

Workshop Proceedings



STATE OF TECHNOLOGY AND APPLICATION OF OPTICAL PARTICLE COUNTERS

*Honolulu, Hawaii
April 21-23, 2004*



*Funded by NOAA's Coastal Services Center through
the Alliance for Coastal Technologies (ACT)*

An ACT 2004 Workshop Report

A Workshop of Developers, Deliverers, and Users of Technologies for Monitoring Coastal Environments:

State of Technology and Application of Optical Particle Counters

Honolulu, Hawaii
April 21-23, 2004



Sponsored by the Alliance for Coastal Technologies (ACT) and NOAA's Center for Coastal Ocean Research in the National Ocean Service.

Hosted by ACT Partner organization the Hawaii Institute of Marine Biology (HIMB), School of Ocean, Earth Science and Technology (SOEST), University of Hawaii.

ACT is committed to develop an active partnership of technology developers, deliverers, and users within regional, state, and federal environmental management communities to establish a testbed for demonstrating, evaluating, and verifying innovative technologies in monitoring sensors, platforms, and software for use in coastal habitats.

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**ACT WORKSHOP: STATE OF TECHNOLOGY AND APPLICATION
OF OPTICAL PARTICLE COUNTERS**

EXECUTIVE SUMMARY

The Alliance for Coastal Technology (ACT) convened a Workshop on Optical Particle Counters (OPC) in Honolulu, Hawaii on April 21 to 23, 2004. The workshop was designed to summarize OPC technologies and to make strategic recommendations for future development and application of these technologies to coastal research and management. The workshop was not focused on any specific technology, so the participants reviewed the following four technologies: laser defraction, digital imaging, laser optical particle counters and in-situ flow cytometry. Participants included researchers involved in particle counting, industry representatives and coastal managers. The goals of the workshop were:

- Goal No 1:** What are the present capabilities, strengths and weaknesses of in situ particle counters?
- Goal No 2:** What kinds of data are needed by researchers, and what are the problems with existing particle counters?
- Goal No 3:** What kinds of data are needed by coastal managers?
- Goal No 4:** How should data on particles be incorporated into larger environmental data sets?

Three general recommendations were made:

Recommendation No 1:

The government should provide funding (perhaps through a structure such as ACT) to have managers work directly with industry to develop targeted, inexpensive devices for optical particle measurements. This will allow industry to design and market instruments for management needs, as opposed to just research needs. Hopefully there would be some cost effectiveness through economy of scale. The workshop at this time could not make specific recommendations. Optical particle counters are primarily research instruments.

Recommendation No 2:

It is recommended that scientists and managers work together to development standard protocols for calibration, management, processing, and interpretation of optical particle counter data.

Recommendation No 3:

Data should be collected to evaluate hypothesis driven questions that address the effectiveness of management policy.

ALLIANCE FOR COASTAL TECHNOLOGIES

There is widespread agreement that an Integrated Ocean Observing System (IOOS) is required to meet a wide range of the Nation's marine product and information service needs. There also is consensus that the successful implementation of the IOOS will require parallel efforts in instrument development and validation and improvements to technology so that promising new technology will be available to make the transition from research/development to operational status when needed. Thus, the Alliance for Coastal Technologies (ACT) was established as a NOAA-funded partnership of research institutions, state and regional resource managers, and private sector companies interested in developing and applying sensor and sensor platform technologies for monitoring and studying coastal systems. ACT has been designed to serve as:

- An unbiased, third-party testbed for evaluating new and developing coastal sensor and sensor platform technologies,
- A comprehensive data and information clearinghouse on coastal technologies, and
- A forum for capacity building through a series of annual workshops and seminars on specific technologies or topics.

The ACT workshops are designed to aid resource managers, coastal scientists, and private sector companies by identifying and discussing the current status, standardization, potential advancements, and obstacles in the development and use of new sensors and sensor platforms for monitoring, studying, and predicting the state of coastal waters. The workshop goals are to both help build consensus on the steps needed to develop and adopt useful tools while also facilitating the critical communications between the various groups of technology developers, manufacturers, and users.

ACT Workshop Reports are summaries of the discussions that take place between

ACT Headquarters is located at the UMCES Chesapeake Biological Laboratory and is staffed by a Director, Chief Scientist, and several support personnel. There are currently seven ACT Partner Institutions around the country with sensor technology expertise, and that represent a broad range of environmental conditions for testing. The ACT Stakeholder Council is comprised of resource managers and industry representatives who ensure that ACT focuses on service-oriented activities. Finally, a larger body of Alliance Members has been created to provide advice to ACT and will be kept abreast of ACT activities.

participants during the workshops. The reports also emphasize advantages and limitations of current technologies while making recommendations for both ACT and the broader community on the steps needed for technology advancement in the particular topic area. Workshop organizers draft the individual reports with input from workshop participants.

ACT is committed to exploring the application of new technologies for monitoring coastal ecosystem and studying environmental stressors that are increasingly prevalent worldwide. For more information, please visit www.act-us.info.

ORGANIZATION OF THE WORKSHOP

The workshop was sponsored by ACT and hosted by the Hawaii Institute of Marine Biology, School of Ocean, Earth Science and Technology, University of Hawaii: one of the ACT Partner institutions. The workshop was organized by Drs. Marlin Atkinson, Jim Falter and Mark Huntley of the Hawaii Institute of Marine Biology. Participants arrived on Wednesday April 21 or Thursday April 22, 2004 and gathered for a reception and dinner, during which a presentation of the ACT program was given, and Dr. Mark Huntley gave a personal history and view of his experience with counting particles in the ocean in a plenary talk. The workshop discussions commenced on the next day, beginning with an introduction of the workshop goals, followed by a presentation and discussion of each of the OPC technologies. During the working lunch a demonstration of FlowCam was conducted. The afternoon included two breakout discussion groups and a summary discussion on the needs of researchers and managers, and impediments to monitoring coastal water. The following morning, Saturday April 23, 2004, the whole group engaged in a discussion of future technology and recommendations. An afternoon field trip to Coconut Island and surrounding coral reefs was optional. Below is the workshop announcement and the agenda, provided to participants.

STATEMENT OF THE PROBLEM

Role of optical particle counters in the observation of planktonic communities

Optical particle counters (OPCs) are used to gather data on the abundance and biomass distributions of plankton. Such data is necessary to develop and test models of pelagic community dynamics in either near shore or deep-sea environments. All OPC technologies actually measure size distributions which are then converted to either volume or biomass distributions based on assumptions of the taxonomic composition of the particles measured and known empirical relationships between size, volume, and mass content published in the literature. The quality of ecological data generated by OPCs therefore depends on the accuracy of these conversions. OPCs equipped with video imaging equipment allow for taxonomic identification of larger plankton group (> 1 mm), however, the taxa of smaller particles including many

phytoplankton cannot be identified with the present imaging technology. For smaller particles bearing pigments such as phytoplankton, measurement of particle fluorescence combined with light-scattering data can assign particles to specific functional groups. Flow cytometers are capable of acquiring this kind of data.

Role of optical particle counters for monitoring water quality

OPCs can also be used to measure suspended sediment load since many OPC measurements do not discriminate between inorganic and organic particles. Discriminating natural versus anthropogenic changes in sediment load to near shore aquatic systems is a common issue for many resource managers. OPCs can also be used to help identify and monitor toxic algal blooms, however, the necessary taxonomic identification (i.e., species-level) of such algal blooms are beyond the present capabilities of existing OPC technologies. As a result, OPCs are usually used in concert with other visual, biochemical, and molecular biological techniques for precise taxonomic identification.

NEED FOR MONITORING

Clearly, real time monitoring of inorganic and organic planktonic particles is very important in determining the frequency, duration, and extent of plankton blooms, resuspension of sediment, or inputs of terrigenous material. These data would be extremely important in assessing the effectiveness of management policy. Identification of specific size ranges of plankton or specific taxa are not only effective for identifying bloom species, but also in determining the success of larvae or juvenile of higher trophic level organisms. Thus management on both ecosystem scale processes and populations of specific organisms requires spatial and temporal monitoring of particles. This workshop explored both the technologies and infrastructure is required to achieve routine monitoring of particle concentrations in natural waters.

WORKSHOP GOALS

The ACT workshop on Optical Particle counters was convened on April 22 to 23, 2004 in Honolulu, Hawaii to summarize the state of the technology, and to make strategic recommendations for the future development and application of the technology for coastal environmental research and monitoring. The goals of the workshop are listed below:

1. What are the present capabilities, strengths and weaknesses of in situ particle counters?
2. What kinds of data are needed by researchers, and what are the problems with existing particle counters?

3. What kinds of data are needed by coastal managers?
4. How should data on particles be incorporated into larger environmental data sets?

AVAILABLE OPC TECHNOLOGIES

Commercially available technologies

FlowCAM Technology

Fluid Imaging Technologies, Inc.

www.fluidimaging.com

The FlowCAM® from Fluid Imaging Technologies is a powerful continuous imaging particle analyzer for monitoring of coastal waters, phytoplankton, zooplankton, fluid-borne particulate contamination, ballast water, water quality and aquaculture. A FlowCAM can monitor and image cells and other particles *in situ* or from discrete samples. The laser works interactively with a CCD camera to detect and capture data on a passing particle. Data measurements include particle counts, length and width measurements, ESD, light scatter, chlorophyll and phycoerythrin measurements.

The FlowCAM is available in bench top, portable (12 volt) or submersible models. All models offer pattern recognition capabilities and image management such as post-processing editing and library development. A particle size range from 1 µm to 3 mm is accomplished by using interchangeable magnification lens. A video demonstration is available at the company web site.

LISST Technology

Sequoia Scientific

www.sequoiasci.com

The LISST series laser diffraction instruments were developed at Sequoia for measurement of suspended particles. They filled a two-fold need. First, it was known that all prior technology sediment sensors suffered from changes in calibration with changing sediment color or grain size. Second, they did not produce information about grain size. The laser diffraction method overcomes both difficulties.

Laser diffraction measures scattering at small forward angles by an ensemble of particles. At these small angles, the scattering is dominated by diffraction of light 'around' the particles. In this manner, the scattering does not 'know' what the particle is made of, which is an advantage in that the calibration is unaffected. Further, the diffraction pattern contains information on size, so that the method obtains size distribution from the shape of the pattern of angular scattering, while the magnitude yields concentration. The measurement results in concentrations in 32 logarithmic

spaced size classes covering a 200:1 size range [model B: 1.25 to 250 microns; C: 2.5 to 500; FLOC: 7.5 1500 microns].

Sampling can be programmed with as little as 1 sec sample intervals, with submerged battery life of several months (6 typical). An Anti-fouling shutter BioBlock is available. For other versions of LISST, please visit the company website. The instruments are fully autonomous, programmable, and are equipped with battery and data recording. A pressure sensor and a temperature sensor provide data integrated in to the light scattering data stream. Software for programming the instruments and for data processing is provided. After downloading, the processing step takes just a few minutes where light scattering is converted to size distribution.

Standard systems operate in range of concentrations from approximately 1 mg/l to approx. 500mg/l. Special systems have been developed for much sparser and denser environments such as the deep sea, or the Chinese rivers (~10g/l). Sequoia developed the LISST-25 sensor in response to a USGS need for a simpler, cheaper sensor that provides less detail. A super high concentration version, LISST-INF is under development in answer to USGS needs. Another version, LISST-SL is a streamlined isokinetic version for use in rivers and streams.

Laser Optical Plankton Counter (LOPC)

Brooke Ocean Technologies

The Laser Optical Plankton Counter (LOPC) is the next generation in plankton profiling instrumentation. The LOPC's high speed processing and improved detection plane provides detection counts at higher resolutions and higher concentrations with lower coincidence than previous technologies. This also allows the LOPC to be integrated into towed bodies such as the MVP, traveling at up to 12 knots and still providing reliable data. However, the LOPC is designed to be adaptable to any towed body and can also operate in stand-alone mode as well.

The LOPC uses a high quality laser accompanied by precision optics to create a laser beam or plane which is used to detect a change in the laser path or 'light obstruction', thus indicating a particle in transit through the tunnel. The detection band is very thin [1mm] and the scan rate is extremely fast (35 μ s) which combine to enable the LOPC to operate in very high concentrations of plankton while keeping coincidence levels very low.

With such a high resolution 0.1 mm - 35 mm (100 μ m - 35,000 μ m) and the ability to individualize particles even at a high flow rate, extremely large amounts of data have to be processed. To accomplish this, the LOPC utilizes high speed signal processors and a combination of other analog and digital electronics.

The LOPC also provides interfaces for direct connection of external serial or analog instruments. Data from these instruments is integrated into the main LOPC data stream, thus providing automatic cross referencing of data; all without requiring extra conductors for the external

instruments. The LOPC comes standard with a Deck Unit. The Deck Unit is a 19", (3U) rack mountable unit with easy access to controls and connection points.

The LOPC can be used in the towed configuration (either self logging or cabled to a ship), or it can be used in the laboratory (either by pumping water from outside the hull or with a water sample circulator). The LOPC is available in several different models and has a variety options.

Experimental non-commercial technologies

FlowCytobot and Imaging FlowCytobot

Robert Olson, Senior Scientist, Biology Dept., Woods Hole Oceanographic Institution

Flow cytometry is a valuable tool for the analysis of phytoplankton and other suspended particles because of its speed and quantitative measurements, but the method's oceanographic application has been limited by the need to take discrete water samples for analysis on board ship or in the laboratory. For this reason, we have developed an automated flow cytometer that can operate in situ and unattended: FlowCytobot utilizes a diode-pumped 532 nm laser and can measure light scattering and fluorescence of particles as small as *Synechococcus* cells. It is designed for operation at coastal observatories with connections to shore by power and communications cables, and is controlled by a microcomputer whose programming can be loaded remotely. The sampling rate is adjustable; we have used from 12.5 to 50 l min⁻¹. Integrated signals from each particle (2 light scattering angles and 2 fluorescence emission bands) are transmitted to a shore-based computer, where they are accessible by Internet and can be examined in real time. FlowCytobot was deployed at LEO-15 off New Jersey for several months in 2001, and is currently operating at the Martha's Vineyard Coastal Observatory off Woods Hole. Even after 2 months of in situ operation, FlowCytobot's measurements are similar to those of a conventional flow cytometer, as shown by analysis of discrete water samples taken at the location of the sample inlet. In addition to documenting seasonal and event-scale changes in size distributions and population abundances in the pico- and nanophytoplankton, FlowCytobot has been useful for examining diel cycles in light scattering and pigment fluorescence of cells in situ that can allow estimation of rates of production by different phytoplankton groups.

A new instrument, Imaging FlowCytobot, designed to analyze larger nanoplankton and microplankton (10-100 μ m cells) at higher sampling rates, is currently under development (field tests are planned for summer 2004). Both instruments examine each cell in a water sample by using recirculating filtered sheath fluid and hydrodynamic focusing of the sample stream to confine the cells to the center of flow cell. A programmable syringe pump/distribution valve allows quantitative injection of samples, internal standards, and anti-fouling agents. Imaging FlowCytobot, in addition to measuring light scattering and fluorescence, captures and transmits to shore a digital image of each cell for classification.

Application of OPC technologies

For years, many OPC technologies have been available for use on a bench top, however, the purpose of the present workshop was to evaluate OPC technologies which could acquire data quickly, autonomously, and in great number. The two dominant platforms for collecting data considered were ship-towed and mooring. All of the commercially available OPC technologies can be deployed behind a ship or on a mooring. Flow cytometers can be deployed on a mooring and configured to acquire continuous samples onboard ship rather than having the instrument physically towed behind the ship. The flow cytometers and FlowCAM require the use of umbilical cord to supply power to the instrument and/or provide data transmission from the instrument. For these instruments, power and memory for data storage are not an issue, however, they do require the instrument to be deployed close to a power source and/or data storage onshore and onboard. Mooring of these instruments requires greater planning and site preparation. The LOPC and LISST instruments are completely self-contained and can be deployed anywhere a secured mooring can, however, these instruments will be more limited in the amount of data they can store onboard and the power they consume over a deployment. Given the ever-increasing size of compact memory, it appears that stored power will most likely to limit the length of deployment of these instruments on an independent mooring. The companies which make the LISST and LOPC instruments both estimate a maximum deployment time of around six months. All technologies can be interfaced with a telemetry system which would obviate the need for onboard data storage all together.

Additional considerations for the deployment of moored instruments are the frequency of recalibration, the use of anti-fouling measures, and depth limitations. All OPC technologies need no recalibration to be performed by the user. The flow cytometry systems are self-calibrating and the LISST and FlowCAM systems require no calibration. Brooke Ocean Technologies recommends that the LOPC be returned to them every two years for servicing and recalibration solely for the purposes of quality control. Of the commercially available OPC instruments, the LISST and LOPC offer anti-fouling measures. The flow cytometry systems include automatic anti-fouling process in their recalibration routines. The flow cytometry systems can only be deployed at depths < 50 meters, however, given that their purpose is to characterize phytoplankton populations, it is unlikely that instruments will be designed for much deeper deployments (i.e., several hundred meters). The FlowCAM can be deployed down to 200 meters, while both the LOPC and LISST instruments can be specially designed to reach ocean depths of up to 6000 meters.

OPC strengths and weaknesses Table:

Technology	Advantages	Disadvantages
Laser Diffraction	<ul style="list-style-type: none"> -Particle size range: 1µm to 1.5 mm -Relatively inexpensive (<\$50K) -Autonomous power supply -Anti-fouling measures -Compact design 	<ul style="list-style-type: none"> -No species/composition identification -Large floc is problematic
Digital Imaging	<ul style="list-style-type: none"> -Particle size range: 5µm to 3 mm -Species/composition identification for small and large particles 	<ul style="list-style-type: none"> -Relatively expensive (>\$50K) -Requires external power supply -Identification of small particles difficult
Laser Optical Particle Counters	<ul style="list-style-type: none"> -Particle size range: 100 µm to 350 µm -Relatively inexpensive (<\$50K) -Species/composition identification for large particles (> 1.5 mm) -Autonomous power supply -Anti-fouling measures 	<ul style="list-style-type: none"> -No species/composition identification for small particles (<1.5 mm) -Relatively high minimum particle size threshold of 100 µm
In situ Flow Cytometry	<ul style="list-style-type: none"> -Particle size range: 0.5 µm to 10 µm -Species/composition identification for very small particles (pico - and nano-phytoplankton) -Anti-fouling measures 	<ul style="list-style-type: none"> -Relatively expensive (>\$50K) -Requires external power supply -Not commercially available

**DATA NEEDS FOR RESEARCHERS AND MANAGERS:
ISSUES AND PROBLEMS (GOALS 2, 3 & 4)**

Technological Issues:

1. Biofouling is a major problem for these technologies.
2. Long term deployment is a problem for managers

3. Mooring re-design for long term, shift in design for higher power. Optimized for mooring requires different application

Management Issues:

4. Managers do not know what plankton size range to measure; they need help from scientists.

5. No real models to incorporate specific criteria for particles

6. Learning to use these instruments is now difficult, it requires trained personnel; it is not a simple measurement and the manuals are difficult.

7. Size -spectrum analysis is difficult and funding for training of people is not readily available.

8. Different management needs require measurements of different plankton size ranges, which requires different instrumentation. There is no single instrument that will solve management problems.

9. Data management is difficult. The technology generates huge amounts of data and software is not available to reduce those data to something meaningful. There is no uniform way of handling data.

10. Real-time data are required for sampling and verification

11. Cost-conscious\corporate mentality of managers resists appropriate use of technology

12. Managers willing to pay more for robust sensor and data analysis package; service is expensive.

13. Inexpensive devices can be designed to answer specific targeted questions, such as the abundance of a specific phytoplankton associated with a toxic bloom.

One of the biggest concerns brought up in the workshop was how to manage and process the very large data streams produced by newer OPCs. Many participants felt that acquiring large amounts of information on particle sizes, distributions, and composition would not be useful unless numerical procedures for interpreting the large data sets were developed. Often the data sets produced by OPCs are so large that software is needed to simply assess the data they are producing as well as translate it into information which is scientifically meaningful. For plankton community dynamics, this can mean feeding these large data sets into numerical models to quantify a specific process or answer a specific ecological question. However, if the plankton models are not built to incorporate the kind of data produced by OPCs, then such large datasets run the risk of not being used to their full potential. It was suggested that size-based numerical community models be coded to specifically receive the data that OPCs generate. It is still an open question as who will carry the burden for developing the software necessary for data processing as well as the responsibility for its correct application.

There is clearly a potential for resource managers to use OPCs for monitoring water quality, however, there are three important issues which need to be addressed: 1) purpose, 2) cost, and 3) training.

Motivation for use of OPCs

Resource managers need very explicit reasons for using OPCs to measure suspended particles. Often the purpose of making OPC measurements depends upon the desired question being asked by the resource manager. State and federal resource agencies will require advisory input from scientists in order to know what kind of measurements need to be made to gain information relating to specific water quality issues and what instruments are needed to make these measurements. Only then can resource managers approach private companies to decide the kind of instrument which suits their need.

Cost

Present costs of OPCs range from \$10,000 to \$90,000, increasing with the amount of information that a particular OPC generates (abundance, size, images, fluorescence, etc.). OPC technologies are considered to be somewhat advanced and warrant this kind of price range in terms of the costs of development and production. Unfortunately, it is often difficult for resource managers to justify the purchase of instruments this expensive in their budgets. More expensive instrumentation requires greater justification in state and federal budgets. It is possible that if OPCs were purchased by many resource managers across different federal and state agencies, then the resulting economies of scale would reduce the per instrument cost for each OPC. It was pointed out that existing companies building OPCs would require a certain period of time and 'up-front' investment in order to increase production substantially enough to realize such economies of scale. Additional means of decreasing OPC production costs were suggested and include creating targeted meetings which bring together industry, scientists, and resource managers which specifically discuss the design and use of OPCs. Such meetings will 1) reduce the need for companies to dilute their effort and resources attending many more general aquatic and water quality meetings, and 2) focus the development of OPCs on those technologies which will carry the greatest demand for purchase once they become commercially available. In general, it was agreed by all participants that industry currently carried too much of the economic burden in developing and promoting OPC technologies.

Training

The advanced nature of OPC technologies requires that the scientists or resource managers using OPCs have a certain amount of technical training to run and maintain the instruments, to have a detailed understanding of the data they are collecting, and to know what that data can and cannot tell them about the specific environmental question they are trying to answer. The costs required for training people to use OPCs properly must be included in the total costs of owning and maintaining the instruments. For many resource managers, such training may require prior or concurrent work with research scientists experienced with using OPCs.

WORKSHOP RECOMMENDATIONS

These are general recommendations made by the participants of the workshop:

Recommendation No 1:

The government should provide funding (perhaps through a structure such as ACT) to have managers work directly with industry to develop targeted inexpensive devices for optical particle measurements. Industry can design and market for management needs, as opposed to just research needs. Hopefully there would be some cost effectiveness through economy of scale. The workshop at this time could not make specific recommendations. At present, optical particle counters are primarily research instruments.

Recommendation No 2:

It is recommended that scientists and managers work together to development standard protocols for calibration, management and processing of optical particle counter data. Money for workshops is required.

Recommendation No 3:

Data should be collected to evaluate hypothesis driven questions that address the effectiveness of management policy.

CONCLUSIONS

OPC will be an important technology for monitoring coastal waters, however at present there is a very large void in development of management driven questions, appropriate devices, software development and data handling. It is recommended that scientists need to help guide the design of monitoring programs that can assess the effectiveness of specific management strategies, and industry needs to respond to the requirements of managers.

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