High Resolution Time Series Measurements of Bio-optical and Physical Variability in the Coastal Ocean as Part of HyCODE

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LONG-TERM GOALS

A general long-term goal of our project is to increase understanding of the variability of inherent and apparent optical properties (IOPs and AOPs) and their relationships to each other as well as to physical processes on continental shelves. Data were also collected during our study in order to establish relationships that have utility for quantification and utilization of remotely sensed hyperspectral ocean color data.

OBJECTIVES

Two primary objectives of the project are
1. To study processes which contribute to temporal and spatial (horizontal and vertical) variability of spectral IOPs and AOPs. We are determining how temporal and spatial variability in IOPs and AOPs are affected by:
a) Coastal physical and biological dynamics (upwelling/downwelling, fronts, filaments, eddies, blooms, etc.) and larger scale circulation patterns
b) Wave fields (e.g., tides and surface, internal, and solitary waves)
c) Water column stratification and current shears
d) Near surface and near bottom mixing (e.g., effects on primary productivity, sediment resuspension, dilution, dispersion, etc.)
e) Diurnal and seasonal biological and physical cycles
f) Riverine and runoff inflows (i.e., changes in relative contributions of sedimentary, biological, and colored dissolved material (CDM) components, buoyant plumes, and phytoplankton blooms).
2. To provide the maximum number of *in situ* observations (highest possible number of match-ups) of IOPs and AOPs possible for calibrating, groundtruthing, and relating subsurface optical properties (algorithm development) to aircraft and spacecraft ocean color data, and to develop, test, and validate optical models and high resolution interdisciplinary models of the coastal ocean.

APPROACH

Our approach has entailed collection of field observations during two HyCODE experiments in the summers of 2000 and 2001. The area chosen for the studies was the LEO-15 region, which is on the continental shelf off New Jersey. There, coastal upwelling fronts, riverine plumes, and internal

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14. ABSTRACT
A general long-term goal of our project is to increase understanding of the variability of inherent and apparent optical properties (IOPs and AOPs) and their relationships to each other as well as to physical processes on continental shelves. Data were also collected during our study in order to establish relationships that have utility for quantification and utilization of remotely sensed hyperspectral ocean color data.

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solitary waves are common features. Our work is part of a large coordinated effort involving several other institutions. During the first field year, the UCSB/OPL HyCODE mooring was deployed on May 16, 2000 on the New Jersey shelf (~24 m depth). The mooring was serviced and redeployed on July 25 and recovered on September 15, 2000. High temporal resolution measurements of IOPs and physical properties were collected at several depths. Hyperspectral optical instruments to measure AOPs were deployed in addition to the physical and IOP-optical instruments during the summer 2001 field program between June 20 and August 7, 2001. The data have been processed and analyzed by OPL researchers. Collaborative efforts have involved other HyCODE investigators, e.g., Oscar Schofield and Scott Glenn (Rutgers University), Mark Moline (Cal Poly), Emmanuel Boss (University of Maine), Scott Pegau (Oregon State University), Curt Mobley (Sequoia Scientific), Rick Gould (NRL, Stennis) and Alan Weidemann (NRL, Stennis). Additional details may be found in Dickey et al. (1999) and papers by Chang et al. (2002 and 2003) and Chang and Dickey (2003) and on the web site: http://www.opl.ucsb.edu/hycodeopl.html.

WORK COMPLETED

We have completed deployment and recovery of the first, second, and third HyCODE moorings spanning the periods of May 16 - July 25, 2000; July 25 - September 15, 2000; and June 20 – August 7, 2001. All data have been processed. Datasets were complete with little to no bio-fouling seen in optical signals (see paper by Manov et al., 2003 and data reports by Chang et al., 2000; Dickey et al., 2000; Jiang et al., 2001). Summer 2000 and 2001 data and data reports have been made available to other HyCODE investigators via a CD-ROM and through our website: http://www.opl.ucsb.edu/hycodeopl.html.

A paper describing some of the results from the 2000 field observations has been published in the Journal of Geophysical Research (Chang et al., 2002). Mid-shelf mooring and tripod data, nearshore node data, and complementary shipboard transect data were analyzed statistically (frequency autospectra, coherence, autocorrelations, etc.) to investigate the temporal and spatial variability of hydrographic, physical, biological, and optical properties on scales of minutes to months and meters to ~50 km and to examine the relationships between nearshore and mid-shelf processes. Shipboard profile and tether data and radiative transfer simulations (spectroradiometer and HyperTSRB and Hydrolight) were utilized to examine and compare three different methods to derive water-leaving radiance ($L_w(\lambda)$). This paper was published in Applied Optics (Chang et al., 2003). Another paper focusing on solar transmission and radiant heating rates (Chang and Dickey, 2003) has been revised and resubmitted for publication in the Journal of Geophysical Research. This paper utilizes HyCODE optical and physical data sets to explore the influences of cloud cover, chlorophyll, particulate matter, and colored dissolved organic matter (CDOM) upon the magnitude and variability of solar transmission, sea surface albedo, and radiant heating rates in the shallow coastal waters of the LEO-15 shelf region. These results are quite unique because of the concurrent, high temporal resolution optical and physical measurements in shallow waters and utilization of radiative transfer simulations.

RESULTS

Several major processes contributed to bio-optical variability in summer 2000 in the LEO-15 HyCODE study area. These included: a coastal jet, an upwelling front, tides, river flows, and internal solitary waves (Chang et al., 2002; Schofield et al., 2003). Temporal decorrelation scales of optical and biological properties increased from nearshore (~1 day) toward the mid-shelf (2-3 days), whereas decorrelation scales for hydrographic properties were 2-3 days at both locations (Chang et al., 2002). Absorption at the mid-shelf location was dominated by phytoplankton and colored dissolved organic matter (CDOM), each accounting for roughly 50% of all absorbing materials at 440 nm. On the other hand, nearshore absorption was mainly influenced by particulate material (~70% of absorbing material) as compared to CDOM (~30% of absorbing material). Phytoplankton dominated the turbidity near the surface and intermediate depths and detritus dominated near the bottom. The interaction of tidal currents with the mean currents and the water mass/turbidity front were important for the formation of small-scale convergence and divergence zones (on the order of a few km) in the HyCODE experimental region. Frequency autospectra revealed that the M2 semidiurnal tides dominated temporal variability of physical, hydrographic, optical, and biological properties in both the nearshore and mid-shelf regions (Chang et al., 2002).

Time series of remote sensing reflectance were generated utilizing the optical model Hydrolight 4.0 (Mobley, 1994) and UCSB OPL mooring IOP data. Analyses of Hydrolight-generated $R_{rs}(\lambda)$ time series show that low salinity water masses in spring 2000, likely from the Hudson River, greatly influenced the optical properties at the HyCODE site. Correlations between $a_{t\text{-}w}(412)$:$a_{t\text{-}w}(676)$, $a_{t\text{-}w}(676)$-$a_{t\text{-}w}(650)$ (a proxy for phytoplankton), and $b_{t\text{-}w}(412)$ versus the reciprocal of salinity (salinity^{-1}) show that these river flows resulted in increased CDOM in near-surface water. Spectral shifts of $R_{rs}(\lambda)$ were detected as well; the ratio of $R_{rs}(405)$:$R_{rs}(675)$ increased from ~1.25 during times of particulate-dominated waters to >2 during times of CDOM-dominated near-surface waters.

Closure analyses between Hydrolight-generated (Mobley, 1994), and TSRB- and profiled radiometer-measured and calculated (using the relationship: $k_u = (-1/\Delta z) * \ln(L_u(\lambda)_2/L_u(\lambda)_1)$ upwelling and water-leaving radiance ($L_u(\lambda)$ and $L_w(\lambda)$, respectively) were performed with summer 2000 HyCODE data (courtesy of E. Boss and W. S. Pegau; Chang et al., 2003). These closure analyses resulted in r^2 of >0.95 and percent errors of less than 25% on average between measurement methods for $L_w(\lambda)$. Results from these analyses will prove useful for groundtruthing of remotely sensed data (Chang et al., 2003). The results of the solar transmission/radiant heating rate study (Chang and Dickey, 2003) show that over the 41-day time series, the average loss solar radiation was 274 W m^{-2} for mean surface radiation of 365 W m^{-2} (average solar transmission of 21%). The maximum loss of solar radiation (attenuation of 483 W m^{-2} for surface radiation of 492 W m^{-2}; 1.9% solar transmission) occurred during a period of 70% cloud cover, 12 m MLD, and near-average values for bio-optical properties. Quantitative coherence and principle component analyses suggest that cloud cover, chlorophyll concentration (Chl), and CDOM have the greatest impacts on solar transmission variability on timescales of ~1 week. Radiative transfer simulations show that Chl, absorption, and attenuation have the most significant impact on solar transmission, whereas solar angle and cloud cover greatly influence albedo. This differs from past open ocean studies that have focused on phytoplankton pigments (e.g., Chl) as the only bio-optical influence on solar transmission. Our coastal ocean results also emphasize that the attenuation of solar energy in turbid nearshore waters is much greater than that found in clearer open ocean and Arctic waters.

Moored hyperspectral radiometer data are being compared with satellite-derived remote sensing reflectance (R_{rs}) for groundtruthing purposes (in collaboration with Rick Gould; NRL, Stennis). Preliminary results indicate that atmospheric corrections for LEO-15 waters are still not adequate. Additionally, differences between *in situ* and satellite-derived R_{rs} are largely due to differences in scale, i.e., point measurements versus pixel-averaged and hourly averaged versus single point in time.

HyCODE mooring data are also being presented in several review papers for the HyCODE TOS issue, due out in June 2004.

IMPACT/APPLICATIONS

The results of our research will lead to 1) improved understanding of variability of inherent and apparent optical properties (IOPs and AOPs) and their relationships to each other as well as to physical processes on the ocean's continental shelves, 2) expanded usefulness and utility of high spectral and spatial resolution remotely sensed ocean color data, and 3) more accurate predictive interdisciplinary models of the coastal ocean; particularly primary productivity and optically-mediated radiant heating rate (inclusion of penetrative component of solar radiation) models in shallow waters. All three of these points are fundamental to tactical naval applications in the coastal ocean and central to the ONR HyCODE program.

TRANSITIONS

Our statistical time series analyses will facilitate the development of interdisciplinary models (e.g., to predict the movement and distribution of biological matter, and study the anthropogenic effects on the coastal ocean) and facilitate the development and testing of ocean color algorithms to derive organic matter and primary production from remotely sensed data. Our data sets will also be valuable for development of a variety of optical, biological, and physical models and their couplings. Results of our work (see impacts above) should also be of interest to several levels of the operational Navy, particularly naval operations in the littoral zone.

RELATED PROJECTS

This project builds on the ONR Coastal Mixing and Optics (CMO) and PRIMER programs (see http://www.opl.ucsb.edu/cmo.html). Results of our CMO work appeared in the reviewed literature (Journal of Geophysical Research, volume 106, number C5) as well as reports and conference proceedings (please see previous CMO Annual Report, 2001). Our HyCODE activity involves close collaborations with several other HyCODE, Naval Research Laboratory (NRL), and LEO-15 scientists. Our activity was also coordinated with the NRL COJET program. Hydrographic data from COJET were used in analyses for interpretation of our time series data.

REFERENCES

Chang, G. C. and T. D. Dickey, Coastal ocean optical influences on solar transmission and radiant heating rates, J. Geophys. Res., accepted pending revision, 2003.

Chang, G. C., T. D. Dickey, E. Boss, C. D. Mobley, and W. S. Pegau, Toward closure of upwelling radiance in coastal waters, Appl. Opt., 42(9), 1574-1582, 2003.

Chang, G. C., T. D. Dickey, O. M. Schofield, A. D. Weidemann, E. Boss, W. S. Pegau, M. A. Moline, and S. M. Glenn, Nearshore physical processes and bio-optical properties in the New York Bight, J. Geophys. Res., 107, 3133, doi:10.1029/2001JC001018, 2002.

Chang, G., S. Jiang, X. Yu, S. Zedler, D. Manov, D. Sigurdson, F. Spada, and T. Dickey, High resolution time series measurements of bio-optical and physical variability in the coastal ocean as part of HyCODE, Data Report: Hyperspectral Coupled Ocean Dynamics Experiment (HyCODE) Deployment II: 25 July – 15 September, 2000, Ocean Physics Laboratory Technical Report OPL-05-00, 2000.

Dickey, T., S. Ackleson, R. Arnone, P. Bissett, J. Donovan, S. Glenn, W. Hou, W. McBride, O. Schofield, J. Smart, and W. Snyder, Report of the First HyCODE Data Management and Distribution Workshop, Rutgers University, April 12-13, 1999.

Dickey, T., X. Yu, S. Jiang, S. Zedler, D. Manov, D. Sigurdson, F. Spada, and G. Chang, High resolution time series measurements of bio-optical and physical variability in the coastal ocean as part of HyCODE, Data Report: Hyperspectral Coupled Ocean Dynamics Experiment (HyCODE) Deployment I: 16 May – 25 July, 2000, Ocean Physics Laboratory Technical Report OPL-04-00, 2000.

Jiang, S., G. Chang, D. Manov, F. Spada, and T. Dickey, High resolution time series measurements of bio-optical and physical variability in the coastal ocean as part of HyCODE, Data Report: Hyperspectral Coupled Ocean Dynamics Experiment (HyCODE) Deployment III: 19 June – 6 August, 2001, Ocean Physics Laboratory Technical Report OPL-02-01, 2001.

Manov, D. V., G. C. Chang, and T. D. Dickey, Methods for reducing biofouling of moored optical sensors, *J. Atmos. Oceanogr. Tech.*, *accepted pending revisions*, 2003.

Mobley, C. D. (1994) *Light and Water*, Academic Press, San Diego, CA, 592pp.

Schofield, O., T. Bergmann, M. J. Oliver, A. Irwin, P. W. Bissett, M. A. Moline, and C. Orrico, Inversion of the Bulk Absorption in the Mid-Atlantic Bight and its Utility for Water Mass Analysis in Optically Complex Coastal Waters, J. Geophys. Res., *submitted*.

Web sites: http://www.opl.ucsb.edu/hycodeopl.html; http://www.opl.ucsb.edu/hycode.html

PUBLICATIONS (2002-present)

Chang, G. and T. Dickey, 2003, Coastal ocean optical influences on solar transmission and radiant heating rates, J. Geophys. Res., accepted pending revision.

Chang, G. C. and T. D. Dickey, Interdisciplinary sampling strategies for detection and characterization of harmful algal blooms, in: Monographs on oceanographic methodology, Edited by: M. Babin, C. Roesler, and J. Cullen, submitted, 2003.

Chang, G., T. Dickey, E. Boss, C.D. Mobley, and W.S. Pegau, Toward closure of upwelling radiance in coastal waters, Appl. Opt., 42(9), 1574-1582, 2003.

Chang, G. C., T. D. Dickey, S. Jiang, D. V. Manov, and F. W. Spada, Optical methods for interdisciplinary research in the coastal ocean, in: Recent Research Developments in Optics, 2, Edited by: M. Kawasaki, N. Ashgriz, and R. Anthony, in press, 2003.

Chang, G. C., T. D. Dickey, O. M. Schofield, A. D. Weidemann, E. Boss, W. S. Pegau, M. A. Moline, and S. M. Glenn, Nearshore physical processes and bio-optical properties in the New York Bight, J. Geophys. Res., 107, 3133, doi:10.1029/2001JC001018, 2002.

Dickey, T., 2002, A vision of oceanographic instrumentation and technologies in the early 21st century, Chapter 9, Oceans 2020: Science for Future Needs, eds. J.G. Field, G. Hempl, and C.P. Summerhayes, Island Press, Washington, DC, 213-256.

Dickey, T., 2002, Emerging ocean observations for interdisciplinary data assimilation systems, J. Mar. Sys., 40-41, 5-48.

Dickey, T. and P. Falkowski, 2002, Solar energy and its biological-physical interaction in the sea, eds. A.R. Robinson, J.J. McCarthy, and B.J. Rothschild, Chapter 10, The Sea, Vol. 12, John Wiley, New York, 401-440.

Manov, D. V., G. C. Chang, and T. D. Dickey, Methods for reducing biofouling of moored optical sensors, J. Atmos. Oceanogr. Tech., accepted pending revisions, 2003.

Souza, A.J., T.D. Dickey, and G.C. Chang, 2002, Modeling water column structure and suspended particulate matter in the Middle Atlantic continental shelf during passage of Hurricanes Edouard and Hortense, J. Mar. Res., 59, 819-842.

Weller, R., A.S. Fischer, D.L. Rudnick, C.E. Eriksen, T. Dickey, J. Marra, C. Fox, and R. Leben, 2002. Moored observations of upper ocean response to the monsoons in the Arabian Sea during 1994-1995, Deep-Sea Res. II, 49, 2195-2230.

Yu, X., T. Dickey, J. Bellingham, D. Manov, and K. Streilein, 2002, The application of autonomous underwater vehicles for interdisciplinary measurements in Massachusetts and Cape Cod Bays, Cont. Shelf Res., 22, 2225-2245.

Zedler, S.E., T.D. Dickey, S.C. Doney, J.F. Price, X. Yu, and G.L. Mellor, 2002, Analysis and simulations of the upper ocean's response to Hurricane Felix at the Bermuda Testbed Mooring site: August 13 – 23, 1995, J. Geophys. Res., 107(12), P. 25-1. doi: 10.1029/2001JC00969.

Zheng, X., T. Dickey, and G. Chang, 2002, Variability of the downwelling diffuse attenuation coefficient with consideration of inelastic scattering, Appl. Optics, 41(30), 6477-6488.