

The Marine Environmental Prediction System (MEPS) - A New Generation of Moored Ocean Observing Systems

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Abstract - Dalhousie University's Marine Environmental Prediction System (MEPS), designed in 2001, has been operated for three years in support of real-time observation, prediction and visualization of ocean properties and processes. The observatory consists of a network of three moored buoys connected to an unmanned shore station using 802.11b wireless LAN technology. The system is controlled, configured and maintained remotely, over the Internet, using the novel DACNet ocean observatory operating system.

Each mooring has a full suite of meteorological, oceanographic, acoustical and optical sensors, which collect and provide data in near-to-real-time to an access and visualization system (www.cmep.ca/bay). Currently 20 different sensors are on each platform, with the ability to add virtually any type of oceanographic sensor on spare guest ports. An industry standard PC104 computer is used as the primary controller on each buoy, allowing both Ethernet and a scalable number of high-speed serial inputs, creating a highly flexible acquisition node. The system configuration was designed to meet diverse science team requirements including sensors on the main buoy platform, sensor chains, bottom-mounted sensors and a remote surface tracking optical package. Communications and power are provided from the main buoy, with the option to provide shore-based cabled power. A novel serial network protocol called SatNet was deployed on each mooring to allow groups of standard oceanographic sensors to be connected on the same power and communications bus, simplifying wiring and consolidating sensors on a single interface port. SatNet Interface Modules (SIMs) allow devices without built in SatNet protocols and metadata to communicate on the network.

This paper describes the system design, configuration and deployment of the MEPS.

I. INTRODUCTION

Satlantic designed, built and successfully delivered the Marine Environmental Prediction System mooring array to the Dalhousie-based Centre for Marine Environmental Prediction (CMEP) (Fig. 1). Deployed in Lunenburg Bay, Nova Scotia, the MEPS system is designed for deployment in this shallow bay (20 m) with exposure to the open ocean. The array consists of three advanced autonomous moorings, each having a full suite of meteorological,

oceanographic, acoustic and optical sensors, which collect and provide data in near-to-real-time. The operating system for this distributed observatory is based on the DACNet ocean observatory operating system [1] originally developed for the CNRS BOUSSOLE observing system in France [4]. The MEPS system has successfully operated for the last three years in support of real-time observations, prediction and visualization of ocean and atmospheric properties and processes.



Fig. 1. MEPS Buoy in Lunenburg Bay

II. SYSTEM DESIGN

The MEPS system was designed to meet a complex series of scientific objectives. A main buoy platform was required to provide system power and a primary data collection point, in addition to supporting a meteorological station for wind forcing and a conductivity/temperature chain for water structure characterization. A surface tracking optical package was required to provide high quality optical data away from the shadow of the main buoy. An acoustics module was required to be at least 30 m away from the main mooring and located on the sea bottom to measure bottom boundary layer stress unaffected by the main mooring. The challenge of these requirements was to develop a mooring system that would be able to meet the objectives without becoming fouled in its own

mooring lines and to develop a power system to support the aggressive schedule required to support the science mission. Meeting the complex user requirements was key to assuring that all scientific objectives from the various system users were achieved without compromise.

Satlantic provided the entire MEPS, including base station, buoys, sensors, power, communications, data acquisition and control systems. Each buoy node has 20 different sensors from various manufacturers and includes several high bandwidth optical and acoustic systems (Fig. 2). With 24-hour operation, each node was required to collect data for a minimum of 20 minutes per hour. This results in 200 MB of data per platform per day, which is transmitted back to the shore station, and then to the modeling systems at Dalhousie in near real time. DACNet R2 ocean observatory operating system had been designed with a completely scalable, multi-node architecture, and was easily able to manage this system.

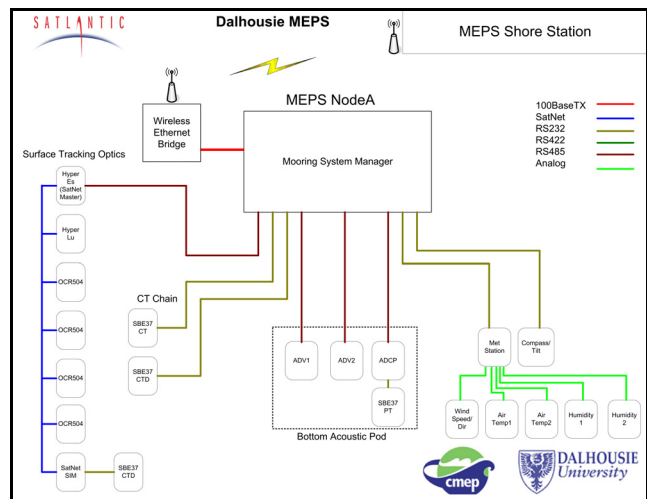


Fig. 2. MEPS Block Diagram

III. MOORING SYSTEM

The mooring design was one of the more complex parts of the system. Each buoy system has three separate components – a main buoy, a surface tracking optical system and a bottom mounted acoustic system. This required two separate floating systems, in addition to the bottom-mounted system (Fig. 4). Both the bottom mounted system and the surface tracking optical package had to share power and telemetry with the main surface unit.

A. Main Buoy

The main buoy was selected to be large enough to survive the environmental conditions of Lunenburg Bay. It also had to be small enough so that it could be moored in shallow waters (15-25 m) and easily transported via small coastal vessels. The buoy platform used is a robust, semi-rigid buoy with a 1.6 m Surlyn foam float, a 1.9 m high aluminum superstructure, and a galvanized steel hull. The

superstructure supports brackets for the solar panels, an ARGOS tracking system, a radar reflector, and a mounting structure for met sensors and antennas (Fig. 3). The buoy has a reserve buoyancy of 980 kg and a designed payload of 500 kg including the mooring chains, leaving 480 kg reserve buoyancy.

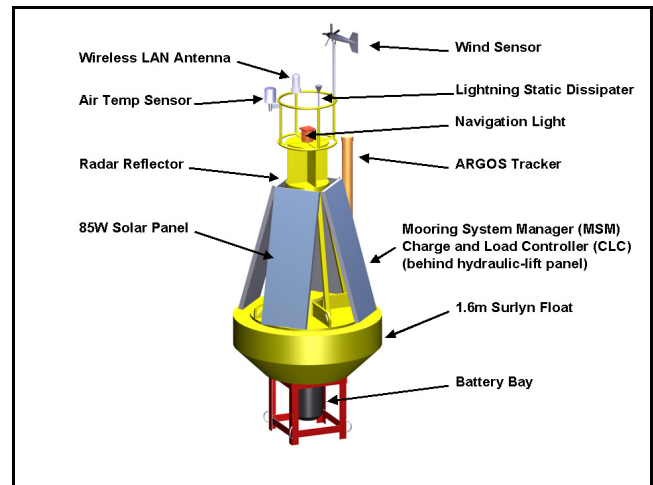


Fig. 3. MEPS Buoy Assembly

B. Surface Tracking Optical System

The most challenging element of the mooring system design was determining a method for deploying the optics in such a manner that it could surface track and not be shaded by the main buoy. Several designs were considered, but a separate, surface tracking optical mooring was determined to be the best option to meet these requirements (Fig. 4). This system has the added benefit of being independently deployable, and can be easily removed from the main buoy system if conditions require.

By suspending the smaller radiometer buoy between the main buoy and secondary separation float using lines with built in shock cords, this smaller buoy is decoupled from the motion of the main buoy and is able to accurately track surface waves as required. This provides the positional and rotational stability required to have the two moorings in close proximity with instruments suspended below and still have an electromechanical connection between them (Fig. 4).

The optical chain has four OCR504 radiometers located at 2, 4, 8 and 10 m are suspended below a Hyperspectral TSRB with a Sea-Bird SBE37 at 12 m. Power to and telemetry from the optical system is achieved through a custom electro-mechanical cable that is suspended between the surface packages. This cable is mechanically decoupled using an elastic snubber line and is kept from tangling as the systems move by secondary separation float (Fig. 4).

C. Bottom Mounted Acoustic System

The bottom mounted acoustic pod consists of two 10MHz Sontek ADVs, one Sontek 1.5MHz ADP and a PT

probe mounted in a square frame located 30 m from the main buoy. An electro-mechanical cable connects from the main mooring, down one of the mooring chains (using a custom designed anti-chafing system), and to the acoustic package (Fig. 4).

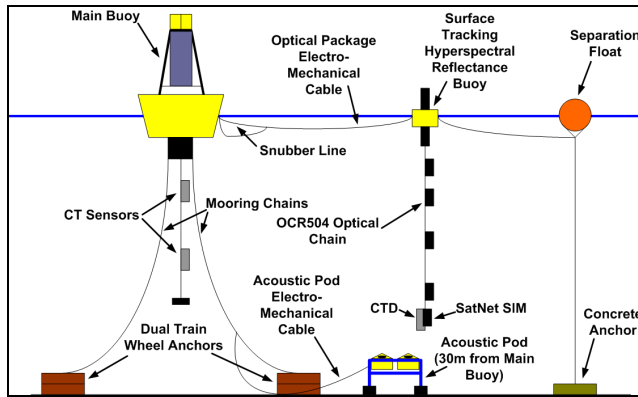


Fig. 4. MEPS Mooring System Configuration

IV. CONTROL SYSTEM

Each buoy has a local computer system (Mooring System Manager or MSM) (Fig. 5) to execute system schedules, control system power, and the manage acquisition process. The MSM is mounted in a water resistant enclosure (NEMA4 rating) located inside the buoy tower behind the solar panels, allowing easy access for connecting new sensors and for periodic system maintenance.

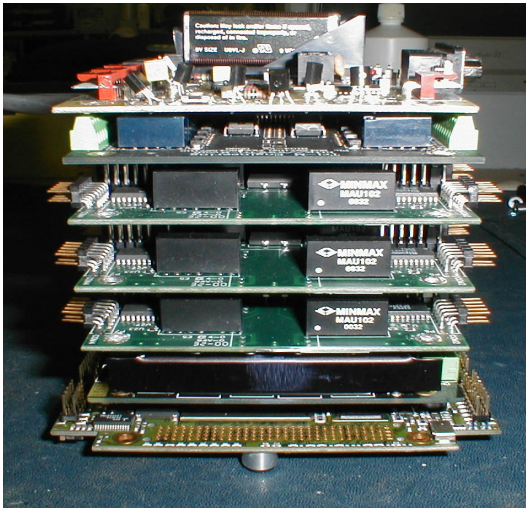


Fig. 5. Mooring System Manager

The PC104 computer was selected for the MSM to provide a scalable, reliable platform for acquisition that did not restrict the science team’s ability to collect large amounts of data from high-speed sensors nor restrict their ability to dynamically connect guest instruments to the system. The use of the Linux operating system in each

MSM allows the system to multitask, and use higher level programming languages such as Java. Each MSM runs the DACNet R2 Node Manager software.

The DACNet Network Administrator module runs in both the Linux or Windows operating systems and resides on a shore station computer that controls all the MSM Node Managers on the network. The shore station computer also acts as a central server for all of the MEPS data.

A. Power Supervisor

The power supervisor is a custom circuit board that acts as a system watchdog, controls power to the MSM computer, maintains the system clock, and allows the main computer system to sleep in a low current state. The power supervisor also monitors the main battery voltage and will not attempt to turn on the buoy system if the battery status is too low, avoiding damage to the system disk in the case of a power failure.

When the MSM is powered on, the power supervisor acts as a watchdog. The DACNet node manager sends periodic messages to the power supervisor to assure that the hardware is still running properly. If not, the power supervisor will shut down the computer and attempt a reboot later. Under normal operations, the computer will run through its schedule and send a message to the power supervisor indicating when it should be turned on again. The computer then runs through its shutdown sequence before being powered down by the power supervisor. It is restarted again at the next scheduled data collection event

B. Node Manager

The Node Manager controls all the DACNet resources on the local node on the buoy. It has three main operating modes: acquisition, telemetry and node maintenance. In the acquisition mode (normal operation), it runs the preprogrammed schedule, managing data and power resources. In telemetry mode the system connects to the central server for data uploads and schedule maintenance. In user interface mode, an operator can access the node resources through the Network Administrator.

In acquisition mode, the Power Supervisor turns on the MSM, which executes the Node Manager. The Node Manager runs through the programmed sequence of sensors, powering them up and logging their data to the MSM disk. Binary time tags are added to each data frame from the instruments so that data records can be collated later in processing.

Once the logging schedule is completed, if scheduled, the Node Manager switches to telemetry mode starts up the wireless bridge and links to the Network Administrator uploading all the data to the central server. Before shutting down the link, the Node Manager looks for any schedule updates and also checks to see if the Network Manager wants to interrupt the schedule. Any updated schedules are downloaded and stored for future execution. If the Network Manager requests an interrupt, the Node Manager switches to node maintenance mode.

In node maintenance mode the Node Manager allows the observatory operator to remotely access the file system and buoy resources for maintenance and/or system testing. The operator may then manually turn on devices and connect buoy serial ports over TCP.

C. Network Manager

The Network Manager controls all the nodes that are the system configuration. The Network Manager has five operating modes (which are accessed through a series of GUIs): acquisition, node administration, node maintenance, PortLink, and node configuration.

In acquisition mode, the Network Manager acts as a central server for the Node Managers as they upload data on their preprogrammed schedule.

In node administration mode, the Network Manager shows all the currently defined network nodes, locations, status, next scheduled upload. New nodes can be added and defined. Password access allows the user to activate a maintenance mode button. Selecting this will cause the selected node to keep its wireless link up after it has completed its next file upload, entering node maintenance mode. Administration mode also displays node status information such as battery voltage, file system status, instrument status and other diagnostics.

The Network Manager automatically switches into node maintenance mode once a selected node is connected and ready for direct user interface. In node maintenance mode, new processes can be downloaded to the MSM, the file system can be accessed, and sensors can be tested. Also, in this mode PortLink can be executed on the Network Manager.

In PortLink mode the Network Manager has access and control of all the buoy node resources. Devices can be turned on, test logs can be run, and the serial data stream from buoy instruments can be redirected over the TCP link to a serial port on the Network Manager (or some other IP address). By feeding this serial output back into another serial port on the target computer (or other computer), another process can be executed (such as SatView, WetView, SEASOFT, etc) that has access to the serial data. It is transparent to these third party processes that the instrument is not locally connected. PortLink is bi-directional so direct access to the instrument's menus and configuration are available as if it was plugged in to the local computer. Instruments with special configuration requirements can be configured remotely using this technique. PortLink also acts as a powerful debug tool, or as real time access to data in critical scenarios.

In node configuration mode, a GUI allows the user to edit node configuration files and change scheduling parameters offline. Once saved on the central server, the node will automatically get the new update when it logs in next.

V. POWER SYSTEM

The power system was designed to maximize the duty cycle of the system within the physical constraints of the main buoy. The scientific requirements of the system were to be able to collect data from the sensors on each platform 20 minutes per hour every day. The system power requirements peak at 42 W, with a maximum of 15 W used for the MSM computer and telemetry system.

The first step in the power system design was to obtain solar insolation data. These data were obtained from AES (Atmospheric Environment Service, Canada) and the NASA daily radiation database for the Halifax Citadel, the closest monitoring site to Lunenburg bay. These values represent 10 year monthly averages (Fig. 6).

The solar energy flux ranges from about 30 kWh/m²/month in December to 175 kWh/m²/month in June (Fig. 6). The science requirements of the MEPS dictate a flux of about 60 kWh/m²/month (see "Summer Schedule" Fig. 6), which is not sustainable throughout the entire year. During the period of March-October, the system samples the sensors for 20 minutes every hour, resulting in an averaged effective daily power load of 10.1 W (equivalent to a battery capacity of 20.3 Ah/day)

The MEPS buoys are switched to a lower duty cycle for four months of the year where the flux is below 60 kWh/m²/month. During this period, the sensors systems measure from 10-20 minutes every two hours, resulting in an averaged daily effective power load of 5.4 W (equivalent to a battery capacity of 10.8 Ah/day).

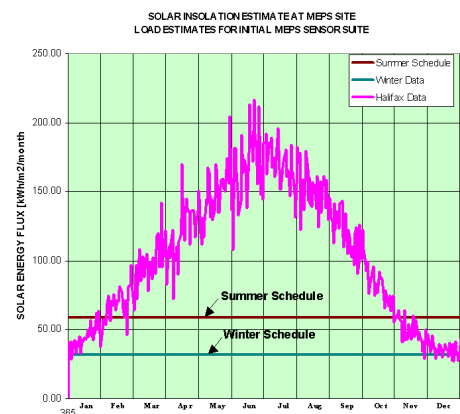


Fig.6. Power Model for MEPS

A. Solar Panel Array

The solar panel array consists of four 85 W solar panels mounted on each of the four sides of the buoy superstructure. Each panel is swept forward at an angle of 60 degrees from horizontal to maximize power collected from the incoming solar irradiance. One of the four panels was hinged at the top and latched with quick release pins at the bottom. A hydraulic piston system was mounted to this panel and when the pins were activated, the panel slowly lifted skyward. This access panel allows scientists and technicians the opportunity to perform maintenance on the

buoy systems, and to connect new science instruments to the MSM.

B. Battery Pack

The primary battery pack design criteria were to create a safe and durable system, sufficient for system expansion. Each buoy contains a center well, made from a section of 0.3 m diameter galvanized steel tubing 1.4 m long. Five 50 Ah gel cell batteries are used in parallel for a capacity of 250 Ah, sufficient for 10 days operations with no solar flux. These batteries were chosen for their ultra low hydrogen gas release while charging. Each battery was mounted in an aluminum frame and individually fused. The top shelf of the battery cage has a jack bolt that secures the whole assembly in place when the battery bay endcap is installed. A fitting was installed on the endcap with a snorkel hose so that no excess pressure or hydrogen gas could build up in the battery bay.

C. Charge and Load Controller

The charge and load controller (CLC) is used to safely deliver charging energy from the solar panel array to the battery pack. The battery voltage level is closely monitored by the CLC along with the battery bay temperature. If voltage or temperature threshold limits are exceeded, the CLC automatically removes charging current from the battery pack

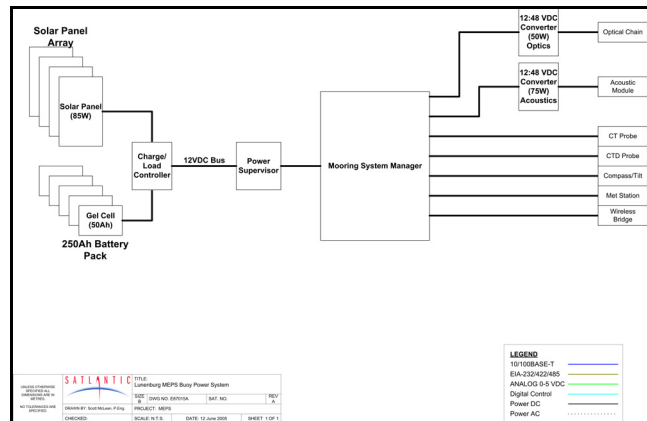


Fig. 7. MEPS Power System Block Diagram

D. Power Distribution

The main 12 VDC bus from the CLC is switched through a power relay on the power supervisor, controlling power to the MSM (Fig. 7). The MSM controls power to each instrument through a relay board, according to the acquisition schedule provided from the shore station. The main buoy instruments are powered from 12 VDC. Both the bottom mounted acoustic pod and the surface tracking optical package are powered from 48 VDC to overcome line losses. These two packages also represent the largest power loads, with the bottom mounted acoustic pod requiring 12 W through a 60 m electro-mechanical cable,

and the surface tracking optics requiring 11 W through a 40 m electro-mechanical cable.

Additional power can also be provided to the system via a shore-based cable by adding 400V to 12 or 48V DCDC converters in the MSM enclosure.



Fig. 8. MEPS Shore Station with Antenna Mast

VI. COMMUNICATIONS SYSTEM

A. Wireless Telemetry System

The primary communications system for the MEPS is based on wireless network bridges using the 802.11b protocols. For short-range systems (within 10km of a shore station), this type of system greatly reduces operational costs and while greatly increasing system bandwidth, as opposed to cellular or satellite based systems.

Satlantic has used the Cisco BR350 wireless bridges in previous projects (such as BOUSSOLE), primarily due to the compact size and efficiency of the unit's power system. The BR350 is capable of data rates of up to 11 Mbits/s, which allows high volumes of raw data to be transmitted very quickly to the shore station.

For the MEPS configuration each buoy has a Cisco BR 350 wireless bridge mounted in a water-tight enclosure, connecting to the MSM via a wet-pluggable Ethernet cable. The wireless bridge connects to shore with a 5.2 dBi omni-directional antenna. The shore station has three Cisco BR350 wireless bridges, each with a 21 dBi, 60 cm parabolic dish antenna. The antennas are located at a 50 m hill in clear line of sight of all three platforms (Fig. 8). The telemetry ranges to the buoys are 1.2, 4.0 and 5.9 km from the shore station.

Tests have shown that the Cisco BR350 wireless bridge system requires about 50 seconds to startup and establish a telemetry link and the system throughput averages 6.9 Mbits/s. Assuming a minimum transfer rate of 5 Mbits/s, the 8.3 MB of data each buoy collects per hour can be transferred in about 17 seconds. Despite a 5

W power load on the buoy, the system is very power efficient with a total connect time of just over a minute.

In the case of telemetry link failure, each MEPS buoy has approximately 500MB of reserve storage capacity, allowing a three-day maintenance window.

System backhaul is via a fourth BR350 wireless bridge connects the shore station to the Maritime Fisheries Museum of the Atlantic, approximately 2 km away in the Town of Lunenburg. From here the system connects to the Internet and the data is sent back to Dalhousie University in Halifax for processing.

B. Sensor Interfaces

The MEPS currently has eight science instrument interfaces, accessible from the MSM enclosure on the buoy superstructure. Each interface is opto-isolated and has switch selectable protocols for RS-2232/422/485. Interface baud rates (up to 115200 baud) and byte formats are configured through the DACNet Network Manager on the shore station computer. MSM science interfaces are expandable in groups of four ports. The MSM has been run with up to 12 serial ports running 115200 baud simultaneously onto the disk with an aggregate throughput of over 500 kbits/s in sustained testing. In addition to serial sensor interfaces, Ethernet sensors are also supported by the MSM.

Sensor configurations and drivers are all configured through the shore station computer (or through remote user access) and are uploaded to each MSM automatically, thus adding a new sensor to the system just requires a physical connection to the MSM on the buoy.

C. SatNet

SatNet was originally designed in 1999 using an I²C (Inter-Integrated Circuit) bus to network local groups of Satlantic sensors interchangeably into a single instrument platform. In 2001, this was redesigned to form a more distributed and robust network for connecting multiple Satlantic and other manufacturer's instruments onto a common instrument bus. SatNet currently uses a half duplex RS485 multidrop bus to connect to a group of instruments. A network master controls the communication of SatNet devices on the bus (typically at 38400 baud) and retransmits them on a single RS485 port (typically at 57600 baud), greatly simplifying connections to a group of sensors. All of Satlantic's radiometers conform to the SatNet protocol. For connecting other manufacturer's instruments to the SatNet bus, a SatNet Interface Module (SIM) was developed. This provides isolated power, a serial input for the instrument and a SatNet interface to the bus. SIMs can operate in network master or slave modes.

The SIM is programmed as a proxy server, allowing a common command interface to instrument configuration parameters. The SIM also provides for a unique identifier string to prefix each data frame, as it is for all Satlantic instruments, allowing this metadata to be used to easily identify specific instrument frames for processing. MEPS

used the first implementation of SatNet over a distributed sensor system (over 40 m long) and the first implementation of the SIM.

In the MEPS, the hyperspectral surface radiometers, the 12 m long OCR504 chain and the chain bottom CTD are all connected via a single SatNet bus (Fig. 2,3). Since the Satlantic radiometers all comply with SatNet protocols, only one SIM was needed (for the CTD). One of the hyperspectral radiometers acts as the network master. With this chain located 30 m away from the main mooring buoy, this configuration greatly reduces wiring complexity, and only requires a single port on the MSM for all seven instruments.

VII. DEPLOYMENT

The MEPS is designed to be deployed using small, local vessels with minimal effort. All three mooring systems can be deployed in one day.

For deployment after annual maintenance, each buoy is lowered into the water via boom truck and secured to the side of a small (10 m) fishing boat. This method significantly reduces the lift requirements of the service vessel. The buoy is then towed into location at a maximum speed of four knots. The main mooring chains, which are connected and marked with a tag line and float when the buoys are removed, are hoisted to the surface from the deployment vessel one at a time and reconnected to the main buoy by divers. The acoustic pod and tracking optical package cables are coiled and mounted to the buoy's topside during this operation. The acoustic pod is lowered to the bottom and divers connect the main electro-mechanical cable to the pod. The surface tracking optical package is attached to the electro-mechanical cable, moved into position, and is attached to the line from the separation float to keep it in position. Power is applied to each buoy via a main bus switch in the CLC and all instrument and wireless communications are tested using an onboard laptop to ensure that the system is fully operational.

VIII. OPERATIONS

The data from the MEPS system is relayed from the shore station to a database server at Dalhousie University. The data is batch processed daily using QA/QC subroutines, data that passes QA/QC criteria is available to users online (www.cmep.ca/bay).

Divers service the moorings every two weeks in summer to clean off sensors and mooring lines, primarily removing mussel spat as they accumulate.

In addition to the observatory data, profiling instruments are used to measure salinity, temperature, and several optical properties that can be related to measurements from the buoys. Also, samples are taken for the determination of nutrient concentrations and several measures of phytoplankton and optical properties. These observations are used to develop the circulation model and also algorithms relating optical measurements from the

buoys to the concentration of different constituents of the water (phytoplankton, detritus, suspended sediment and colored dissolved organic material).

The MEPS system has been deployed since 2002, including operations during a Category 2 hurricane in 2003 (Fig. 9).

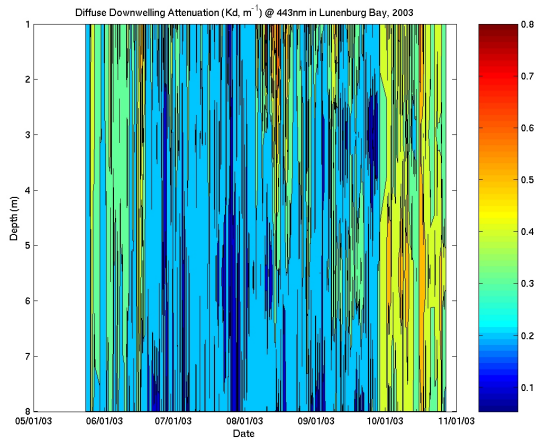


Fig.9. Diffuse attenuation coefficient data from one of the MEPS radiometer chains for June-November 2003. (Green through red indicates plankton blooms, or in the case of late September 2003 when hurricane Juan passed over the MEPS array, saturation of the water column with suspended sediments)

REFERENCES

- [1] R.S. Adams, P. Hoyt, G. Davidson, and S.D. McLean, The Data Acquisition and Control Network (DACNet) ocean observing operating system, *Proceedings of Oceans 2005*, in press.
- [2] B. de Young, K.M. Brown, R.S. Adams, and S.D. McLean, "Design and deployment of the Bonne Bay Observatory (B₂0)," *Proceedings of Oceans 2005*, in press.
- [3] E.L. Creed, S. Glenn, O. M. Schofield, H. Barrier, R.F. Petrecca, J.A. Dobarro, S.D. McLean, A.H. Barnard, K. Brown, R.S. Adams, and S. Feener, "LEO-15 Observatory – The next generation," *Proceedings of Oceans 2005*, in press.
- [4] D. Antoine, A. Morel, S.B. Hooker, B. Gentili, F. Louis, J. Ras, E. Roussier, D. Tailliez, J-F. Desté, P. Guevel, and C. Dempsey, "Medium Resolution Imaging Spectrometer (MERIS) validation: early results at the BOUSSOLE site (Mediterranean Sea)," *Envisat Validation Workshop Proceedings*, ESRIN, Frascati, Italy, 9-13 December, 2002.