in the Yukon/Northwest Territories. (4) northern Alaska - north of 66N: (a) standard AEIC model NORTHAK; (b) Canadian model for events in the Yukon/Northwest Territories (5) Aleutian arc - west of 160W and south of 57N: (a) standard AEIC model, (b) averaged model for the arc constructed from a variety of the along- and across-arc marine seismic surveys.

(4) We tested these Green's functions in the moment tensor inversion of the recent M 4.5+ earthquakes in Alaska. Our tests indicate that the most likely candidate as a base velocity model for southcentral Alaska is a modified SCAK model (standard AEIC model for earthquake locations south of 62.5N). We have tested several of this model's modifications. Adjustments were based on the seismic refraction/reflection surveys in southcentral Alaska. The model still needs some refining; however, its major features are a good base for a future final model for calculating Green's functions for southcentral Alaska. This model, however, will not work for southeastern Alaska, where the earth crust is thinner and where the plate boundary is strike-slip rather than subduction. Our conclusion at this point is that the TACT velocity model with a crustal thickness of 30 km is the best for calculating Green's functions for the moment tensor inversions in interior Alaska (area between ~62.5N–66N).

(5) Additional preparatory work for the moment tensor inversion and Green's function calculations included modifications to the computer codes to account for the specific conditions of the Alaskan seismic network and the data archiving format, testing these modifications, and construction of the instrument response files and data files.

(6) A primary focus of the current effort was testing a system for the real-time earthquake detections and locations that initiate the moment tensor calculations. This system is based on the Antelope System from Boulder Real-Time Technologies (BRTT). There are trade-offs between using only digital CREST stations versus a hybrid network of modern and antiquated stations. The hybrid system will associate and locate more regional events but has a higher incidence of event mislocations due to noise triggers on the older stations. So, while from the analyst's point of view it is better to have more false event associations in parallel with more actual arrival and event detections, for the alarm and emergency service notification the current system would result in too many false alarms. This is also tempered by the fact that most false locations are for smaller events; however, some noise triggers generate unreasonably high magnitude calculations. The possible solution could be some sort of analysis of the station distribution for a given detected event. It could be either a clustering analysis or a nearest neighbor analysis with a simple criterion of rejection of stations located beyond a certain dist_max from the nearest neighbor. It is important to understand the behavior of the system since magnitudes are going to be a primary criterion for triggering a real-time moment tensor inversion algorithm.

(7) We have also continued working on program modifications for the automatic focal mechanism calculations based on the P-wave first motions.

Appendix

1. **Projects funded during the first year of CIFAR Cooperative Agreement NA17RJ1224 (1 July 2001–30 June 2002)**

CIFAR Projects
1 July 2001 – 30 June 2002

Investigator Last	First	Institution	Proposal Title	AMD#	Proposal Budget	Subaward F&A	Total Award Amt.	Research Theme
Weller	Gunter	U. Alaska Fairbanks	TASK I Administration	0	$ 100,000		$ 100,000	Admin
Weller	Gunter	U. Alaska Fairbanks	TASK I Administration	1	$ 8,400		$ 8,400	Admin
Subtotal Task I Administration					**$ 108,400**		**$ 108,400**	
Belkin	Igor	U. Rhode Island	Ocean Fronts of the Bering, Chukchi and Beaufort Seas	1	$ 39,586	$ 11,775	$ 51,361	ARI
D'Arrigo	Rosanne	Columbia University	Paleoclimatic Reconstructions of the Arctic Oscillation	1	$ 85,946	$ 11,775	$ 97,721	ARI
Francis	Jennifer	Rutgers University	Interactions of Laterally Advected Heat and Moisture with Arctic Cloud Properties	1	$ 67,751	$ 11,775	$ 79,526	ARI
McNutt	Lyn	U. Alaska Fairbanks	Do Recent Changes in Sea Ice and Snow Cover Impact the Arctic Oscillation?	1	$ 16,912		$ 16,912	ARI
Springer	Alan	U. Alaska Fairbanks	Trophic Pathways on the Chukchi-Beaufort Shelf: Where do the Ice Algae Go?	1	$ 142,657		$ 142,657	ARI
Springer	Alan	U. Alaska Fairbanks	Trophic Pathways on the Chukchi-Beaufort Shelf: Where do the Ice Algae Go?	2	$ 66,000		$ 66,000	ARI
Walsh	John	University of Illinois	An Arctic Archive of Model Output and Application to SEARCH	1	$ 75,347	$ 11,775	$ 87,122	ARI
Yang	Daqing	U. Alaska Fairbanks	Hydrologic Response of Siberian Major Rivers to Climate Change and Variation	1	$ 31,325		$ 31,325	ARI
Subtotal Arctic Research Initiative					**$ 525,524**	**$ 47,100**	**$ 572,624**	
Barrie (joint with Cahill)	Len	Battelle Pacific Northwest Division	Persistent Organic and Trace Element Pollutants in the Alaskan and Eastern Russian Arctic	1	$ 92,101	$ 11,775	$ 103,876	Contaminants
Cahill (joint with Barrie)	Cathy	U. Alaska Fairbanks	Persistent Organic and Trace Element Pollutants in the Alaskan and Eastern Russian Arctic	1	$ 7,483		$ 7,483	Contaminants
Barrie	Leonard	Battelle Pacific Northwest Division	Persistent Organic and Trace Element Pollutants in the Alaskan and Eastern Russian Arctic (modification to Amendment 1 project)	2	$ 5,000		$ 5,000	Contaminants
Subtotal Contaminants					**$ 104,584**	**$ 11,775**	**$ 116,359**	
Adkison	Milo	U. Alaska Fairbanks	Relationship Between Growth and Survival of Coho Salmon Utilizing the Coastal Gulf of Alaska	2	$ 36,000		$ 36,000	Fisheries
Herrmann	Mark	U. Alaska Fairbanks	Regional Impact of the Effect of Steller Sea Lion RPAs on the Fishing Economy of Kodiak, Alaska	2	$ 45,000		$ 45,000	Fisheries
Jewett	Stephen	U. Alaska Fairbanks	Effects of Bottom Trawling on Bering Sea Infauna	3	$ 100,000		$ 100,000	Fisheries
Naidu	Sathy	U. Alaska Fairbanks	Granulometry and Organic Carbon Contents of Sediments, Bering Sea, Alaska	4	$ 30,983		$ 30,983	Fisheries
Norcross	Brenda	U. Alaska Fairbanks	Reproduction Potential of Pacific Cod	2	$ 150,000		$ 150,000	Fisheries
Smoker	William	U. Alaska Fairbanks	Analysis of Genetic and Phenotypic Differentiation Between Inbred and Outbred Lines of Steelhead and Rainbow Trout	2	$ 39,399		$ 39,399	Fisheries
Smoker	William	U. Alaska Fairbanks	Analysis of Genetic and Phenotypic Differentiation Between Wild and Hatchery-bred Chinook Salmon, Ongoing at Little Port Walter Research Station	2	$ 41,473		$ 41,473	Fisheries
Weingartner	Thomas	U. Alaska Fairbanks	ALPHA HELIX for 2001 GLOBEC	1	$ 477,312		$ 477,312	Fisheries
Subtotal Fisheries Oceanography					**$ 920,167**		**$ 920,167**	

CIFAR Projects
1 July 2001 – 30 June 2002

Investigator Last	First	Institution	Proposal Title	AMD#	Proposal Budget	Subaward F&A	Total Award Amt.	Research Theme
McNutt	Lyn	U. Alaska Fairbanks	Observational and Theoretical Foundation for the Dynamics in a High-resolution Sea Ice Model	2	$ 50,000		$ 50,000	Hydro/Sea Ice
Subtotal Hydrographic and Sea Ice Studies					**$ 50,000**		**$ 50,000**	
Berman (joint with McBeath)	Matt	Univ. of Alaska Anchorage	Decision-Making Under Uncertainty: Management of Commercial Fisheries and Marine Mammals	1	$ 54,172		$ 54,172	SSL
Burns	Jennifer	Univ. of Alaska Anchorage	The Role of Physiological Constraint in the Acquisition of Foraging Ability: Development of Diving Capacity in Juvenile Steller Sea Lions	1	$ 153,924		$ 153,924	SSL
Coyle	Ken	U. Alaska Fairbanks	Climate-driven Bottom-up Processes and Killer Whale Abundance as Factors in Steller Sea Lion Population Trends in the Aleutian Islands: Zooplankton and Acoustic Component	1	$ 694,218		$ 694,218	SSL
Dearborn	Ronald	U. Alaska Fairbanks	Publication Support for "Is It Food II" A Workshop on Steller Sea Lion Declines	1	$ 23,300		$ 23,300	SSL
Finney	Bruce	U. Alaska Fairbanks	Impacts of Climate Change on the Bering Sea Ecosystem over the Past 500 Years	1	$ 198,507		$ 198,507	SSL
Foy	Robert	U. Alaska Fairbanks	Seasonal Assessment of Prey Competition Between Steller Sea Lions and Wal eye Pollock	1	$ 202,308		$ 202,308	SSL
McBeath (joint with Berman)	Gerald	U. Alaska Fairbanks	Decision-Making Under Uncertainty: Management of Commercial Fisheries and Marine Mammals	1	$ 65,828		$ 65,828	SSL
Okkonen	Stephen	U. Alaska Fairbanks	Interannual Variability of Biophysical Linkages Between the Basin and Shelf in the Bering Sea	1	$ 113,340		$ 113,340	SSL
Royer	Thomas	Old Dominion University	Ocean Climate Variability as a Potential Influence on Steller's Sea Lion Populations	1	$ 192,548	$ 11,775	$ 204,323	SSL
Straley (joint with Trites)	Jan	Univ. of Alaska Southeast	Predator/Prey Investigations of Killer Whales and Steller Sea Lions in Alaska	1	$ 32,655		$ 32,655	SSL
Thorne	Richard	Prince William Sound Sci Ctr	Investigation of the Foraging Behavior of Steller Sea Lions in the Vicinity of Kodiak Island, Alaska	1	$ 541,200	$ 11,775	$ 552,975	SSL
Trites (joint with Straley)	Andrew	North Pacific Marine Science Foundation	Predator/Prey Investigations of Killer Whales and Steller Sea Lions in Alaska	1	$ 168,165	$ 11,775	$ 179,940	SSL
Subtotal Steller's Sea Lions					**$ 2,440,165**	**$ 35,325**	**$ 2,475,490**	
Hansen	Roger	U. Alaska Fairbanks	Alaska Earthquake Information Center Seismic Station Upgrade and Installation	1	$ 162,575		$ 162,575	Tsunami
Hansen	Roger	U. Alaska Fairbanks	Alaska Tsunami Inundation Mapping Project	1	$ 37,774		$ 37,774	Tsunami
Hansen	Roger	U. Alaska Fairbanks	TWEAK ELEMENT I: Tsunami Warning and Environmental Observatory for Alaska	2	$ 103,947		$ 103,947	Tsunami
Hansen	Roger	U. Alaska Fairbanks	TWEAK ELEMENT II: Tsunami Warning and Environmental Observatory for Alaska	2	$ 208,211		$ 208,211	Tsunami
Highsmith	Ray	U. Alaska Fairbanks	TWEAK ELEMENT III: Tsunami Warning and Environmental Observatory for Alaska	2	$ 164,596		$ 164,596	Tsunami
Subtotal Tsunami Research					**$ 677,103**		**$ 677,103**	
Grand Total					**$ 4,825,943**	**$ 94,200**	**$ 4,920,143**	