REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average one hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden to Washington Headquarters Services. Directorate for Informtion Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. and to the Office of Management and Budget. Paperwork Reduction Project (0704-0188). Washington, DC 20503.

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1. REPORT DATE (DD-MM-YYYY)
10/08/2001

2. REPORT TYPE
Final

3. DATES COVERED (FROM - TO)
02/15/1999-02/14/2001

4. TITLE AND SUBTITLE
Optical SOLO Autonomous Profiler Development and Operation

Deployment in the Japan-East Sea

5a. CONTRACT NUMBER

5b. GRANT NUMBER
N00014-99-1-0348

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER

5e. TASK NUMBER

5F. WORK UNIT NUMBER

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8. PERFORMING ORGANIZATION REPORT NUMBER
99-1258

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
Attn: Joan S. Cleveland
Ballston Centre Tower One
800 North Quincy Street
Arlington, VA 22217-5660

10. SPONSOR/MONITOR'S ACRONYM(S)
ONR

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
Approved for Public Release; distribution is Unlimited

20010918 083

13. SUPPLEMENTARY NOTES
See attachments.

14. ABSTRACT
We developed a unique system, called K-SOLO, that is an integration of the Sounding Oceanographic Lagrangian Observer (SOLO) and a profiling 3-wavelengh downwelling irradiance (Ed) sensor (Biospherical Instruments PER-300). The system measures temperature and allows calculation of spectral diffuse attenuation coefficients (K) at 380, 490 and 555 nm from the depth derivative of downwelling irradiance (e.g. K = -1/Ed dEd/dz). Data is relayed via satellite when the unit is on the surface. By measuring K rather than absolute radiometric quantities or inherent optical properties, the system is not sensitive to changes in calibration or bio-fouling. K-SOLO was deployed from R/V Khromov in the Sea of Japan near 41° N and 134° E in March, 2000 and transmitted profiled data every second day until the middle of August, 2000. The unit was caught by a Japanese fishing vessel and recently returned to SIO. The SOLO unit suffered major damage and can not be re-utlized. The radiometer is being assessed.

15. SUBJECT TERMS
ocean optics, diffuse attenuation coefficient, autonomous profiling, Japan-East Sea, ocean color remote sensing, phytoplankton, CDOM

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER (Include area code)
Unrestricted	Unrestricted	Unrestricted	None	5	B. Greg Mitchell / (858) 534-2687

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI-Std Z39-18

Final Report

Optical SOLO Autonomous Profiler Development and Operational Deployment In The Japan-East Sea

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Award Number: N00014-99-1-0348, Modification P00002

LONG-TERM GOALS

To develop an inexpensive, autonomous optical profiling system for spectral diffuse attenuation coefficients (K-SOLO) that is independent of calibration errors and to develop models for estimating inherent and apparent optical properties of the ocean from K determined for 3 wavelengths. To quantify the influence of phytoplankton absorption on mixed layer heating during spring stratification.

OBJECTIVES

Our objectives were to develop and deploy an autonomous temperature and optical profiling system in the Japan (East) sea to characterize the spring bloom in the deeply mixed waters of the Japan Basin. The experiment was designed as a proof-of-concept of the integration of simple, low power optical systems to existing autonomous profilers, to characterize the phytoplankton spring bloom and quantify the role of phytoplankton absorption on thermal forcing during spring stratification.

APPROACH

Figure 1 illustrates the primary design elements of K-SOLO. The principles of autonomous Lagrangian drift profilers have been described elsewhere (Davis et al., 1992). SOLO (Sounding Oceanographic Lagrangian Observer) is a simple system that uses a single stroke piston to force hydraulic oil into or out of a sealed, hydraulic bladder. By changing volume, SOLO can change density and therefore can achieve repetitive vertical profiles. Most deployments of SOLO (or predecessor instruments) have been limited to observations of temperature, salinity, or both. Recently SOLO has also been interfaced to microstructure profilers to study the upper ocean mixing processes (Sherman and Davis, 1995). We integrated a Biospherical Instruments PER 300 3-channel irradiance (Ed) sensor to SOLO. K-SOLO was programmed to descend to a nominal depth

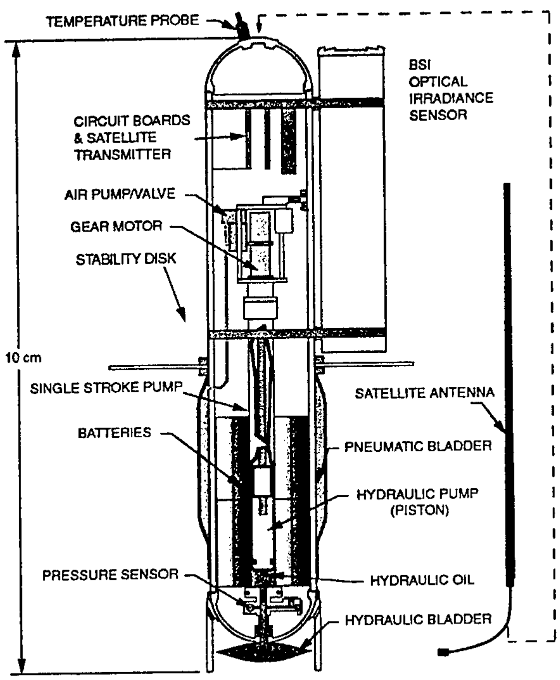

Figure 1. Diagram of the Sounding Oceanographic Lagrangian Observer developed by the Scripps Instrument Development Group, integrated to a Biospherical Instruments PER 300 3-channel (380, 490, 555 nm) downwelling irradiance sensor. K-SOLO changes buoyancy by pumping hydraulic oil into or out of the hydraulic bladder to accomplish the vertical profiling of temperature and irradiance.

of 400 m, and then to accomplish a vertical profile to the surface near noon, to spend 24 hours on the surface transmitting data via System ARGOS on the NOAA polar orbiter satellites, descend to 400 m, and repeat the cycle every two days. Data are collected only on the up-cast and K-SOLO was programmed to ascend near mid-day so that it would acquire data close in time to NASA's SeaWiFS ocean color satellite (nominal equatorial crossing is noon). Data on K-SOLO are acquired at several Hz, but are binned at 5 m resolution in the upper 100 m, and 10 m resolution below 100 m. Temperature data are binned by the numerical mean. Irradiance data are log-transformed, and a linear regression is used over a ± 5 m window (e.g. 10 m total) to interpolate depth-binned irradiance. Spectral channels for the PER 300 are 380, 490 and 555 nm.

After transmission, data profiles were analyzed to estimate spectral K, the depth derivative of the attenuation coefficient ($K = -1/E_d \, dE_d/dz$). By estimating K over short distances (10 m), the estimates are therefore made at very short time scales (a few minutes). Thus, long-term calibration changes caused by biofouling, or opto-electronic changes are not of consequence. Of course since K is an apparent optical property, environmental issues like wave focusing, partly cloudy skies, etc. do perturb the signal. However, in the case of clear or uniformly overcast skies, the E_d profiles are very smooth, and hence the derived K values are quite robust.

WORK COMPLETED

Following our design and development of K-SOLO in year 1, we built and deployed the system in the second and final year of this project. The system is an integration of SOLO and a profiling 3-wavelengh downwelling irradiance (Ed) sensor (Biospherical Instruments PER-300). K-SOLO measures temperature and allows calculation of spectral diffuse attenuation coefficients (K) at 380, 490 and 555 nm from the depth derivative of downwelling irradiance. Data is relayed via satellite when the unit is on the surface. K-SOLO was deployed in the Sea of Japan near 41° N and 134° E from R/V Khromov by Russian colleagues from the Far East Hydrometeorological Research Institute and the Pacific Oceanological Institute.

RESULTS

Figure 2 provides example profiles of temperature and E_d at 380, 490 and 555 nm. The first profile transmitted for March 11, 2000 indicated very clear waters, with K(490) less than 0.04 m^{-1}, and an almost uniformly mixed upper 200 m surface layer with a temperature of 1.25° C. Temperature profiles indicated isothermal conditions extended > 400 m (data not shown). By May, significant thermal stratification had reduced the mixed layer to less than 20 m and a phytoplankton bloom developed as indicated by the more rapid attenuation of light in the near-surface.

The time series of SeaWiFS-derived K490 and K-SOLO estimates of K490 were generally in good agreement (Mitchell et al., 2000). K-SOLO overestimated the SeaWiFS values by approximately 20-30% initially, but from mid-April through mid-May there was excellent agreement during development of the spring phytoplankton bloom. After June, K490 derived from SeaWiFS and K-SOLO declined, presumably due to nutrient exhaustion and loss of the phytoplankton in the stratified surface waters by sinking and/or grazing.

The vertical structure of the temperature and K490 time-series from K-SOLO is shown in Figure 3a and 3b, respectively. Weak thermal stratification that caused the mixed layer to shoal to about 75 m is evident by early April (day 100 of the year). By day 125 the mixed layers shoaled to less than 25 m and stratification intensified through the remainder of the observation period. A large bloom of phytoplankton indicated by a change in K490 from ~0.07 to 0.15 m^{-1} appeared rapidly after day 125 and remained strong through about day 150. K490 ≈ 0.15 m^{-1} corresponds to approximately 2-3 μg chlorophyll per liter according to the model of Mitchell and Kahru (1998). After day 150 surface temperatures continued to increase, and the surface K490 declined, but a sub-surface maximum in K490 persisted. The magnitude of K490 through the end of the record after day 200 indicates a decline in phytoplankton biomass as the "biological pump" exports the nutrients to depth over time.

Initially, K-SOLO circulated within a small radius of approximately 50 km until late May. Then the track of K-SOLO moved east along a front of high chlorophyll water that defined the boundary between waters north and south of the sub-polar front. The surface bloom observed by K-SOLO in May (Figure 3b) was evident as a large feature in the central Sea of Japan in the SeaWiFS GAC composite for May 2000. In June, SeaWiFS data indicate that the large surface bloom subsided, consistent with the time series from K-SOLO. The combined vertical resolution of K-SOLO and surface maps from satellite will be used to characterize the time series of the spring bloom and the role of phytoplankton absorption on thermal stratification following the deep convective winter mixing in the northern basins of the JES.

IMPACT/APPLICATIONS

The K-SOLO system we developed and deployed will have an important impact by demonstrating the concept of acquiring optical properties in the ocean using low cost autonomous profiling systems. The autonomous capability allows the system to provide data for extended periods of time in regions of interest without the need for ship support. The channel at 490 nm provided direct measurement of K490 that is independent of ship shadow effects and serves as an ideal validation tool for K490 derived from satellite. Our successful demonstration deployment will define a new option for SOLO configuration in the future. Deployment of this system will prove valuable in diverse applications including autonomous optical observation in regions with difficult access and global validation of ocean color remote sensing products. In particular, K-SOLO will be the most

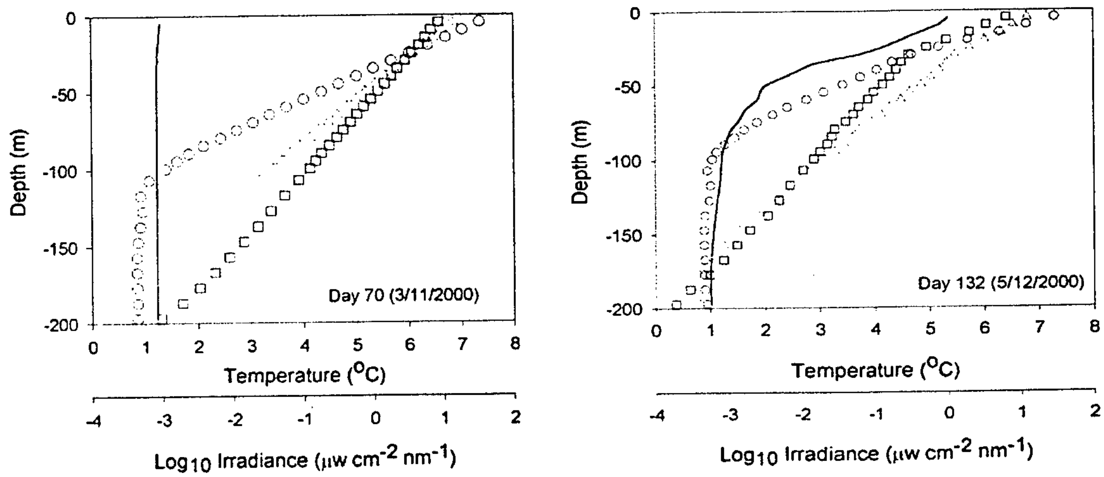

Figure 2. Vertical profiles of temperature (—) and irradiance at three wavelengths (380 m - O; 490 nm - □; 555 nm - △) transmitted by KSOLO for A. March 11 and B. May 12, 2000. Initially there was very minor stratification in the top 20 m and water column temperatures were near 1.25° C. Subsequent profiles during March indicated minimal changes in diffuse attenuation coefficients determined from KSOLO. By May, strong thermal stratification was evident and the diffuse attenuation coefficients in surface waters were greater, as indicated by the rapid decline in irradiance with depth near the surface for the May 12 profile.

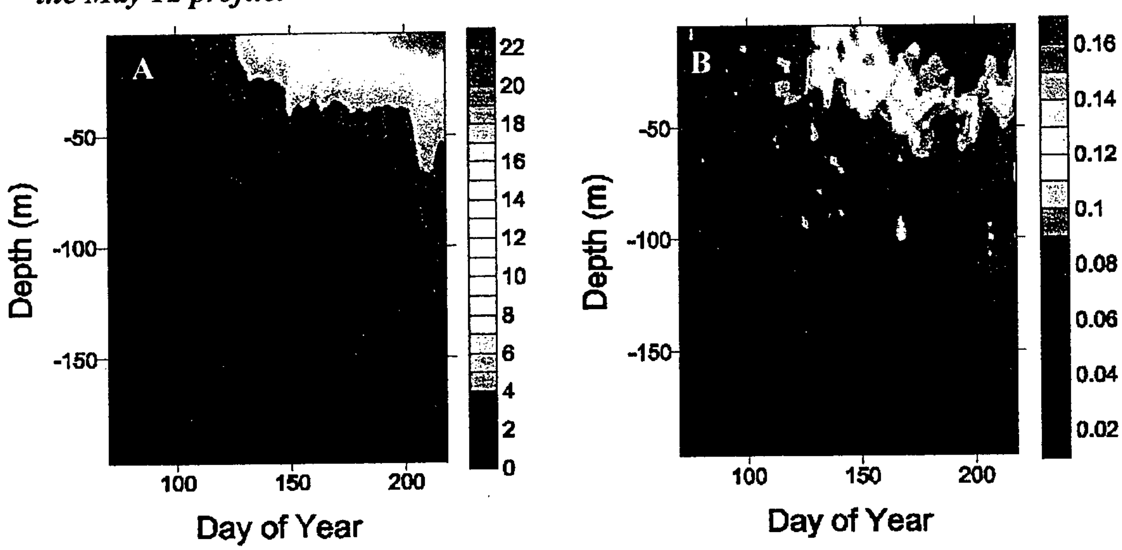

Figure 3. Time evolution of A. temperature and B. K(490) in the upper 200 m during the KSOLO experiment. From the initial deployment there is evidence of higher attenuation coefficients in the upper 100 m compared to deeper water indicating some growth of phytoplankton even in deeply mixed waters. Following strong stratification starting after day 125, a bloom of phytoplankton occurred with maximal values observed near day 150. The increase in phytoplankton led to a strong increase in K(490) in the surface waters. Subsequently, the surface bloom declined and maximum values of K(490) were found near 50 m depth. K(490) below 150 m approached values close to the pure water value for this wavelength.

accurate and cost-effective validation system for K(490) – one of the standard products of all existing or planned ocean color satellite missions. The direct estimates of the biological profile of heat storage will allow quantitative estimates of phytoplankton control of physical stratification.

TRANSITIONS

Mechanical design and integration, control and communications software, experiment data and optical models will be provided with final report.

RELATED PROJECTS

The development of K-SOLO depends on the separate development program for SOLO as a physical oceanographic autonomous profiler. Also, the Scripps Instrument Development Group who pioneered ALACE and SOLO autonomous profilers have recently been awarded funds under the National Ocean Partnership Program to upgrade SOLO. Thus, the optical integration we are accomplishing now will benefit the community by providing an option for future configurations of the more advanced SOLO that will be available by 2001.

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PATENTS

None.