GROUP 1: PHYSICAL /CHEMICAL OCEANOGRAPHY AND CLIMATE

CalCOFI hydrographic climatology

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Introduction

Routine oceanographic sampling within the California Current System has occurred under the auspices of the California Cooperative Oceanic Fisheries Investigations (CalCOFI) since 1949, providing one of the longest existing time-series of the physics, chemistry and biology of a dynamic oceanic regime. All data are now available on a CalCOFI CD-ROM, obtainable from the Scripps Institution of Oceanography (for details see http://www.calcofi.org). The principle objective in preparing the CD-ROM was to make these data easily accessible to the general oceanographic community, as well as to provide a baseline data set from which water property anomalies can be computed and compared between regions along the West Coast. Thus, in addition to providing the 50-year dataset, we also include a climatology of the CalCOFI hydrographic data, as well as a program for computing the mean values of various physical variables at any given location within the CalCOFI domain and for any day of the year. (Data and software are also available directly from the website noted above.)

Data

The historical CalCOFI sampling grid extends from the southern reaches of Baja California northward to the California-Oregon border, and out to several hundred kilometers offshore, with 36 nominal lines oriented approximately perpendicular to the coastline. Stations are designated by a line and station number (e.g., 77.60 is station 60 on line 77). Nominal station spacing is approximately 70 km offshore (e.g., distance between 77.60 and 77.70), but is considerably less inshore of station 60. The greatest spatial and temporal coverage occurred during the early years of the program (1950-1960), when multi-vessel cruises occupied significant portions of the grid at monthly intervals (Moser *et al.* 1988). Quarterly surveys were conducted annually from 1961 to 1965, with target months of January, April, July and October. Monthly coverage was resumed, but only triennially, between 1966 and 1984. Measurements were made on over 23,000 stations on this grid over the 35-year period from 1949 to 1984. Through 1964, standard station sampling consisted of 12- to 18-Nansen bottle casts mostly to 500-m depth (and occasionally to 1,200 m or 2,000 m). STD or CTD casts were taken subsequently, often in conjunction with a Nansen cast or with several water-bottle samples for calibration (Lynn *et al.* 1982). Values of oceanographic parameters were interpolated to standard depths. All data from observed and standard depths are published in Scripps Institution of Oceanography data reports.

The present CalCOFI grid, a subset of the historical grid which has been occupied quarterly since 1984, comprises nearly 7,500 station occupations (through January 2001) from six nominal lines between San Diego and Point Conception. Routine station activities include CTD/rosette casts to 500-m depth, bottom depth permitting, with continuous measurements of pressure, temperature, conductivity, dissolved oxygen and chlorophyll fluorescence. Water samples are collected at 20 depths, with variable spacing depending on depth of the chlorophyll, oxygen and salinity extrema and the thermocline depth (Hayward and Venrick 1998). Salinity, oxygen and nutrients are determined for all sampled depths, while chlorophyll-*a* and phaeo-pigments are determined within the top 200 m, bottom depth permitting. Details of the standard sampling and analysis procedures can be found in any of the recent CalCOFI data reports, e.g., SIO (1999).

Methods

The CalCOFI CD-ROM and website include climatologies of the hydrographic data. We describe the mean seasonal variability of 7 hydrographic variables (temperature, salinity, density, oxygen concentration, oxygen saturation, dynamic height anomaly and spiciness) at 14 standard levels (0, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, 300, 400, 500 m) for all stations within the CalCOFI dataset for which sufficient data exist. Spiciness, as defined by Flament (1986), is a state variable (units of σ_t) that is most sensitive to isopycnal thermohaline variations and least correlated with the density field. It is conserved in isentropic motions, and is defined to be largest for warm and salty water.

Our approach follows that of Lynn (1967) and Lynn *et al.* (1982), in which the mean seasonal variation is obtained by a least squares regression of the data to annually periodic sinusoids. Since the time intervals between measurements are irregular, and typically consist of 3-4 month gaps, we restrict our harmonic analysis to include only the annual and semiannual harmonics. The general form of the regression curve is:

$$Y = A_1\cos\Phi + B_1\sin\Phi + A_2\cos2\Phi + B_2\sin2\Phi + C,$$

where Φ is the angular equivalent of the day of the year in radians, and C is the annual mean value. In the least squares regression, the sum of the squares of the data anomalies from the regression curve is minimized with respect to each of the five coefficients, with the resulting set of equations solved simultaneously for the coefficients (Lynn 1967). In order to maintain sufficient data for performing the regression, the criterion of at least 5 occupations (for a given variable, at a particular station and standard depth) were required within each 60-day period of the time series.

The files containing the derived harmonic coefficients for each station, standard depth and variable for which sufficient data exist are included on the CD-ROM. These files are used to compute the mean values for a selected variable, station, standard depth and day of year, or to compute anomalies for a particular set of measurements.

Climatological base periods

Not all stations within the CalCOFI region have been regularly occupied since 1949. As mentioned above, there have been several fundamental changes in the areal extent of the nominal sampling grid, with the latest change occurring in 1984. It was therefore necessary to construct several climatologies that represent different portions of the region over different baseline periods. For the period 1950-1984, harmonic coefficients were computed for all stations on the entire historical grid, from Baja California to northern California, which had sufficient data. The harmonic analysis was performed on only those data from the present grid for two additional baseline periods: 1950-1999 and 1984-1999. The latter base period was chosen because it represents the period in which various changes in sampling methods and strategies were employed.

Tables of monthly mean values of each of the physical variables for the periods 1950-1984 (historical grid) and 1950-1999 (present grid), for all stations and standard depths for which sufficient data exist, are included on the CD-ROM. We also included coefficient files for the base periods 1950-1976 and 1977-1999 for all stations within the present grid, as these represent both sides of an observed “regime shift” in Pacific climate (e.g., Trenberth and Hurrell 1994; Francis and Hare 1994), and may be of use in diagnosing decadal variability in the region.

We encourage caution when using these climatologies to determine anomalies from independent observations made along the West Coast. The choice of baseline period has a significant effect on the derived mean values (Figs. 1 and 2), due primarily to an upper-level warming and freshening trend in the Southern California Bight over the past 20 years.

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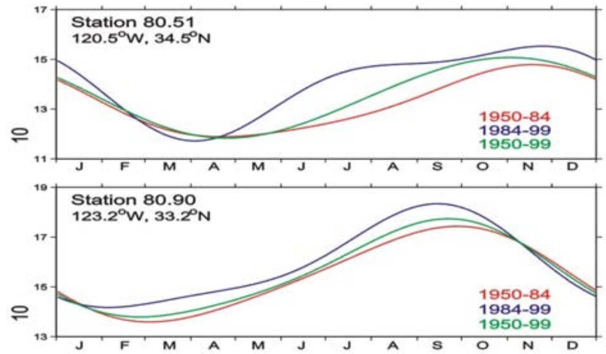

Fig. 1 Harmonic means of 10-m temperature at CalCOFI stations 80.51 (inshore) and 80.90 (offshore) for different base climatologies.

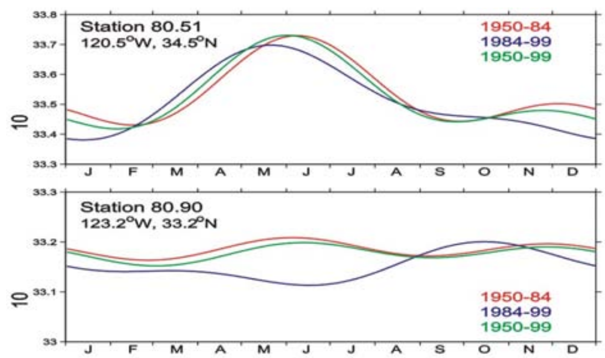

Fig. 2 Harmonic means of 10-m salinity at CalCOFI stations 80.51 (inshore) and 80.90 (offshore) for different base climatologies.

Improving access to environmental datasets: Data holdings at Pacific Fisheries Environmental Laboratory

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Introduction

Research in oceanography and other environmental sciences often involves obtaining data from many sources. Unfortunately, these data are usually in multiple formats, causing investigators to spend a discouraging amount of their research time reducing data to a form useful for analysis. In addition, it is rarely possible to obtain only the small subsets of data that are pertinent to their research. This problem is often particularly acute in fisheries research, where investigators may not have familiarity with oceanographic datasets and appropriate means of subsetting them (Boehlert and Schumacher 1997). At the Pacific Fisheries Environmental Laboratory

(PFEL), we are working to provide environmental data to investigators in a more usable form.

PFEL, a component of the National Marine Fisheries Service (Southwest Fisheries Science Center), specializes in analyzing the effects of environmental variability on fisheries. Due to its cooperation with the Navy's Fleet Numerical Meteorology and Oceanography Center (FNMOC) and other data centers, PFEL has a wide variety of oceanographic and atmospheric datasets that are relevant to many areas of fisheries science, marine resource management, and climate change in the ocean. For many years, PFEL has supplied extracts from these datasets to users around the world, and has also developed a number of derived products from these datasets. These have been used in many areas of research. Currently PFEL is increasing the number of datasets available and improving access to these datasets by converting them to common formats and making them readily available over the Internet.

PFEL receives both observational data and gridded model output in near-real time (Table 1). These data include: Global Telecommunications System (GTS) surface observational data; Global Temperature-Salinity Profile Program (GTSPP, Hamilton 1994) subsurface data; and FNMOC operational forecasts of the state of the atmosphere and ocean. PFEL also maintains the World Ocean Database (WOD98, Levitus *et al.* 1998) and Comprehensive Ocean-Atmosphere Data Set (COADS, Slutz *et al.* 1985). Each data set arrives at PFEL in its own native format, each requires a different set of extraction software, and each presents its own unique problems in attempting to organize, extract, subset and distribute the data. Detailed descriptions of each currently held data set and the methods employed to place them in common formats are available in the unabridged version of this data summary (deWitt and Mendelssohn 2001), available from PFEL.

Data products

PFEL makes available a variety of products derived from the observational products and Fleet Numerical Meteorology and Oceanography Center (FNMOC) model output. Most of these products can be obtained on the Live Access Server (described below).

Table 1 PFEL Data Holdings. G or O refers to (G) Gridded derived (model output) data or (O) non-gridded observational data. Dimensions are (L)Latitude by (L)Longitude by (D)Depth by (T)Time. All data generally have global coverage, except for FNMOC SLP, which, for the years 1967 - 1981, is only available for the Northern Hemisphere. Observational (O) data, although available globally, is often locally sparse.

Data Set	Native Format	Frequency of Arrival at PFEL	Monthly Storage Required	G or O	Availability Dates	Dimensions
GTS Surface	BUFR	hourly	500Mb[1]	O	Jan 1997 - present	LxLxT
GTSPP Subsurface	MEDS	monthly	8Mb	O	Jan 1990 - present	LxLxDxT
FNMOC						
Sea Level Pressure	GRIB	6 hrs	10Mb	G	Jan 1967 - present	LxLxT
Surface Winds (20 m)	GRIB	12 hrs	18Mb	G	Jul 1998 - present	LxLxT
Surface Winds (10 m)	GRIB	bimonthly	9Mb	G	Nov 1999 - present	LxLxT
Geopotential Height	GRIB	6 hrs	14Mb	G	Jul 1998 - present	LxLxT
World Ocean Database 1998 Standard Level Data	NODC/ OCL	Archived	1541Mb Total[2]	O	Jan 1950 - Dec 1994	LxLxDxT

1 Uncompressed, compressed size is 50 megabytes (Mb)

2 Total uncompressed size for all probe types for standard level data for entire period of availability (from Conkright *et. al*. 1998, appendix 12A).

Historical products

On a monthly basis, PFEL generates indices of the intensity of large-scale, wind-induced coastal upwelling at 15 standard locations along the west coast of North America (3-degree intervals, 21°N to 60°N). The indices are based on estimates of offshore Ekman transport driven by geostrophic wind stress (Bakun 1973; Schwing *et al*. 1996). Geostrophic winds are derived from monthly averages of six-hourly FNMOC surface atmospheric pressure fields. The following monthly products are available for subsetting and downloading (upwelling index and along-shore transports are also available as 6-hourly and daily averaged values) for 1967 to the present:

- Surface Atmospheric Pressure
- North-South component of surface wind
- East-West component of surface wind
- North-South component of wind stress
- East-West component of wind stress
- Curl of surface wind stress
- Cube of wind speed
- North-South component of Ekman Transport
- East-West component of Ekman Transport
- Offshore Ekman transport (Upwelling index)
- Vertical Velocity into Ekman Layer
- Sverdrup Wind Stress Curl Transport

In recent years, PFEL has re-calculated upwelling indices and transports, updating the procedure to include averaging the 6-hourly transport fields rather than computing the fields from the averaged pressure, and eliminating the earlier 3°-grid limitation. In order to offer a consistent time-series to those who have been using PFEL products for a number of years, both the historical and new products remain available and are updated monthly.

Near real-time six-hourly products

Six-hourly products from the current and previous month (sea level pressure, geostrophic wind, wind stress and upwelling index) are available for viewing and download on PFEL's web page ("www.pfeg.noaa.gov", click on the "Upwelling/ Environmental Indices" button, then "Current Month's Six-hourly Products") and Live Access Server (see below). These products are automatically updated daily and include the current day's 0600Z pressure field.

Global upwelling index

From the new monthly pressure-derived products, Live Access Server users can calculate a time series of upwelling index (off-shore component of Ekman transport) for any coastal location in the Northern Hemisphere (1967-1980) and globally (1981-present). The user must provide latitude, longitude and the angle the coastline makes with a vector pointing north. A Ferret script rotates the Ekman transport in the desired direction and returns a time series at the desired location which can be viewed or downloaded.

*Extratropical Northern Oscillation Index (*NOIx*)*

Monthly values of the NOIx (extratropical Northern Oscillation Index) and its analog, the SOIx (extratropical Southern Oscillation Index), along with the traditional Southern Oscillation Index (SOI) are available for viewing and downloading on PFEL's web page ("www.pfeg.noaa.gov", click on the "Upwelling/Environmental Indices" button, and scroll down to "Other Environmental Indices") for 1948 to the present. The NOIx and SOIx are new indices (Schwing *et al.* 2001) of mid-latitude climate fluctuations that are useful for monitoring and predicting climate fluctuations and their physical and biological consequences in the Northeast Pacific.

Mixed layer depth

Monthly mixed layer depth and mixed layer depth climatology computed from the WOD98 (Levitus *et al.* 1998) standard level data are available on the Live Access Server. Mixed layer depth is computed using two different criteria (Monterey and Levitus, 1997; Monterey and deWitt, 2000) from individual WOD98 profiles, then averaged on a 1-degree latitude/longitude grid. The two criteria are: (i) a temperature criterion: mixed layer depth is determined as the depth at which the temperature falls to 0.5°C below the surface temperature, and (ii) a density criterion: mixed layer depth is determined as the depth at which the density difference from the sea surface is 0.125 σ_t units.

Table 2 Products currently available on the PMEL's Live Access Server.

Name of Dataset	**Dates available**	**Types of Measurements/Depths**
GTS Sea Surface Observations	Jan 1997 – present	Sea Surface Temperature SST Anomaly Number observations in the means
GTSPP Subsurface Temperature Real Time Best Copy (Delayed Mode)	 Aug 1996 – present Jan 1990 - Dec 1998	Temperature at 18 standard depths (10 - 1000 m) Depths of 14 and 10-degree isotherms
FNMOC Sea Level Pressure 1-degree model output Interpolated from larger mesh	 Nov 1996 - present Jan 1967 - Oct 1996	Pressure reduced to mean sea level
FNMOC Surface Winds 10 m 20 m	 Nov 1999 - present Jul 1998 - present	Wind components and magnitude Wind Stress components and magnitude Wind Stress curl
FNMOC Geopotential Height	Jul 1998 - present	Geopotential Height at 500 mb
World Ocean Database 1998 Observational means Mixed Layer Depth	Jan 1950 - Dec 1990 Jan 1945 - Dec 1994	 Temperature at 33 standard depths (0 - 5500 m) Temperature and salinity climatology (0 - 5500 m) Mixed layer depth and mixed layer depth Climatology using two criterion
PFEL Derived Products PFEL "Historical" Products Upwelling index (N. America) Monthly Daily and 6-hourly Monthly Wind products	 Jan 1946 - present Jan 1967 - present Jan 1967 - present	 Upwelling index and along shore transport at 15 Locations along the E. North Pacific coast Winds, speed cubed, wind stress, wind stress curl, Ekman Transport at 15 locations along the E. North Pacific coast computed from monthly sea level pressure
Environmental Indices	Jan 1948 - present	Monthly NOIx, SOIx, SOI
Global Upwelling Index SLP and wind products Upwelling index	 Jan 1967 – present Jan 1967 - present	 Winds, wind stress, wind stress curl, and Ekman Transport computed from 6-hourly sea level pressure Upwelling index (calculated using user-supplied Coastline geometry)
Near Real-time Six-hourly SLP and wind products Upwelling index	 Current month Current month	 Winds, wind stress, wind stress curl, and Ekman Transport computed from 6-hourly sea level pressure Upwelling index at 15 North American and 11 South American coastal locations

Live access server

PFEL has implemented a version of PMEL's Live Access Server (LAS) (Hankin *et al*. 1999, and ferret.wrc.noaa.gov/Ferret/LAS/) which allows users to visualize, subset, and extract PFEL's data products over the Internet (deWitt and Mendelssohn, 1999 and "www.pfeg.noaa.gov"). The LAS is designed to handle gridded fields, preferably in netCDF format. As part of our routine monthly processing most PFEL standard and derived products are converted to netCDF by appending a month's worth of data onto pre-existing netCDF files. Products currently available on the LAS are listed in Table 2. Unless specified otherwise, all products are available as monthly summaries on a 1-degree grid.

In order to make observational data available on the LAS, we calculate 1-degree monthly means at standard depths. For the monthly GTS data we have so far only made temperature means available on the LAS, but these include number of observations, monthly anomalies and an attempt at some quality control. The GTSPP netCDF files include number of observations and depths of the 10- and 14-degree isotherms.

Although all the standard level WOD98 data has been converted to HDF-EOS format, we are presently only serving part of it to our users. The amount of data below 1,000 m does not justify the storage required in gridded format. For these reasons, and since we have GTSPP subsurface data available starting in 1990, our WOD98 products include monthly 1-degree summaries of temperature for the upper 1,000 m (19 depths) for the years 1950-1990. The size of the WOD98 makes it prohibitive to save the gridded product in a single netCDF file. We store the data in 51 yearly files (118.2 Mb each for a total of 6 gigabytes), and use the multi-netCDF feature of Ferret to visualize and subset the files with the LAS. In addition to the monthly temperature summaries, monthly climatologies of temperature and salinity are also available on the LAS, and we hope to make other variables available in the future.

Since gathering the supporting data can be the most time-consuming part of a research project, improvements in the time and effort necessary to access and subset environmental data products can be a great benefit to research in fisheries, oceanography, meteorology and other fields. At PFEL, by carefully choosing the formats in which we store our data, we are striving to make data products available to users in ways that are multi-platform, inexpensive and user friendly.

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Japanese repeat hydrographic lines in the North Pacific

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Introduction

In this report, we introduce the present (2001 fiscal year) status of repeat hydrographic lines in the North Pacific conducted by the Japan Meteorological Agency (JMA), Hydrographic Department/Japan Coast Guard (HD/JCG), Japan Fisheries Agency (JFA) and Faculty of Fisheries, Hokkaido University (HU). The information is provided by Koichi Ishikawa (JMA), Hiroyuki Yoritaka (HD/JCG), Shin-ichi Ito (JFA) and Yutaka Isoda (HU).

Repeat lines by JMA

Long lines

JMA currently maintains two long repeat sections (Fig. 3):

1. 137°E line by the R/V *Ryofu Maru* and the R/V *Keifu Maru*
   - 1.1. every winter since 1967, every spring since 1989, every summer since 1972, and every autumn since 1992;
   - 1.2. interval of 1 degree in latitude from 34°N to 3°N;
   - 1.3. from surface to 2,000 m or bottom (every 5 degrees); temperature (T), salinity (S), oxygen (O_2), total carbonate, nutrients and others.
2. 165°E line by the R/V *Ryofu Maru* and the R/V *Keifu Maru*
   - 2.1. once a year since 1996, and twice a year since 2001;
   - 2.2. interval of 1 degree in latitude from 50°N to 3°S;
   - 2.3. from surface to 2,000 m or bottom; T, S, O_2, total carbonate, nutrients and others.

Short lines

JMA currently supports the following short repeat lines (Fig. 3):

1. PH line, along 41.5°N, south of Hokkaido, by the R/V *Kofu Maru*
2. 144°E line, along 144°E, east of Honshu, by the R/V *Kofu Maru*
3. PM line, northwest of Echizenmisaki, Japan sea, by the R/V *Seifu Maru*
4. "G" line, northwest of Sado, Japan sea, by the R/V *Seifu Maru*
5. PN line, northwest of Okinawa, East China Sea, by the R/V *Chofu Maru*
6. TK line, Tokara Straits, south of Kyushu, by the R/V *Chofu Maru*
7. "OK" line, southeast of Okinawa, south of Okinawa, by the *R/V Chofu Maru*
8. "ASUKA" line, southeast of Ashizurimisaki, south of Shikoku, by the R/V *Ryoufu Maru* and the R/V *Keifu Maru*

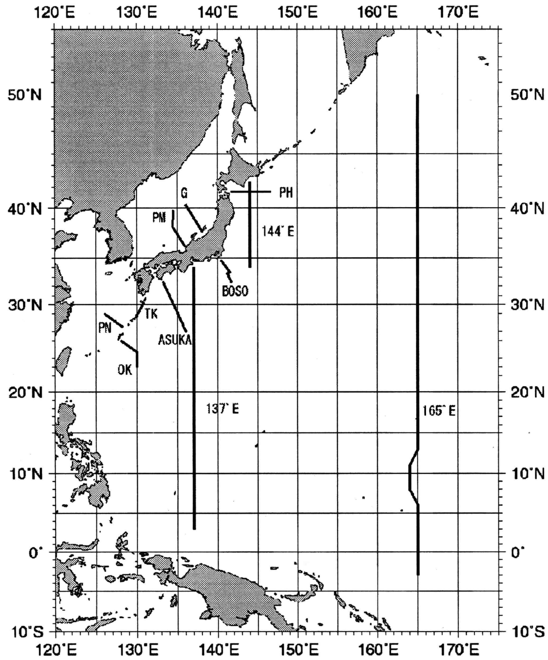

Fig. 3 Repeat lines currently conducted by JMA.

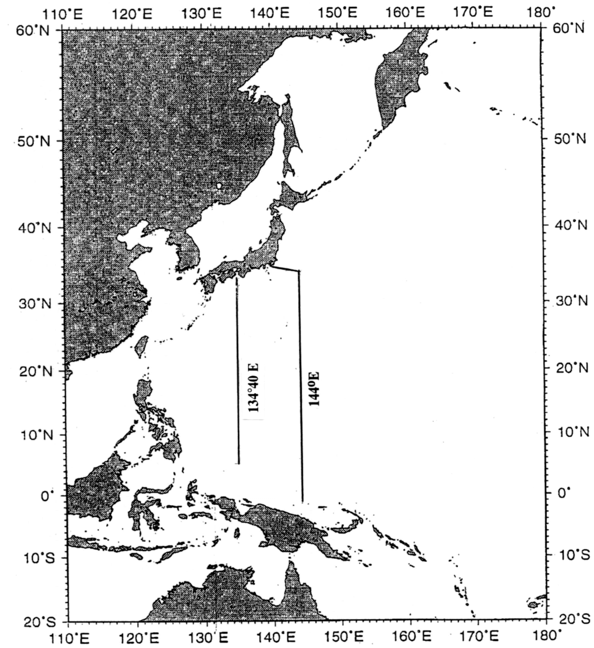

Fig. 4 Long repeat lines currently conducted by HD/JCG.

9. "BOSO" line, southeast of Boso Peninsula, east of Honshu, by the R/V *Ryofu Maru* and the R/V *Keifu Maru*

These lines are sampled at an interval of 3 months, *i.e.*, four times a year, with almost the same set of observations as at the long repeat sections.

Repeat lines by HD/JCG

Long lines

The following two long repeat sections have been maintained by HD/JCG (Fig. 4). Unfortunately, the 134°40'E line has not been supported since 1999.

1. 144°E line by the S/V *Takuyo* or the S/V *Shoyo*
   1.1. every winter since 1984;
   1.2. interval of 1 degree in latitude from 34°N to 1°S;
   1.3. from surface to 4,500 m or bottom; T, S, O_2, surface current, nutrients and others.

2. 134°40'E line by the S/V *Shoyo*
   2.1. every summer and winter since 1994 to 1999;
   2.2. interval of 1 degree in latitude from 34°N to 5°N;
   2.3. from surface to 4,000 m or bottom; T, S, O_2, surface current and others.

Repeat lines by JFA

Long lines

The following two long repeat sections are conducted by JFA (Fig. 5):

1. 179.5°W line by the T/V *Wakatake Maru*
   1.1. every summer since 1991;
   1.2. interval of 1 degree in latitude from 38.5°N to 58.5°N;
   1.3. from surface to 600 or 800 m; T, S, plankton and others.

2. 165°E line by the R/V *Hokko Maru*
   2.1. every summer since 1992;
   2.2. interval of 1 degree in latitude from 40°N to 50°N;
   2.3. from surface to 1,500 m; T, S, plankton and others.

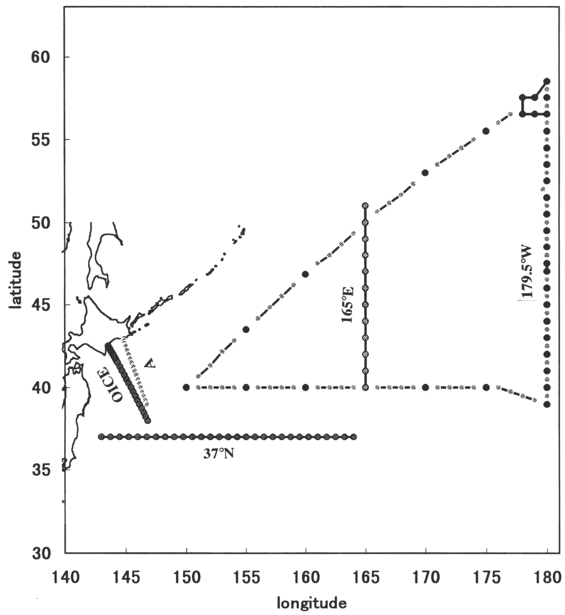

Fig. 5 Long repeat lines currently conducted by JFA.

3. A (Akkeshi)-line by the Hokkaido National Fisheries Research Institute
   3.1. 7 times a year since 1988;
   3.2. from surface to 3,100 m; T, S, plankton and others.

4. OICE (Oyashio Intensive Observation line off Cape Erimo) by the Tohoku National Fisheries Research Institute
   4.1. 4 times a year since 1997;
   4.2. from surface to 3,000 m; T, S, plankton and others.

5. 37ºN line by the Tohoku National Fisheries Research Institute
   5.1. every spring since 1983;
   5.2. interval is 45' in longitude from 143ºE to 165ºE;
   5.3. from surface to 1,000 m; T, S, plankton and others.

Short lines

Ocean monitoring of JFA is carried out by 7 National Fisheries Research Institutions and fisheries laboratories of 39 prefectures. Observational lines are classified into two categories. One is repeat-lines in coastal waters and the other is repeat-lines extending to offshore waters. T, S, surface current and other variables are measured at intervals of 1 month (coastal line) and 3 months (offshore line).

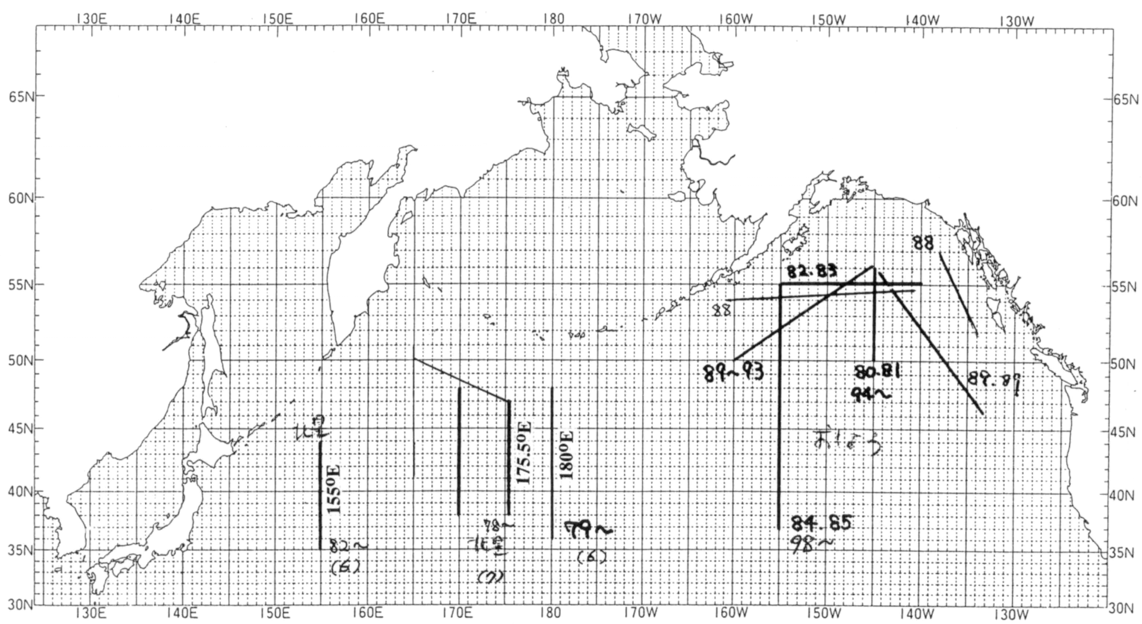

Fig. 6 Long repeat lines currently conducted by Hokkaido University.

Repeat lines by Hokkaido University

Long lines

The Faculty of Fisheries currently supports two long repeat lines (Fig. 6):

1. 155°E line by the T/V *Hokusei-Maru* to 2001, by the R/V *Oshoro Maru* from 2002
   1.1. every summer since 1979;
   1.2. interval of 1 degree in latitude from 36°N to 48°N;
   1.3. from surface to 3,000 m; T, S, O_2, nutrients and others.

2. 165°W line by the T/V *Oshoro Maru*
   2.1. every summer since 1998;
   2.2. interval of 1 degree in latitude from 35°N to 48°N;
   2.3. from surface to 3,000 m; T, S, O_2, nutrients and others.

Although HU had maintained the following two meridional lines since 1970s, they were unfortunately ended recently (Fig. 6):

1. 180° line by the T/V *Oshoro Maru*
   1.1. every summer since 1979 to 2000
   1.2. interval of 1 degree in latitude from 36°N to 48°N;
   1.3. surface to 3,000 m; T, S, O_2, nutrients and others.

2. 175.5°E line by the T/V *Hokusei Maru*
   2.1. every summer since 1979 to 1999;
   2.2. interval of 1 degree in latitude from 36°N to 48°N;
   2.3. from surface to 3,000 m; T, S, O_2, nutrients and others.

Monitoring of climatic variations in Far Eastern Seas

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The Far Eastern Seas and the adjacent Pacific waters are the main interest for Russia in the PICES area. One of our scientific goals in this area is to understand how climate affects the ecosystem structure and the productivity of key fish species in the Russian EEZ. The research is based on several types of climatic and oceanographic data used for detecting and describing climatic variations in the northwest Pacific, and searching for empirical relationships between physical and biological parameters.

The first group of data includes time-series of monthly means of different atmospheric indices (e.g. WP index, PNA index, etc.) and basic atmospheric characteristics (pressure, geopotential heights, air temperature at different levels). These data for the period from 1950 to the present are provided by the NOAA-CIRES Climate Diagnostic Center, Boulder, Colorado, from their web site at http://www.cdc.noaa.gov. Similar time-series are available from the Russian Hydrometeorological Center. All these data are used to give a general characteristic of climatic situation in the northwest Pacific and in the whole northern hemisphere in different seasons of the given year, or to detect tendencies in variations of large-scale atmospheric circulation with the emphasis on identifying the climatic regimes.

Sea surface temperature anomalies (SSTA), especially in winter season, are a very good indicator of climatic changes in the ocean. It is important to have SSTA time-series that are representative for vast oceanic areas. Such time-series may be obtained by partitioning the North Pacific into several sub-domains with coherent anomaly fluctuations in each sub-domain. For this purpose, mean winter (January-April) values of SST in the North Pacific (from 20°N to 55°N) at grid points of 5°-longitude by 5°-latitude were used for the 1957-2000 period. These data are available from the Russian Hydrometeorological Center. For each grid point, winter SSTA were calculated as deviations from the 1961-1990 mean. To divide the North Pacific into several sub-domains, one of the hierarchical clustering methods, known as the Ward's method (1963), was used. This method is distinct from all other hierarchical clustering methods because it uses an analysis of variance approach to evaluate the distances between clusters. In short, this method attempts to minimize the sum of squares of any two (hypothetical) clusters that can be formed at each step. In general, this method is regarded as most efficient. A detailed description of the algorithm for the Ward's method used in our research can be found in Krovnin (1995). Based on results of the cluster analysis, the North Pacific was divided into five major regions: the eastern part, the central part, the northwestern part, the southwestern part, and the southern part (Fig. 7). Further analysis showed that changes in SSTA in the eastern and central North Pacific, and those in the northwestern and southwestern North Pacific, are out of phase. For each region, time-series of area-averaged SST anomalies were calculated as the spatial average of the non-normalized detrended local time-series over the region specified by the corresponding cluster (Fig. 8). The use of these calculated time-series allowed us to obtain some information about the mechanisms governing large-scale SST fluctuations. In particular, it was shown that variations in mean winter SSTA in two western regions are closely related to Western Pacific teleconnection pattern.

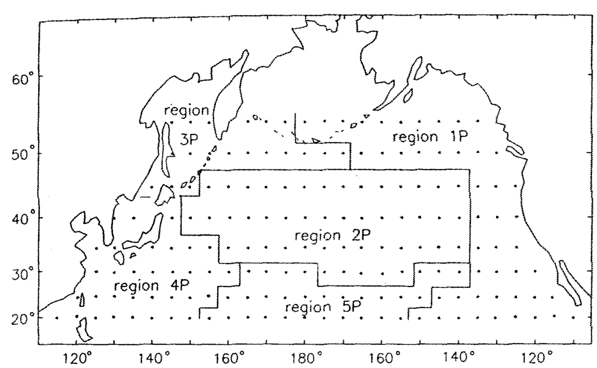

Fig. 7 Results of cluster analysis for the SST anomaly field in the North Pacific. Dots show the position of the 5°-latitude by 5°-longitude grid for the SST data.

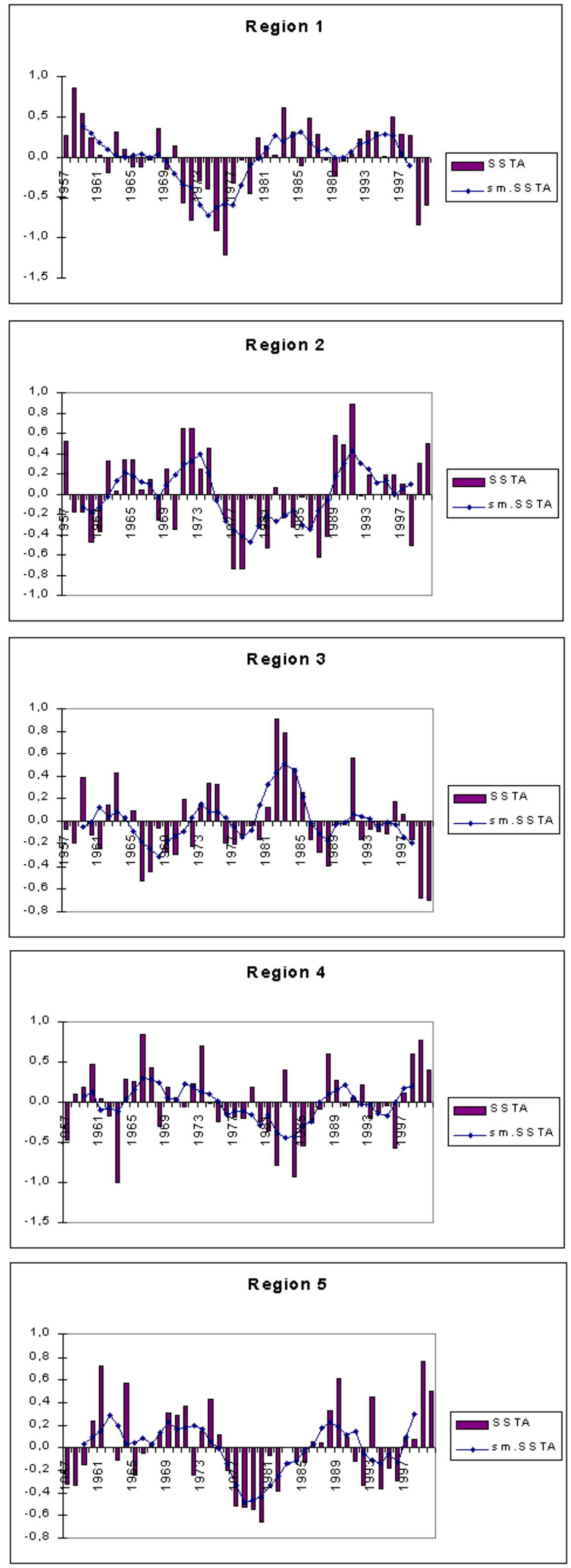

Fig. 8 Time-series of the detrended area-averaged SSTA in Regions 1-2 in the North Pacific.

In our research we used the area-averaged SSTA time-series not only to identify tendencies of changes and climatic regimes but mainly to search for teleconnections with physical characteristics in other regions of the Northern Hemisphere, e.g., in the North Atlantic, for a better understanding and explanation of the causes of climatic changes in the northwest Pacific.

The second group of data contains information on ice cover area (in % from the total area of the sea). These data are available from 1929 onwards for the Sea of Okhotsk, from 1960 for the Bering Sea, and from 1951 for the Sea of Japan. The old data are obtained with air reconnaissance. Recent data are based on information from NOAA satellites and Japanese Meteorological Agency. With the use of these data, a long-term forecast of thermal conditions in Far East Seas till 2020 was made. According to the forecast, the cold period that started there in 1998 will continue for about 20 years.

The third group of data includes a set of weekly and monthly maps of SST in the Okhotsk and Bering Seas and adjacent Pacific waters constructed at VNIRO, as a part of the program on the use of satellite and ship data to monitor the dynamics of SST in various fishing areas of the world ocean. These data are available for May-July of 1992-1993, April-November of 1994, and for the whole year from 1995 onwards. On the basis of these maps, some non-traditional characteristics of thermal conditions, such as ice-free areas, position of ice margins at different latitudes, duration of ice staying north or south of the given latitude, rates of spring warming and autumn cooling, etc., were calculated. Some examples of these characteristics are given in Figure 9. Though now these time-series are considered short, they are rather informative for describing and understanding changes in the development of seasonal processes from year to year. For example, from 1995 to 2000, ice conditions in the Sea of Okhotsk became more and more severe, but the rates of spring-summer warming increased during this period.

The fourth group of data consist of temperature and salinity time-series at several standard sections in the Far East Seas and Pacific waters (Fig. 10). Coordinates of stations and the period and frequency of observations at each section are presented in Tables 3 and 4 respectively. All these sections (except for Avachinsky conducted by KamchatNIRO) are carried out by TINRO-Centre vessels with depth resolution of 1 m during the last 10 years. The Kamchatsky section is conducted jointly by TINRO-Centre and KamchatNIRO. Until 2000, CTD Mark II and later ICTD developed by Falmouth Scientific Inc. were used for sampling. Only in recent years were the dates of cruises stabilized and sections were carried out at approximately the same time of year: Sangarsky and Trans-Okhotsk sections – in winter and summer; Kamchatsky section and section along 132°E - in summer and autumn; Avachinsky – mainly in June. All temperature and salinity measurements are controlled by deepwater thermometers and salinometer at each station.

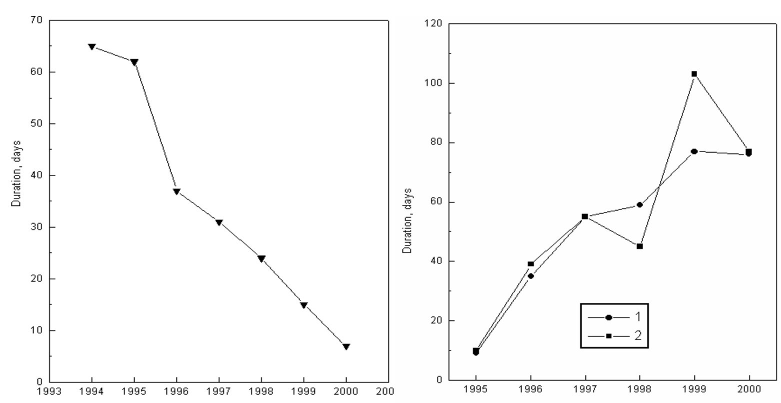

Fig. 9 Rate of spring-summer warming from 5°C to 8°C (in days) at point 49°N, 155°E (left panel), and duration of the ice period east of 148°E at 50°N (1) and south of 53°N off West Kamchatka (2) (right panel).

Table 3 Coordinates of stations at standard sections.

Sta. No.	NW Pacific Trans-Okhotsk Section[1]		Kamchatka Strait Section [2]		Sangarsky Section[3]		Section along 149°E [1] (Japanese)	Section along 132°E [3]	Section from Cape Mayachny[3] (Avachinsky)	
1	49°30'N	144°30'E	55°28'N	165°30'E	42°30'N	133°00'E	33° 00'N	43°00'N	52°30'N	159°36'E
2	49°37'N	144°56'E	55°37'N	165°12'E	42°25'N	133°30'E	33° 30'N	42°55'N	52°20'N	160°00'E
3	49°45'N	145°29'E	55°43'N	164°56'E	42°18'N	134°00'E	34° 00'N	42°50'N	52°06'N	160°40'E
4	49°52'N	146°01'E	55°46'N	164°43'E	42°12'N	134°30'E	34° 30'N	42°40'N	52°48'N	161°20'E
5	50°00'N	146°31'E	55°52'N	164°30'E	42°07'N	135°00'E	35° 00'N	42°30'N	51°30'N	161°66'E
6	50°08'N	147°01'E	55°56'N	164°13'E	42°00'N	135°30'E	35° 30'N	42°25'N	51°04'N	163°56'E
7	50°15'N	147°31'E	56°00'N	164°03'E	41°55'N	136°00'E	36° 00'N	42°20'N	50°37'N	163°53'E
8	50°22'N	148°00'E	56°05'N	163°52'E	41°50'N	136°30'E	36° 30'N	42°10'N	50°10'N	164°50'E
9	50°30'N	148°30'E	56°07'N	163°42'E			37° 00'N	42°00'N		
10	50°38'N	149°00'E	56°09'N	163°32'E			37° 30'N	41°50'N		
11	50°46'N	149°30'E					38° 00'N	41°40'N		
12	50°52'N	150°00'E					38° 30'N	41°30'N		
13	51°00'N	150°30'E					39° 00'N			
14	51°09'N	151°00'E					39° 30'N			
15	51°17'N	151°31'E					40° 00'N			
16	51°25'N	152°01'E					40° 30'N			
17	51°32'N	152°34'E					41° 00'N			
18	51°40'N	153°05'E					41° 30'N			
19	51°48'N	153°35'E					42° 00'N			
20	51°55'N	154°05'E					42° 30'N			
21	52°04'N	154°37'E					43° 00'N			
22	52°11'N	155°12'E								
23	52°19'N	155°44'E								

[1] sampling interval 0-1000 m; [2] sampling interval 0-1500 m; [3] sampling interval 0-500 m

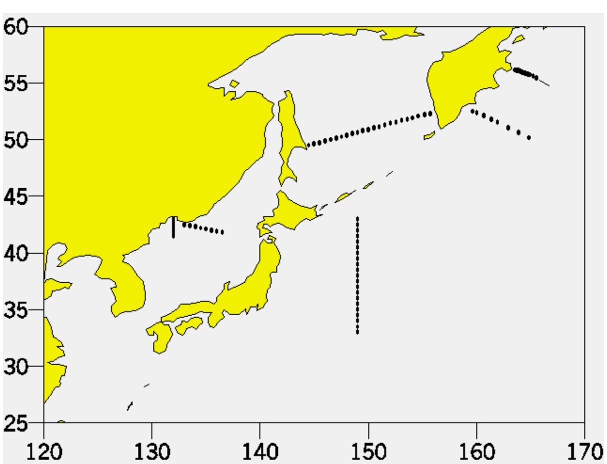

Fig. 10 Scheme of standard sections in the northwest Pacific.

The combined analysis of all described data allowed us to make the following conclusion about the present situation in Far East Seas:

1. Following the shift to a cold regime in the Sea of Okhotsk (since 1998), the cyclonic circulation in the sea strengthened. The volume transport of its main currents increased by a factor of 3 compared with the mid-1990s (warm regime). As a result, in contrast to the surface layer the warm regime was established in the intermediate layer of 500-1,000 m. It seems that the heat loss in upper layer is compensated by its increase at intermediate depths. This possibly allows a range of interannual variations in total heat budget of the sea to be smoothed, which is favorable for ecosystem stability.

Table 4 Frequency of observations at standard sections in the NW Pacific.

Years	Vladivostok Section (along 132°E)	Sangarsky Section	Trans-Okhotsk Section (Kamchatka-Sakhalin)	Kamchatsky Strait	Avachinsky Section	Section along 149°E
1953	5					1
1954	5			1		
1955	1					
1956	2					
1957	5				1	
1958	6				1	
1959	1				1	
1960	5				1	
1961	3			1	1	
1962	4				1	
1963	7			1	1	
1964	6			2	1	
1965	5	1			1	
1966	4			2	1	7
1967	6	1			1	5
1968	7	1			1	7
1969	2	1			1	10
1970	2				1	8
1971	10	1			1	6
1972	7	1			1	7
1973	6	1			1	8
1974	3				1	4
1975	5			2	1	9
1976	10	2				3
1977	4	2				1
1978	2	1		1	1	
1979	6	1			1	2
1980	13			1	1	1
1981	16	1			1	
1982	11	3			1	
1983	19	5			1	4
1984	28	15				
1985	25	18			1	7
1986	10	25			1	2
1987	7	18			1	
1988	33	38		1		
1989	22	30				
1990	10	21		2	1	
1991	10	11		1	1	
1992	7	11		1	1	
1993	5	4		1	1	
1994	7	1		1	1	
1995	3	5	1	1	1	
1996	5	1		2	1	
1997	2	2	1		1	
1998	3	2	1	2	1	
1999	2	1	1	1		
2000	2	2	2	3		
	369	227	6	27		

2. In the Bering Sea the period of weak water exchange with the North Pacific still continues. The transport of the Kamchatka Current in the layer of 0-1,500 m during summer is at a low level of about 2 Sv, while during the period of intensive water exchange it might be 10-15 Sv. But the autumn survey gave some hope on strengthening of water exchange in the near future.

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On time-series observation programs in the northwestern Pacific in Russia

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Existing and interrupted programs

Hydrographic monitoring in Russia/USSR had a peak in the 1950-70s when "weather ships" and "centennial sections" programs were rapidly developed by the State Hydrometeorological Committee, State Committee on Fisheries, and Academy of Sciences. Since the 1950s, a system of standard ("centennial") sections with biannual or seasonal hydrographic observations was designed for the Japan and Okhotsk Seas. A serious decline in observations began at the end of the 1980s, due to economical problems, but some remnants of the system survived. These include two sections in the Japan Sea and two sections in the Okhtosk Sea (see A. Krovnin in this report). Additionally, some information on Russian long-term series is presented below.

Perhaps the most impressive time-series was a system of sections around Sakhalin Island that have been maintained by the local Hydrometeorological Administration and Sakhalin Fisheries Research Institute (SakhNIRO). Luckily SakhNIRO is still managing to continue these observations (contact – Dr. Gennadiy Kantakov – okhotsk@sakhniro.ru). The principal area of monitoring covers waters in a 100-mile zone around Sakhalin Island in the Okhotsk Sea and Tatar Strait (Fig. 11). Hydrographic parameters and plankton are observed twice yearly along the standard sections, down to 500-1,500 m depth. Results of historical observations since the 1950s were published as printed and electronic versions of an atlas by Dr. Vladimir Pishchalnik *et al*. 2000 (vpishchalnik@mail.ru).

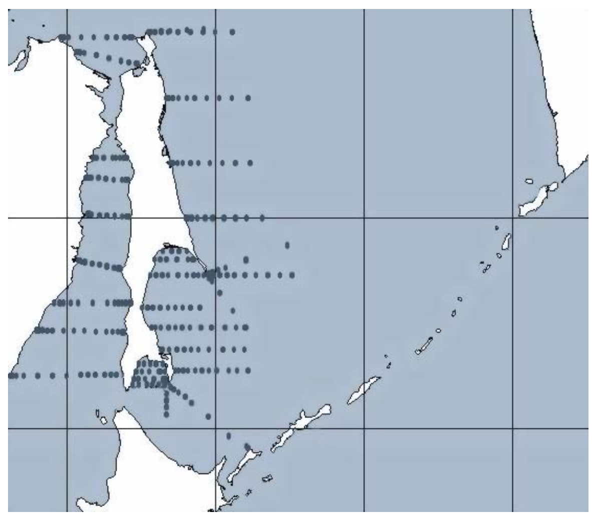

Fig. 11 Scheme of continuing survey around Sakhalin Island (source: G. Kantakov).

Another time-series is a repeated CTD survey of the Kuroshio area from 27 - 43°N and 132 - 149°E under the Russian *Razrezi* (*Sections*) program. The sections were repeated seasonally (4 times a year) in the period 1980-1990, by the Far Eastern

Regional Hydrometeorological Research Institute (FERHRI) (contact - Dr. Yuriy Volkov, director - hydromet@online.ru).

In 1989, the Pacific Oceanological Institute started regular surveys of the Kuril Islands area on an annual or semiannual bases. This included surveys implemented under the International North Pacific Ocean Climate Experiment (INROC) and observations that allow an examination of interannual variability in the Western Subarctic Gyre (see below).

Operational satellite data are available for the northwestern Pacific, Japan, Okhotsk and western Bering Sea from the Far Eastern Regional Receiving Center in Khabarovsk (FERRC), which holds historical data from Russian *Meteor, Kosmos, Ocean* and *Resurs* and *NOAA* satellites series since the 1970s, and receives operational information. The Inter-Institute Center for Satellite Monitoring of the Environment has been established in Vladivostok (contact - Dr. Emil Herbeck – ftp://herbeck.satellite.dvo.ru). This Center has maintained time-series from NOAA AVHRR since January 1999.

Monitoring of the Kuril area under INPOC and other programs

One of the findings of the INPOC project is the important role of mesoscale eddies in water exchange and modification in the Kuril area. A chain of anticyclonic eddies of 60-120 miles in diameter is regularly observed along the Kurils (e.g. Bulatov and Lobanov 1983; Yasuda *et al.* 2000), as it is evident from satellite images (Fig. 12). Intensity and location of the eddies influence the Kuril-Kamchatka Current and Oyashio branches' development and volume transport, as well as water exchange between the Okhotsk Sea and the Pacific. Correct sampling of the eddies and current branches is important for reliable estimation of mass and heat transport and their interannual variations in the area. That is why detailed hydrographic observations based on operational satellite information on eddy locations were implemented during the INPOC surveys. These observations and the following occasional surveys allowed the tracing of characteristics of

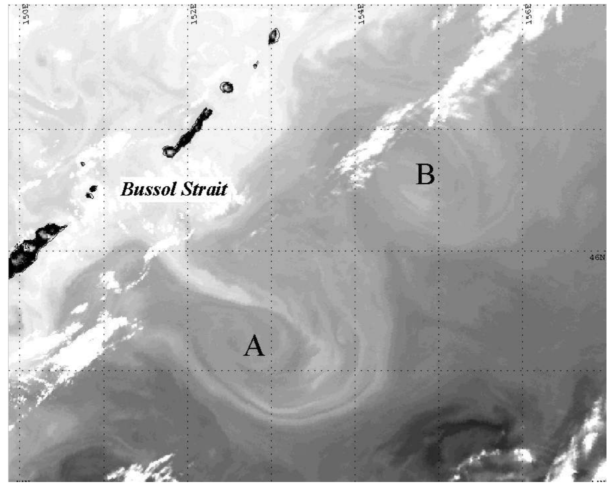

Fig. 12 Kuril eddies (A and B) on the NOAA satellite AVHRR image of May 29, 2001. Light shades correspond to cold water, white are clouds.

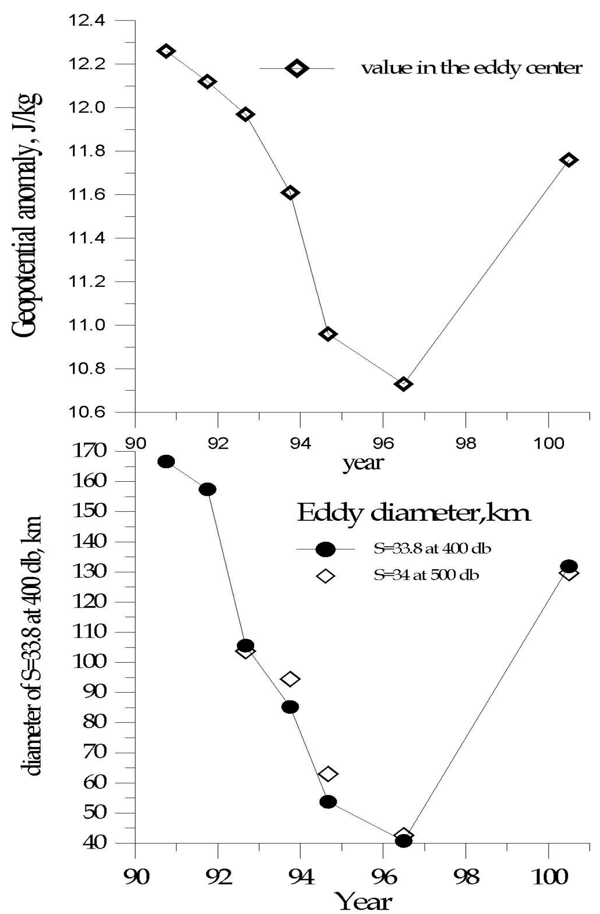

Fig. 13 Change of geopotential anomaly (upper panel) and diameter (lower panel) of the Kuril eddies off Bussol Strait during the recent decade.

the eddies and determining the Oyashio volume transport over the decadal period of 1990-2000 (Rogachev 2000). The decrease in the size and intensity of the eddies located off Bussol Strait from 1990 by the mid-1990s, and subsequent increase again by 2000 (Fig. 13), corresponds well with variations in the volume transport of the off-shore branch of the Oyashio and opposite changes in the coastal Oyashio. It was also found that eddies might be a good indicator of interannual variability in the Western Subarctic Gyre. Thus the monitoring of eddy characteristics could indicate changes of the whole large area. This program would be recommended for continuation. However, at the present, it seems hardly possible to carry out these observations on a regular basis because of a funding deficit in Russia.

Data holdings at POI

Most Russian time-series data are archived at the National Oceanographic Data Center and also in local institutional databases. Currently under a new federal program on development of the *Integrated Information System on the World Ocean*, all data storage should be combined. The main oceanographic institutes in the Russian Far East, POI, FERHRI and TINRO, have prepared an inventory and electronic catalogues of the available oceanographic data. At present, this information is being posted on web sites of these institutes:

POI: "www.pacific.marine.su" and "poi.dvo.ru"
FERHRI: "www.hydromet.com"
TINRO: "www.marine.su/TINRO"
Other sites: "www.meteo.ru"; and
"www.fegi.ru/primorye"

The POI database includes more than 750 cruises with around 360,000 stations taken from 1990 till now, from which around 125 cruises with 18,600 stations were implemented by POI expeditions.

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Physical and biophysical time-series originating from or used by Fisheries Oceanography Coordinated Investigations (FOCI) in the North Pacific Ocean and Bering Sea

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North Pacific region

Recent indicators suggest that the climate of the North Pacific region is changing. Scientists think this may have started as early as 1989, when the Arctic Oscillation (AO) changed phase. However, the most significant change is the cooling of coastal waters of the Pacific Northwest and Alaska since 1997-1998, when the Pacific Decadal Oscillation (PDO, see below) probably switched phase. With coastal cooling came shifts in marine abundance, e.g., West Coast salmon that were suffering declines in abundance early in the 1990s appear to be recovering, while

Alaska salmon abundance is waning. The following sections discuss some of FOCI's climate and pollock abundance indicators in light of climate change.

Interannual variability of atmospheric forcing

The winter magnitude and position of the Aleutian Low explain much of the interannual variability of atmospheric forcing and physical oceanographic response of the North Pacific Ocean and Bering Sea. The Aleutian Low is a statistical feature formed by averaging North Pacific sea level pressure for long periods. Because this is a region of frequent storms, the averaged pressure pattern describes a closed-cell, low-pressure area over the North Pacific, much like an individual storm on a weather map. The amplitude and location of the Aleutian Low have a strong bearing on weather and ocean conditions in the region and are correlated with other climate indices such as ENSO (El Niño Southern Oscillation), AO, and PDO. A strong Aleutian Low (low pressure) is accompanied by strong winds that drive warm water from the central Pacific into the coastal regions of Alaska and the Pacific Northwest. Conversely, when the Aleutian Low is weak (higher pressure), winds are weak and coastal sea surface temperatures cool.

A measure of the strength of the Aleutian Low is the North Pacific Index (NPI, Fig. 14). It is the sea level pressure over the North Pacific averaged for January through February. The index contains strong decadal variability. For example, there is a shift from high to low values of the index in 1925, a return to high values in 1946, and a shift back to low in 1977. If the data are smoothed, secondary shifts appear (one and a half secondary shifts for each major shift) such as in 1958 and 1989. In the past two years, NPI values have been higher, indicating a weaker Aleutian Low. Consequently, wind-driven advection of warm water from the central North Pacific into the coastal regions of Alaska and the U.S. Pacific Northwest has diminished, and local processes play a larger role in determining ocean temperature near the coast.

Figure 15 shows the averaged monthly anomaly of sea surface temperature for the North Pacific during May 2000. Note the relative cooling of the coastal waters. This signature is indicative of a recent change in the PDO (see next section). The cooling began in 1998 and has associated with the La Niña, but has persisted in the northeast Pacific, which is taken as an indicator of a change in the PDO. Ocean temperatures throughout the North Pacific continued to cool during June relative to long-term climatology.

Pacific decadal oscillation

The Pacific Decadal Oscillation (PDO) Index (Fig. 16) is defined as the leading principal component of North Pacific monthly sea surface temperature variability. The PDO is a long-lived, El Niño-like pattern of North Pacific Ocean climate variability. Two main characteristics distinguish PDO from ENSO. Firstly, 20th century PDO “events” persisted for 20 to 30 years, while typical ENSO events persisted for 6 to 18 months. Secondly, the climatic fingerprints of the PDO are most visible in the North Pacific/North American sector, while secondary signatures exist in the tropics - the opposite is true for ENSO. Several independent studies find evidence for just two full PDO cycles in the past century: “cool” PDO regimes prevailed from 1890-1924 and again from 1947-1976, while “warm” PDO regimes dominated from 1925-1946 and from 1977 through (at least) the mid-1990s. Some researchers have identified a cold phase starting in 1989, others point to 1997. Beginning in early 2000, it became apparent that a shift had occurred from changes in ocean temperature (Fig. 15) and distribution of salmon and other marine species. A weaker Aleutian Low (Fig. 14) is certainly associated with this change. Major changes in northeast Pacific marine ecosystems have been correlated with phase changes in the PDO. Warm eras bring enhanced coastal ocean biological productivity in Alaska and inhibited productivity off the west coast of the contiguous United States, while cold PDO eras produce the opposite north-south pattern of marine ecosystem productivity. Causes for the PDO are not currently known. Even in the absence of a theoretical understanding, PDO climate information improves season-to-season and year-to-year climate forecasts for North America because of its strong

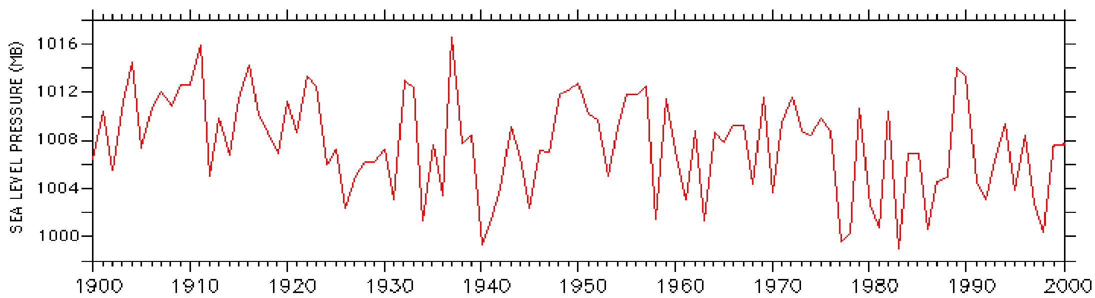

Fig. 14 The North Pacific Index (NPI) from 1900 through 2000 is the sea-level pressure averaged for January through February.

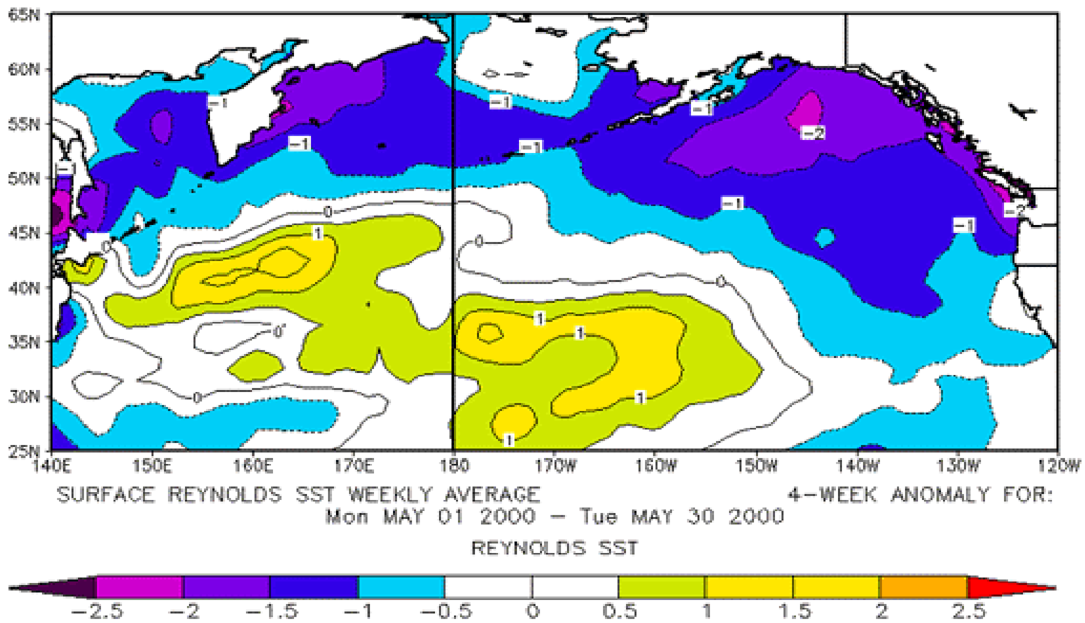

Fig. 15 The pattern of sea surface temperature anomalies for May 2000 shows a return to cool coastal waters with warmer central Pacific waters.

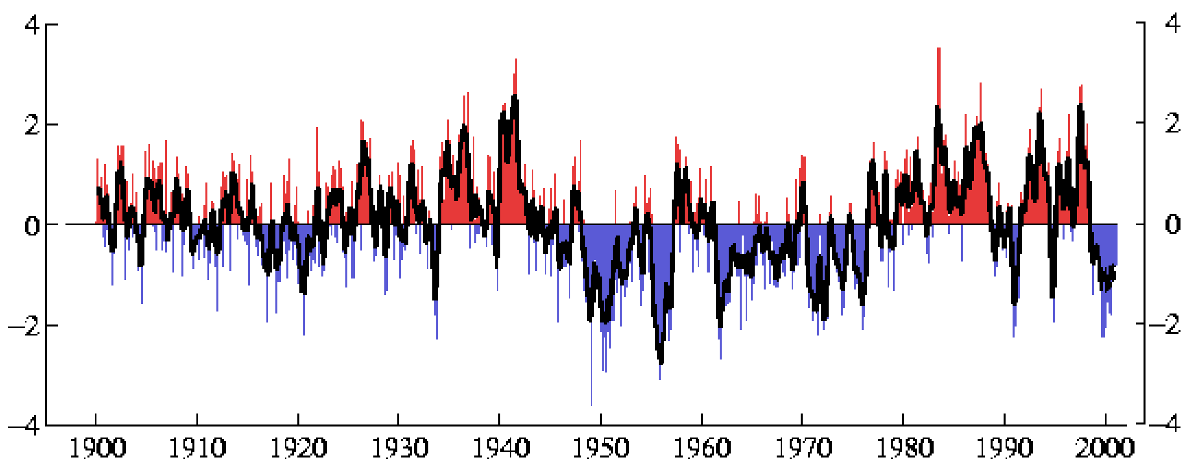

Fig. 16 Monthly and smoothed (black line) values of the Pacific Decadal Oscillation (PDO) index, 1900-2000 (updated from Mantua *et al.* 1997)

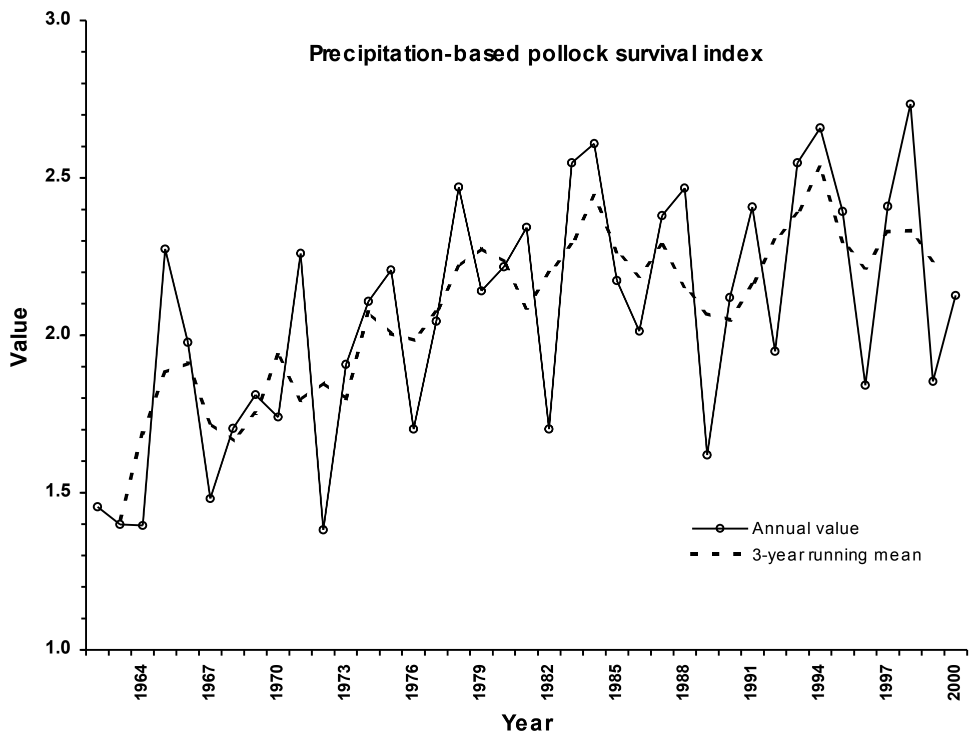

Fig. 17 Index of pollock survival potential based on measured precipitation at Kodiak from 1962 through 2000. The solid line shows annual values of the index; the dashed line is the 3-year running mean.

tendency for multi-season and multi-year persistence. From a societal perspective, recognition of PDO is important because it shows that "normal" climate conditions can vary over time periods comparable to a human's lifetime.

Western Gulf of Alaska

Seasonal rainfall at Kodiak

Patches of larval walleye pollock have been located within mesoscale eddies. For early larvae, presence within an eddy may be conducive to survival. Eddies in Shelikof Strait are caused by baroclinic instabilities in the Alaska Coastal Current (ACC). The baroclinity of this current fluctuates with the amount of fresh water discharged along the coast. A time-series of Kodiak rainfall (inches) is a proxy for baroclinity, and thus an index for survival success of species such as walleye pollock that benefit from spending their earliest stages in eddies. Greater than average late winter (January, February, March) precipitation produces a greater snow pack for spring and summer freshwater discharge into the ACC. Similarly, greater than average spring and early summer rainfall also favor increased baroclinity after spawning. Conversely, decreased rainfall is likely detrimental to pollock survival. A pollock survival index based on precipitation is shown in Figure 17. Although there is large interannual variability, a trend toward increased survival potential is apparent from 1962 (the start of the time-series) until the mid-1980s. Over the last 15 years, the survival potential has been more level. Are the lower values of the last two years commensurate with a phase change of the PDO?

Wind mixing south of Shelikof Strait

Another survival index relates to first-feeding pollock larvae, a key survival stage when baby fish have exhausted their yolk sacs and need to capture food. Possibly because increased turbulence interferes with larvae's ability to feed, strong wind mixing events during the first-feeding period are detrimental to survival of pollock larvae. A time-series of wind mixing energy (W m^{-2}) near the southern end of Shelikof Strait (at 57°N, 156°W) is the basis for a survival index (Fig. 18), wherein stronger than average mixing before spawning and weaker than average mixing after spawning favor survival of pollock. As with precipitation at Kodiak, there is wide interannual variability with a less noticeable and shorter trend to increasing survival potential from 1962 to the late 1970s. Recent survival potential has been high. Monthly averaged wind mixing in Shelikof Strait has been below the 30-year (1962-1991) mean for the last three January through June periods (1998-2000). This may be further evidence that the North Pacific climate regime has shifted in the past few years.

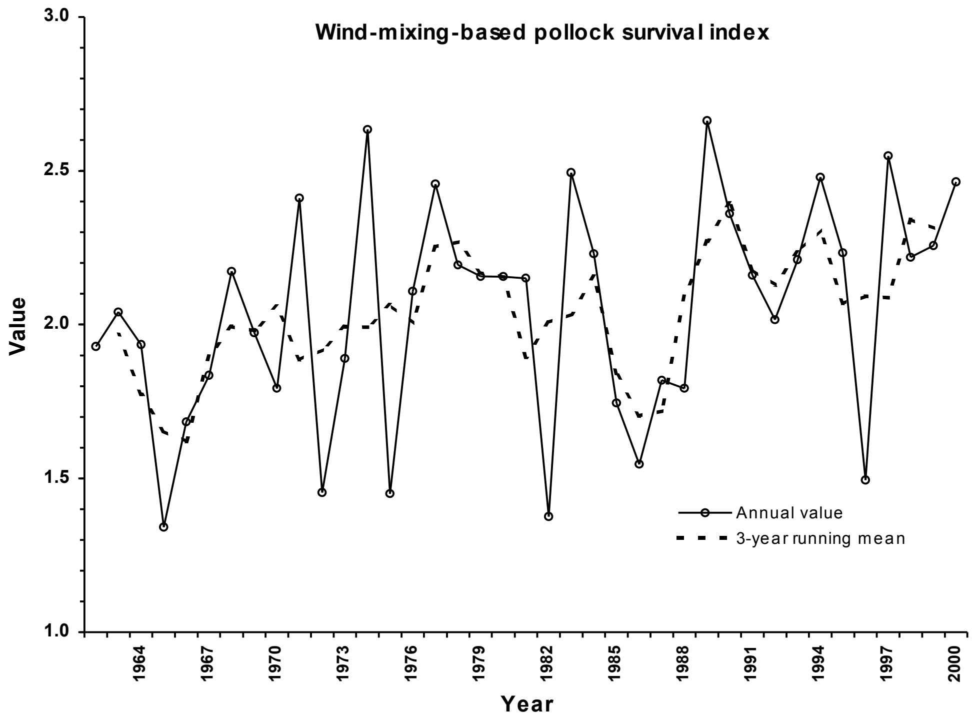

Fig. 18 Index of pollock survival potential based on estimated wind mixing energy at a location south of Shelikof Strait from 1962 through 2000. The solid line shows annual values of the index; the dashed line is the 3-year running mean.

Eastern Bering Sea

Sea ice extent and timing

The extent and timing of seasonal sea ice over the Bering Sea shelf plays an important role, if not the determining role, in the timing of the spring bloom and modifies the temperature and salinity of the water column. Sea ice is formed in polynyas and advected southward across the shelf. The leading edge continues to melt as it encounters above freezing waters. The ice pack acts as a conveyor belt with more saline waters occurring as a result of brine rejection in the polynyas and freshening occurring at the leading edge as the ice melts. Over the southern shelf, the timing of the spring bloom is directly related to the presence of ice. If ice is present in mid-March or later, a phytoplankton bloom will be triggered that consumes the available nutrients. If ice is not present during this time, the bloom occurs later, typically during May, after the water column has stratified.

The presence of ice will cool the water column to 1.7°C. Usually spring heating results in a warm upper mixed layer that caps the water column. This insulates the bottom water, and the cold water (<2°C) will persist through the summer as the "cold pool". Fish, particularly pollock, appear to avoid the very cold temperatures of the cold pool. In addition, the cold temperatures delay the maturing of fish eggs and hence affect their survival.

Figure 19 shows the presence of ice over the southeastern shelf between 57°N and 58°N during the last 28 years. Figure 19 is divided into three panels, each representative of a climate regime: 1972-1976 ice conditions occurred during a cold PDO phase, 1977-1989 during a warm PDO and AO phase, and the years hence which seem to be in an intermediate regime reflecting a warm PDO and a cold AO. The possible change in the PDO that may have occurred about 1997 is reflected in the extreme ice conditions observed in 2000. During the first regime ice was common over this part of the shelf. In the warm period thereafter, ice was less prevalent. Since then, ice has been more persistent but not as extensive as it was prior to 1977. Recently, 2000 had the most extensive seasonal sea ice pack since 1976. There appears to be a slight reduction in ice cover during El Niño years, but the relationship is weak.

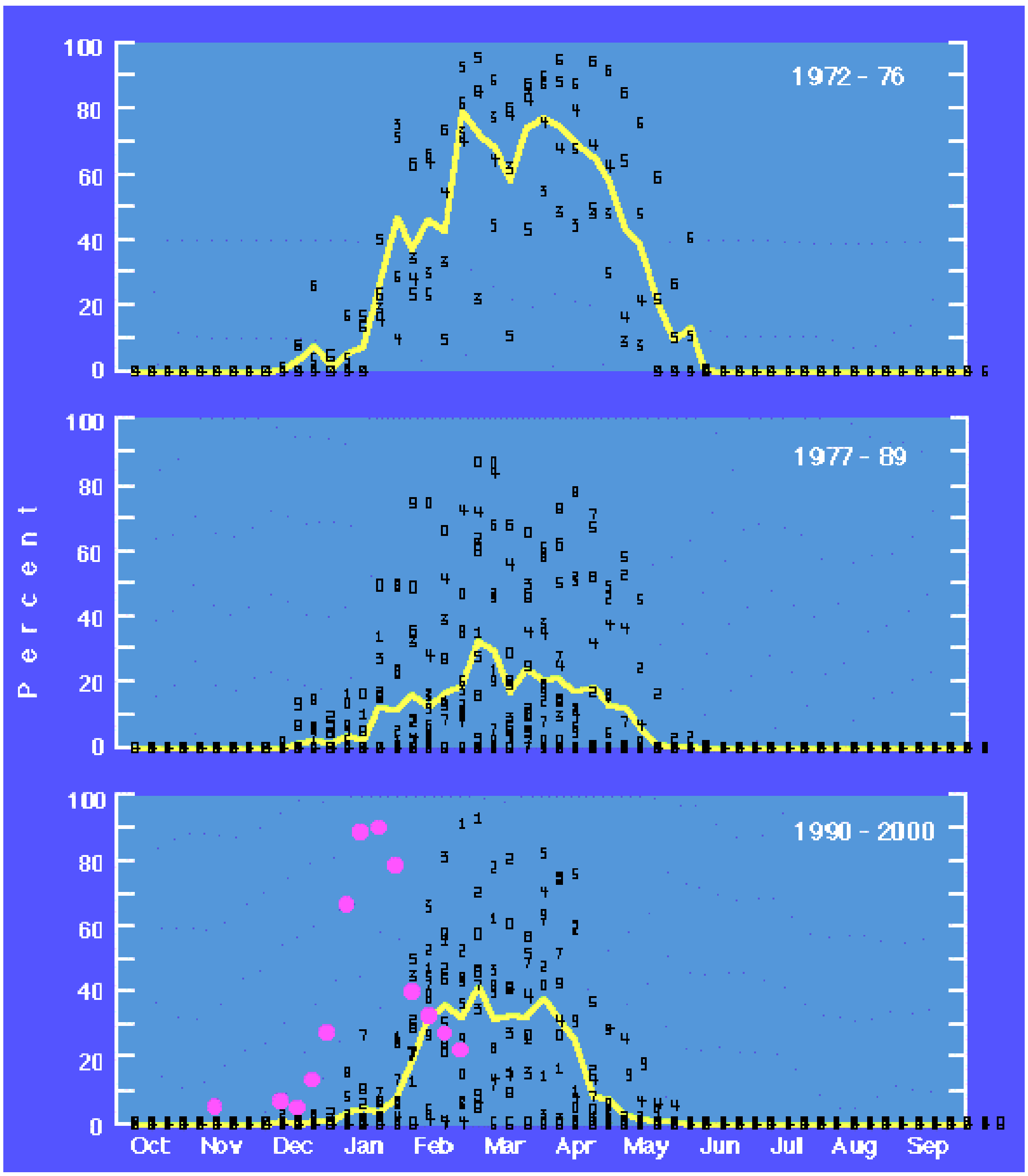

Fig. 19 Percent ice concentration over the southeastern Bering Sea shelf between 57°N and 58°N from 1972 through 2000. The pink dots in the lowest panel are for 2000.

Mooring 2: The cycle in the middle shelf

The cycle in water column temperatures is similar each year. In January, the water column is well mixed. This condition persists until buoyancy is introduced to the water column either through ice melt or solar heating. The very cold temperatures (shown in black in Figure 20) that occurred in 1995, 1997, 1998 and 1999, resulted from the arrival and melting of ice. Shelf temperature during 1999 was the coldest, well below 1995 and 1996, and approaching the cold temperatures of the negative PDO phase of the early 1970s. During 1996, ice was present for only a short time in February, however no mooring was in place. A phytoplankton bloom occurs with the arrival of the ice pack in March and April. If ice is not present during this period, the spring bloom does not occur until May or June, as in 1996 and 1998. Generally, stratification develops during April. The water column exhibits a well-defined two-layer structure throughout the summer consisting of a 15 to 25 m wind-mixed layer and a 35 to 40 m tidally mixed bottom layer (the cold pool if temperatures are sufficiently low). Deepening of the mixed layer by strong winds and heat loss begins in August, and by early November the water column is again well mixed.

The depth of the upper mixed layer and the strength of the thermocline contribute to the amount of nutrients available for primary production. A deeper upper mixed layer makes available a greater amount of nutrients. In addition, a weak thermocline (more common with a deeper upper mixed layer) permits more nutrients to be "leaked" into the upper layer photic zone and thus permits prolonged production. The temperature of the upper layer influences the type of phytoplankton that will flourish. For instance, warmer sea surface temperatures (>11°C) during 1997 and 1998 may have supported the coccolithophorid bloom.

Timing of the last spring storm

One of the striking features of the atmosphere during 1997 and 1998 was a change in the timing of the last storm and strength of summer mixing over the eastern Bering Sea. This ecosystem is particularly sensitive to storms during May. The spring bloom strips nutrients from the upper layer, and the stability of the water column isolates nutrients in the lower layer. Thus mixing and deepening of the upper mixed layer by storms in mid-to late May provide important nutrients for continuation of blooms into summer. June and July storms are less effective mixers because they are weaker and the thermocline has strengthened. May storms also lessen the density difference between the two layers (entraining denser water into the upper layer), thus permitting subsequent minor mixing events to supply nutrients into the photic zone. From 1986 to 1996, the weather during May was particularly calm; during May 1999, winds were again light. By contrast, May of 1997 and 1998 were characterized by strong individual wind events (Fig. 21). These storms presented a pathway for greater nutrient supply, more prolonged primary production, and weaker stability of the water column than observed between 1986 and 1996, and in 1999. In addition to stronger

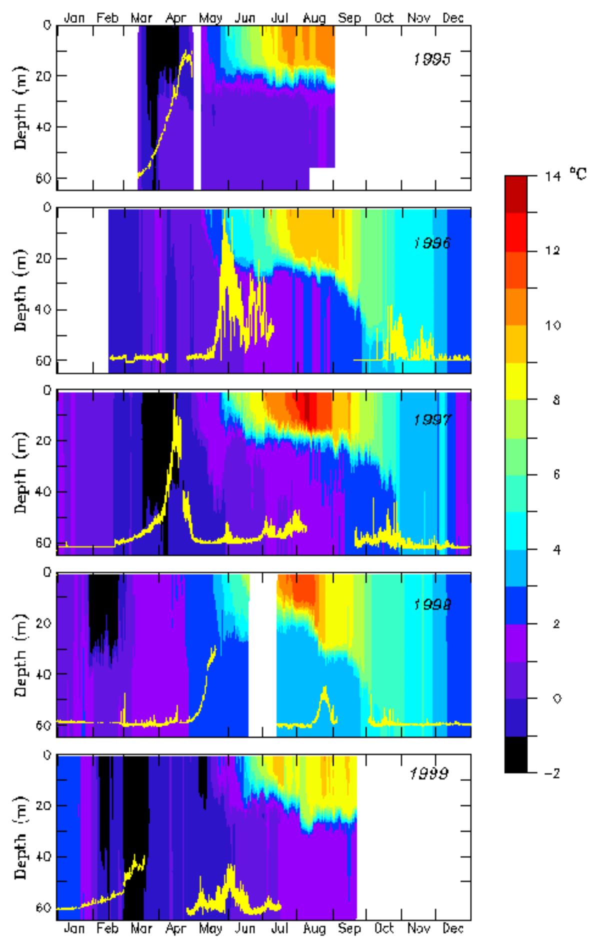

Fig. 20 Ocean temperature (°C) as a function of depth (m) and time (month of year) and fluorescence as a function of time measured at mooring site 2 during 1995 through 1999.

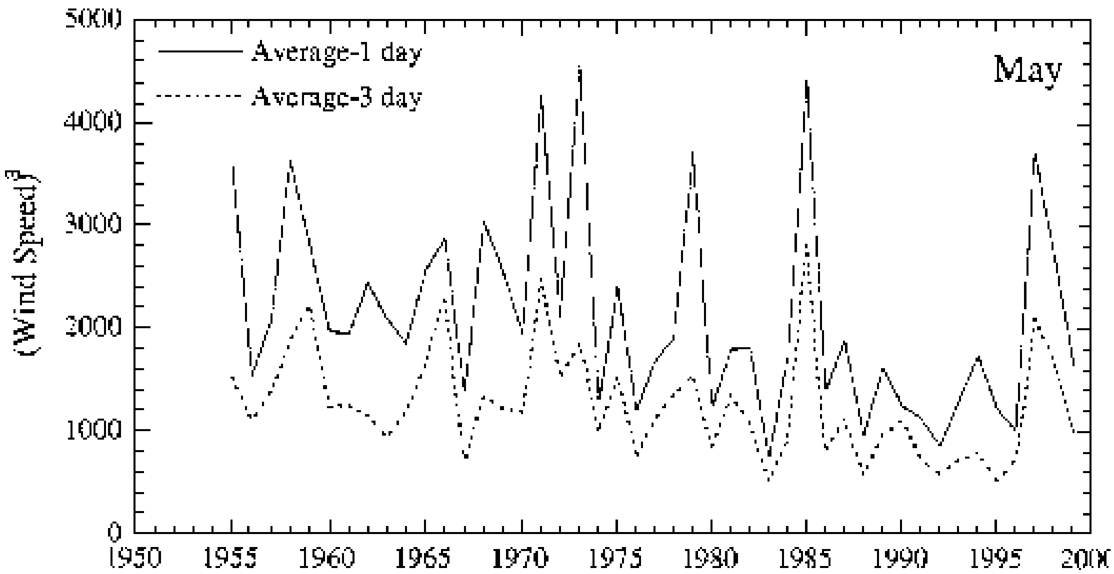

Fig. 21 Cube of wind speed (proportional to wind mixing energy) measured at St. Paul, Alaska. The solid line is the daily average; the dashed line is the 3-day average.

winds in May, the summers of 1997 and 1998 had the weakest mean wind speed cubed (a measure of mixing energy) since at least 1955. This allowed for a shallow mixed layer and thus higher sea surface temperatures. A pattern of late spring storms and weak summer winds could change the phytoplankton community. If production is prolonged into summer, the total productivity of the shelf could be enhanced, thereby affecting higher trophic levels.

Cross-shelf advection

Each spring and summer over the Bering Sea shelf, approximately half the nutrients are consumed. These nutrients apparently are replenished during winter and early spring. Cross shelf advection moves nutrient-rich basin water onto the shelf. A reduction of onshelf flow will reduce the available nutrients and thus productivity of the shelf. Understanding and monitoring the mechanisms that induce cross shelf flow are critical to management of the Bering Sea's living resources.

During the last ten years, FOCI released more than 100 satellite-tracked drift buoys in the Bering Sea. Prior to 1996, drifters deployed in the southeastern corner of the Bering Sea typically revealed persistent northwestward flow along the 100-m isobath, with cross-shelf flow occurring intermittently. In 1997, 1999 and 2000, flow along the 100-m isobath was weak or nonexistent, and there were no occurrences of onshelf flow. Flow patterns in 1998 are less well known as no drifters were deployed that year. Indices of onshelf flow and strength of the 100-m-isobath flow are derived from trajectories of the satellite-tracked drifters. Such indices are important in determining changes in flow patterns, particularly if there has been a climate regime shift as some scientists believe occurred in 1998.

FOCI time-series

FOCI has six long-term monitoring operations in the Gulf of Alaska, seven in the Bering Sea, and 21 years of hydrodynamic model results from Shelikof Strait. These are summarized in Table 5. The first is Line 8, a series of seven stations across the southwestern end of Shelikof Strait. This line has been occupied at least once each year since 1985. Measurements taken there include CTD, fine-mesh net (bongo) tows, and water samples for nutrients, chlorophyll and macrozooplankton. In some years, FOCI also deployed moorings along line 8. The second long-term measurement is a survey of abundance and distribution of late-stage pollock larvae. This survey takes place during late May and early June and has been conducted continuously since 1987, with surveys also in 1982 and 1985. Besides pollock larvae, all other contents of bongo tows are also preserved and identified. Additional measurements include water temperature and salinity. Shelikof Strait transport is measured from moorings and satellite-tracked drifters, and also inferred from a biophysical circulation and individual-based (IBM) model. Finally, FOCI has measured flow in the Alaska Stream at locations ranging from Kodiak Island to the Aleutian Islands using ship-mounted acoustic Doppler current profiles. There are also seven years when moorings were placed in the Alaska Stream. Time-series from long-term monitoring have been invaluable to FOCI in meeting its scientific and operational goals.

Beginning in about 1992, FOCI began systematic monitoring in the southeastern Bering Sea. Some measurements are available from earlier periods. The primary observations that are taken from three moorings (two on the shelf and one in the basin) and from three CTD survey locations (one across the shelf, one along the 70-m isobath, and one in Unimak Pass). In addition, transport estimates are available from satellite-tracked drifters and moorings deployed in the region since 1992.

In order to bring its science to the public table, FOCI synthesizes results from long-term measurements, process studies, and models. One result of this synthesis is a conceptual model of pollock recruitment for Shelikof Strait. The model emphasizes the environmental factors that affect the survival of pollock as they pass through their early developmental stages. Examples of these factors are climate, circulation, wind mixing, and potential for eddies. It is these elements that contribute to FOCI's pollock recruitment forecast. The annual prediction is used by the National Marine Fisheries Service (NMFS) to establish recruitment scenarios for their stock projection model. Results from that model and other information produce a quota recommendation that NMFS delivers to the NPFMC. The forecast procedure is refined as FOCI learns more about the processes that determine recruitment. FOCI presently is working with NMFS to incorporate the forecast mechanism directly into the stock projection model. FOCI's Bering Sea program is about to establish a similar forecast for that region.

FOCI has developed a spatially explicit, individual-based (probabilistic) model of egg and larval development for the purpose of hindcasting the early life history of a population of walleye pollock near Shelikof Strait. Such comparative hindcasts are used to suggest possible physical mechanisms contributing to interannual variability in recruitment success. The behaviorally modified float-tracking algorithm for each individual uses daily velocity, salinity and temperature fields generated by a wind- and buoyancy-forced, 3-D hydrodynamic model. The individual-based biological model includes processes such as consumption, energetics and growth, which differ by life stage (e.g., eggs, yolk-sac larvae, feeding larvae, and juveniles). Representative years for hindcasts are chosen to span the observed range of interannual variability in meteorological conditions and recruitment success. Interannual differences in wind and freshwater runoff lead to interannual differences in the modeled spatial paths of individuals (e.g., their retention in mesoscale eddies), and the distribution of weights and lengths among the survivors. Model output from the circulation model is available for the years 1978 through 1999 and will be updated annually.

Other time-series

FOCI and PMEL have other data series that could be useful for examining climate change in the North Pacific Ocean (Table 6). For example, a data rescue project is currently in progress to archive more than 5,000 historical CTD and X-BT casts from the Northeast Pacific Ocean dating back to 1932. Climate studies at PMEL use the long-term Sitka air temperature time series. This series is of 5-month, winter-averaged (November-March) air temperature measured at Sitka, Alaska, since 1829. The North Pacific Index (NPI) is the average sea-level pressure over the North Pacific during January and February. This index dates back to 1899. Terry Whitledge at the University of Alaska Fairbanks has estimates for Bering Sea productivity (nutrients, chlorophyll, plankton) from the PROBES and modern eras. PMEL's tsunami group maintains a series of bottom-pressure recorders at various sites in the North Pacific. Records begin in 1986 and the sensors

Table 5 FOCI data series and other products.

Series Name	Location	Variables Measured	Times of Observation
Line 8	Seven stations across the SW end of Shelikof Strait	Ocean temperature, salinity, currents, nutrients, chlorophyll, zooplankton including pollock larvae	1985 to present; most measurements in spring
Late larval survey	Western Gulf of Alaska shelf from Shelikof Strait to the Shumagin Islands	Abundance and distribution of pollock larvae and additional species, water temperature profiles, other water properties	1982, 1985, 1987 to present in late May and early June; 1986 in early May
Shelikof Strait ocean transport	Alaska Coastal Current in western Gulf of Alaska	Drifter trajectories, currents from some moorings	1985 to present, winter, spring, summer
Shelikof Strait wind mixing	Southwest end of Shelikof Strait	Wind mixing energy estimates determined from synthetic winds	Monthly since 1962
Kodiak precipitation	Kodiak, Alaska	Monthly averaged measured rainfall	Monthly since 1962
Alaska Stream	Kodiak Island to the Aleutians	Current profiles from vessel-mounted ADCP and moorings	1987 to present, usually in May
Mooring 2	Bering Sea middle shelf	Winds and currents, temperatures, salinity, chlorophyll, nitrates	Near continuous since 1995
Mooring 3	Bering Sea middle shelf	Winds, currents, temperatures, salinity, chlorophyll, nitrates	1995-1999 spring and summer
Mooring 6	Bering Sea basin north of Umnak Is.	Currents, temperatures, salinity, chlorophyll, nitrates	Near continuous since 1996
Cross-shelf survey	Southeastern Bering Sea	CTD, nutrient, phytoplankton and zooplankton samples	Winter, spring, fall since 1996
Along-shelf survey	Southeastern Bering Sea (70-m isobath)	CTD, nutrient, phytoplankton and zooplankton samples	Winter, spring, fall since 1997
Unimak Pass survey	Unimak Pass, Aleutian Islands	CTD, some nutrients, phyto- and zooplankton	At least annually since 1995
Bering Sea ocean transport	Bering Sea	Drifter trajectories, currents from some moorings	1992 to present, mostly during spring
Shelikof Strait hydrodynamic model	Shelikof Strait region, Gulf of Alaska	Modeled currents, salinity at 40 m	1978-1999

sample at least once per minute. Low-frequency instrument drift could interfere with detection of climate-scale signals. PMEL was part of a collective effort under the National Ocean Parthership Program (NOPP) to observe ocean characteristics at Ocean Station Papa (50°N, 145°W) during 1998 and 1999, and at station Mama (35°N, 165°W) during 1999. Measurements included atmospheric pressure, winds, temperature, radiation, rainfall, humidity, oceanic currents, temperatute and salinity. At Station P, chemical and biological instruments also sampled the water column. PMEL's VENTS programs has monitored ocean character in the vicinity of the Juan de Fuca and Gorda submarine ridges off the coast of Oregon since 1989. This list is not exhaustive. Other data series are available that are not mentioned here.

Table 6 Other time-series and observations.

Series Name	Location	Variables Measured	Times of Observation
North Pacific CTDs	Northeast Pacific	Temperature, (salinity), depth	1932 to present
Sitka air temperature	Sitka, Alaska	Air temperature	1829-present
North Pacific Index (NPI)	North Pacific	Average sea-level pressure during January and February	1899-present
Bering Sea productivity	Southeastern Bering Sea	Nutrients, chlorophyll, plankton	1977-1981 1997-2001
Bottom Pressure	Various stations in the North Pacific	Ocean bottom pressure	1986 to present
Ocean Stations Papa and Mama	(50°N, 145°W) and (35°N, 165°W)	Meteorological and oceanic parameters	1998 & 1999; 1999
VENTS Hydrogaphy	Juan de Fuca and Gorda Ridges	Temperature, salinity, depth	Various times since 1989

Gridded atmospheric re-analysis fields

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A major resource for the study of climate variability of the North Pacific is the re-analyses fields for 1948 to present, generated by the National Centers for Environmental Prediction (NCEP). In a re-analysis, an atmospheric forecasting model is run for an extended period with no changes to the physical parameterizations. Observational data from satellites, radiosondes, pilot reports and ground stations are assimilated into the model. For basic atmospheric data such as temperatures and pressures, one can think of the re-analysis as a dynamic interpolation method where the model is used to extrapolate information into data sparse regions and to make sure that the analysis are internally consistent. The model output goes beyond dynamic interpolation to provide secondary derived fields of quantities such as radiation and sensible heat flux fields and diagnostic terms such as vorticity, stream functions and various correlations. 23 variables and 9 anomaly fields are available on 17 pressure levels from 1000 to 10 mb. These include geopotential heights, temperatures, humidity and winds. 48 variable fields and 15 anomaly fields are provided at one level. These include: net and upward long wave and short wave flux at the surface and top of the atmosphere, surface sensible and latent heat flux, and precipitation rate. Secondary variables may not be as accurate as the primary variables, but because the model physics has not changed over the length of the run, they provide a major source of information for comparing spatial patterns of fluxes over decadal time scales. Data are available four times a day, as daily means and as monthly means. Data are available at the NCEP web site "wesley.wwb.noaa.gov/ncep_data/index.html". This site also provides graphics capability and various smoothing formats for displaying fields. FERRET and other programs are designed to work with the data set. Figure 22 was produced at the website showing the 1000 mb geopotential height anomaly field for February 2001. Low heights (low sea level pressure) over the western Bering Sea and high heights (high pressure) in the Gulf of Alaska gave strong southwest winds and warm temperatures over the eastern Bering Sea and Alaska.

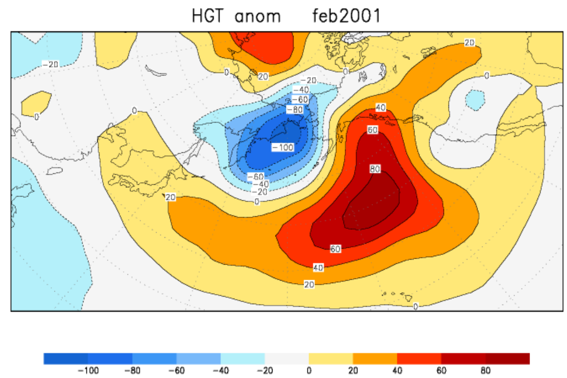

Fig. 22 The geopotential height anomaly field for February 2001 in the Pacific region.

Research on the physical-biological-chemical coupled numerical model in China

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This report introduces research on physical-biological-chemical coupled numerical model and the 3-D baroclinic current model in China, and the Yellow Sea database.

3-D marine ecosystem numerical model

Based on the China-Japan cooperation from 1997-2000, a 7-component physical-biological-chemical coupled numerical model was developed in two steps. First, following two marine mesocosm experiments in the Yangtse River estuary area in October 1997 and May 1998, a 1-D biological-chemical model, which includes nitrogen, phosphate, silicon, flagellate, diatom and detritus, was created, and the model results were compared with *in situ* data (Fig. 23). Second, zooplankton was added to the above model, and the model was combined with a 3-D physical model of Jiaozhou Bay. Located 400 km from Qingdao, this bay is one of two marine ecosystem stations in China. With this 3-D 7-component coupled model, we simulated 4 years of observations and compared them with observations at 10 stations in the bay (Fig. 24).

3-D baroclinic current model of the coastal seas of China and adjacent North Pacific

Currents play an important role in transport of marine ecosystem elements and water temperature directly influences the ecosystem. A 3-D baroclinic current model, mainly focused on the coastal seas of China and adjacent North Pacific, was developed based on the Princeton Ocean Model (POM). The comparison of model results with observations shows our ability to predict physical elements in the North Pacific region (Fig. 25).

Yellow Sea data set

Six comprehensive cruises covering the whole Yellow Sea were carried out from the spring of 1996 to the fall of 1997. Collected data cannot be released until December 2002. A list of cruises is given below (location of sampling stations is shown in Figure 26):

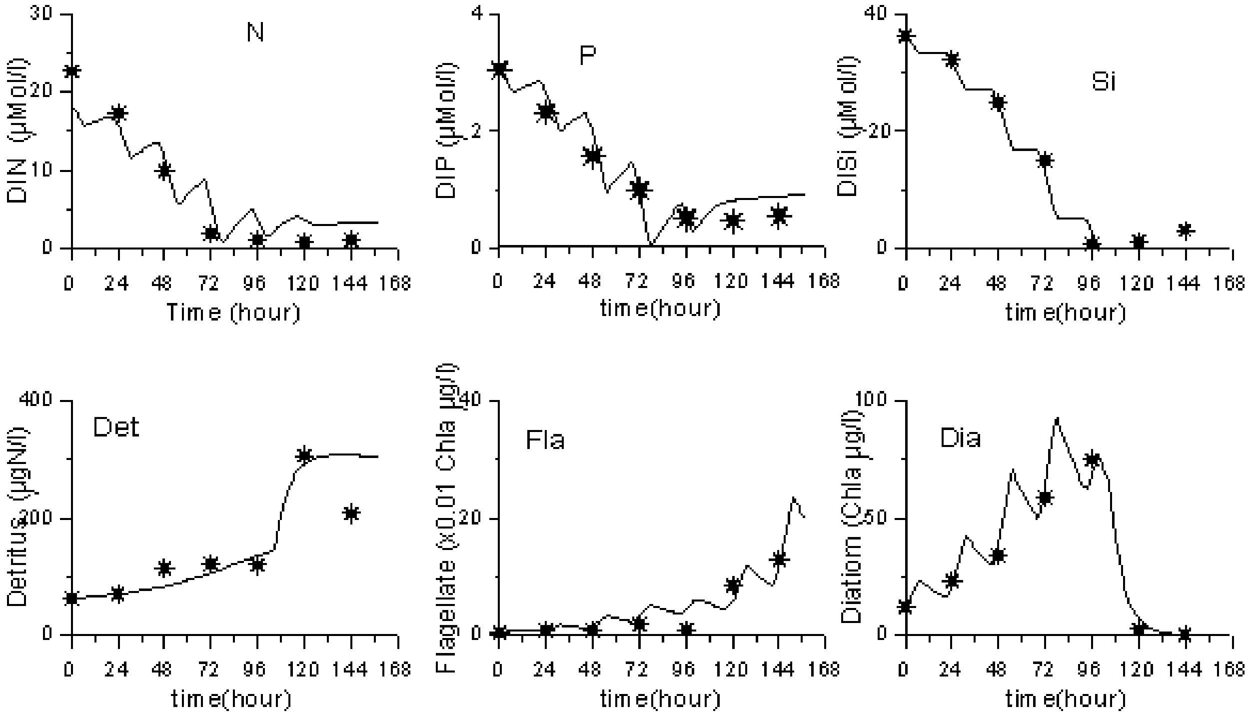

Fig. 23 Comparison of *in situ* observations in Jiaozhou Bay and results from a 1-D 6-component coupled ecosystem model (time from 09:00 (GMY08) on October 11, 1997).

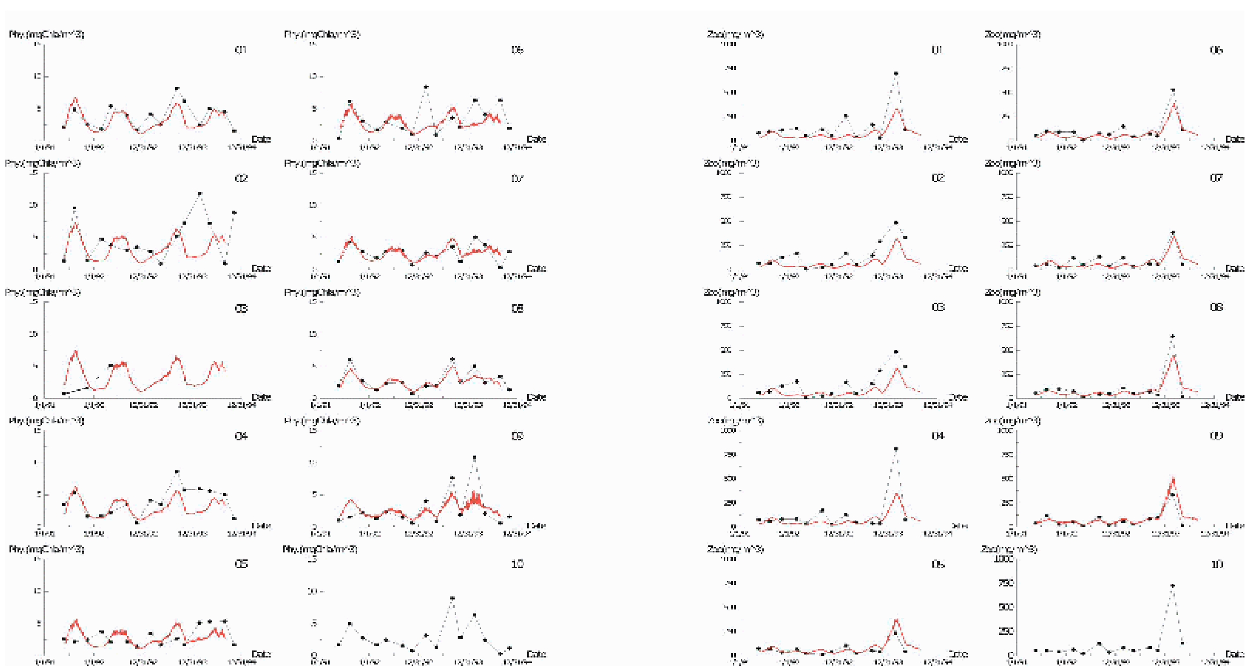

Fig. 24 Comparison of observations in Jiaozhou Bay and results from a 3-D (Princeton Ocean Model) 7-component coupled ecosystem model for phytoplankton (left panel) and zooplankton (right panel). Red lines show model results and black lines show observed data.

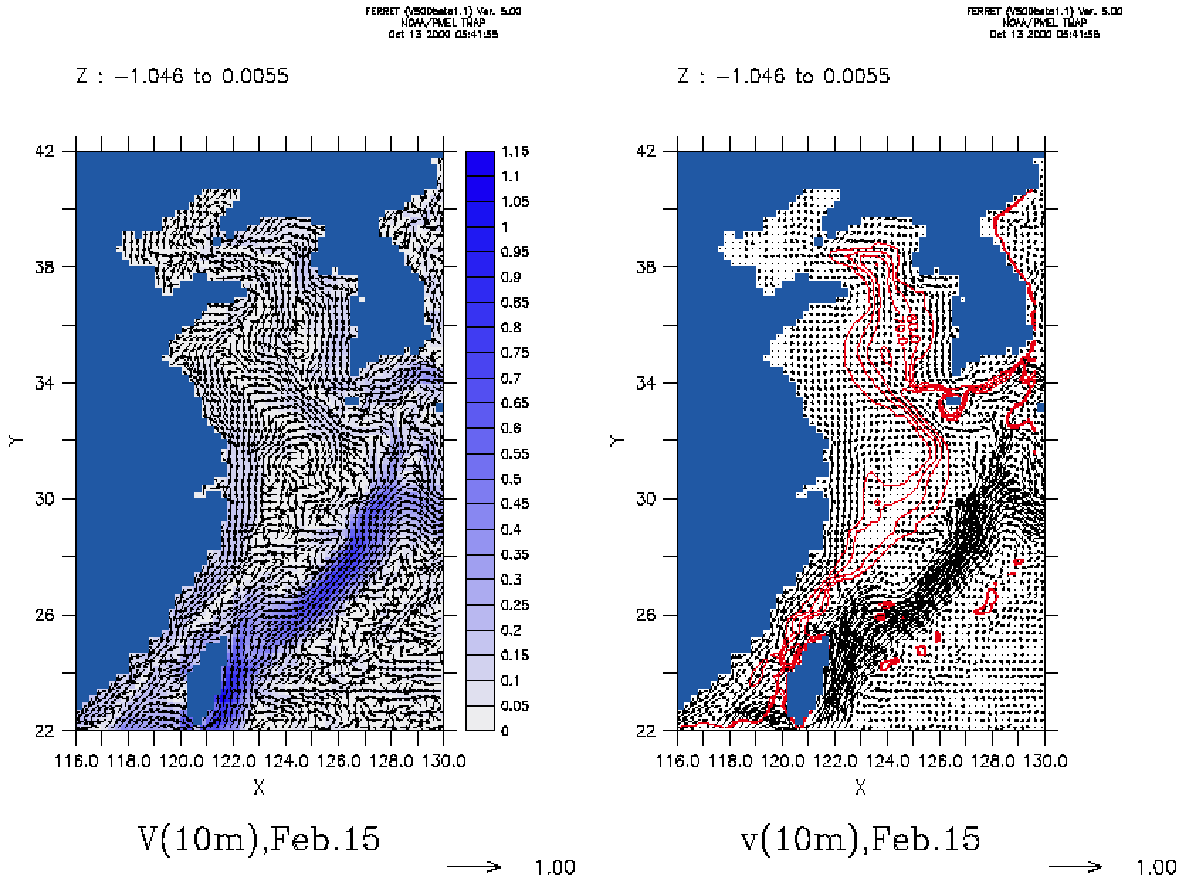

Fig. 25 Comparison of observations in the coastal seas of China and adjacent North Pacific and results from 3-D baroclinic current model for phytoplankton (left panel) and zooplankton (right panel). Red lines show model results and black lines show observed data.

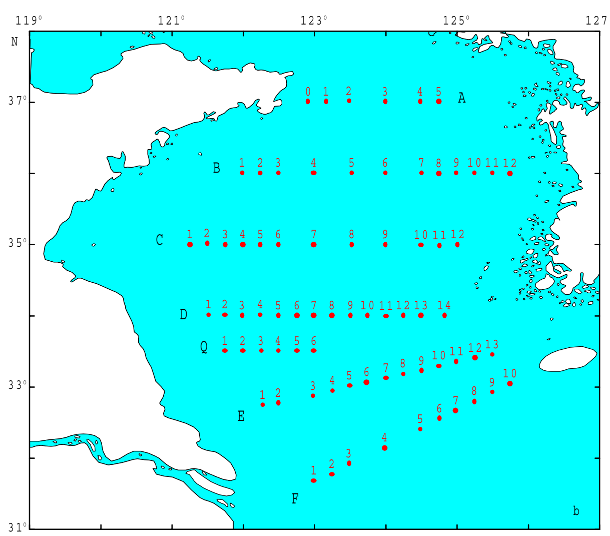

Fig. 26 Cruise tracks in the Yellow Sea.

1.1 spring of 1996: CTD (71 stations), ADCP, chemical and biological observations (71 stations);

1.2 fall of 1996: CTD (79 stations), ADCP, chemical and biological observations (79 stations);

1.3 summer of 1997: CTD (73 stations), ADCP, chemical and biological observations (73 stations);

1.4 winter of 1997: CTD (69 stations), ADCP, chemical and biological observations (69 stations); and

1.5 spring of 1998 CTD (69 stations), ADCP, chemical and biological observations (69 stations).