The first science deployment of a McLane Moored Profiler

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The McLane Moored Profiler (MMP) is an autonomous profiling instrument platform developed through a collaboration between the McLane Research Laboratories, Inc. (MRL) and the Wood Hole Oceanographic Institution (WHOI).

The MMP uses a traction system to propel itself vertically along a subsurface mooring cable on a schedule programmed by the operator through the user interface. The baseline instrument suite includes both a CTD and an acoustic current meter. We acquired the first operational MMP system produced by MRL and, after two trials, carried out a successful scientific deployment in summer 2001. Data from this experiment are reported here.

Keywords : MMP, Kuroshio Extension, mooring bouy

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1. Introduction

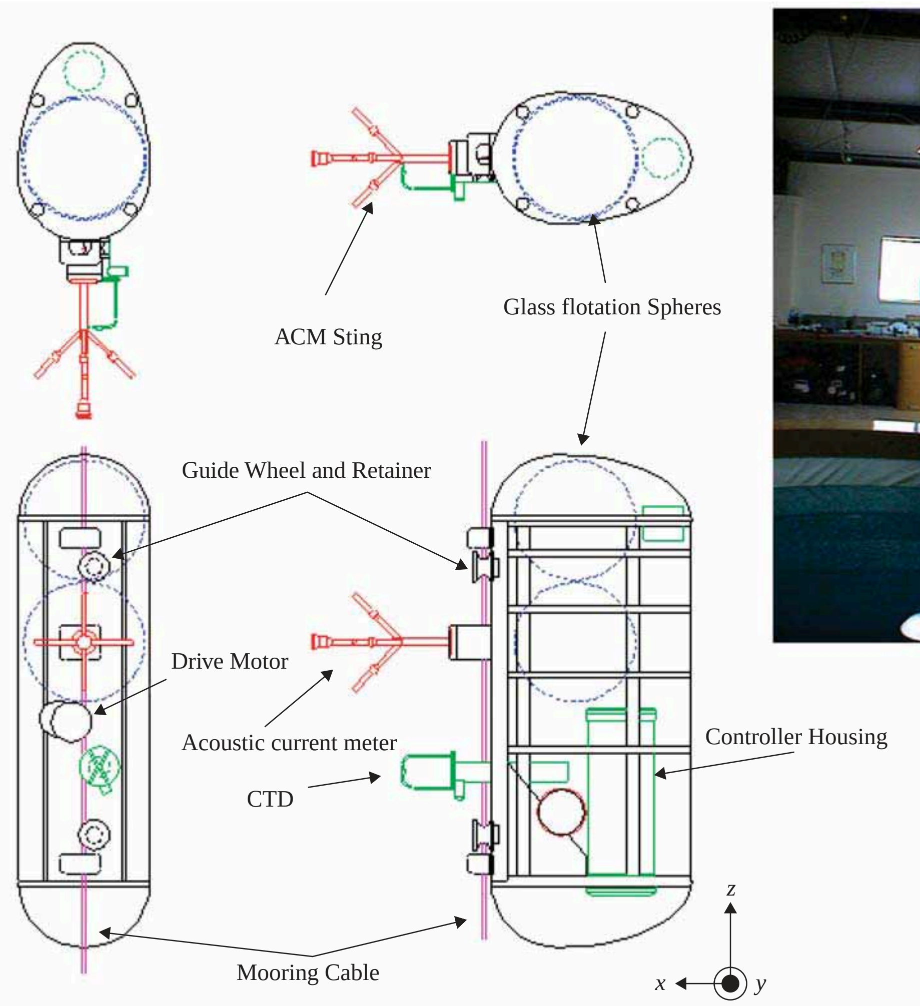
Autonomous moored profilers supporting a suite of oceanographic sensors combine the advantages of long-term moored measurements of water properties and currents using discrete instruments at selected depths with those of short-term ship supported continuous profiling performed at high vertical resolution.

The scientific deployment described here was conducted to provide confidence in the MMP system in advance of several long duration science missions planned by JAMSTEC. Data acquired under field conditions were required to resolve questions about system endurance limits and hydrodynamic behavior in a varying horizontal current field. In addition, an earlier field trial had exposed a weakness in the zero-pressure rate algorithm. Verification that the parameter changes made to the algorithm had solved the problem was also sought.

2. The McLane Moored Profiler

The McLane Moored Profiler (MMP) is one such moored profiling sensor platform. The MMP is capable of making repeated vertical traverses of the water column and acquiring ocean property and current information at resolution comparable to that which is possible using manned research vessels over extended periods of time. The MMP has thus far been fitted with a Conductivity-Temperature-Depth (CTD) sensor and an acoustic current meter (ACM). Additional or alternate sensors can be integrated into the instrument suite.

Side and top views of the MMP are shown in Fig. 1. The overall dimensions of the faired, free flooding, external shell are 130.5 cm × 50.5 cm × 33.3 cm (Fig. 1). The vehicle self-orients to point the ACM sensor head ("sting") into the horizontal flow. The vehicle Cartesian reference frame is defined as shown, with the y-axis having the usual right-handed sense. u, the x-axis component



Dimensions
Height : 130.5 cm
Width : 33.3 cm
Length (body) : 50.5 cm

Weight
Sensors (air) : 70.5 kg
Max Depth : 6,000 m
Endurance : 1Mm

Fig. 1 Side and top view of the MMP

of the velocity, is typically negative in this system. The vehicle was ballasted to be neutrally buoyant at the mid-point of the profiling range (Fig. 2, 3).

A polyethylene skin that can be removed when necessary covers the inner frame. However, normal operations, such as communication, battery replacement, and data offload, require only that the lower polyethylene end cap be removed to gain access to the pressure housing. The glass spheres mounted in the top of the frame are for flotation only and require no servicing by the user.

	Conductivity (S/m)	Temperature	Pressure
Sensor Type	FSI Inductive Cell	Platinum RTD	Micro-machined Silicon
Range	0-7.0 S/m (0-70mS/cm)	-2 to 32°C	7,000m
Accuracy	±0.0005 S/m	±0.0005°C	+/-0.03%full scale
Stability	±0.0005 S/m/month (±0.00005 S/m/month)	±0.0005°C/month	+/-0.01%full scale/month
Resolution	0.00001 S/m (0.00001 S/m/cm)	0.001°C	0.001% full scale
Response	5.0cm at 1 m/sec flow	500 msec	25 msec

Fig. 2　CTD sencer specification

Paramter	Type	Range	Accuracy	Resolution
Velocity	Acoustic	0 to 600 cm/sec	±2% of Reading or ±1 cm/sec	0.01 cm/sec
Direction	3 Axis Magnetometer	0 to 360°	±2°	0.01°
Tilt	2 Axis Accelerometer	0 to 45°	±0.5°	0.01°
Temperature	Semi-Conductor	-2 to 35°C	±0.5°C	0.01°C

Fig. 3　ACM sencer specification

3. MMP Control

Control electronics, data logger, and batteries are housed in a cylindrical, titanium pressure housing (Fig. 4). Connections on the end cap are accessible without disassembling the instrument and allow full communication with the electronics without opening the pressure case. This feature permits users operating MRL's software to perform diagnostics through the end cap and verify sensor operation immediately before a deployment. The MMP follows a programmed trajectory along a mooring cable, automatically sampling the water column with a suite of sensors and logging the results. Using the MRL software interface, the user can easily and flexibly define the trajectory and sampling schedules (Fig. 5). Deployments up to a year or more are possible. Profile patterns can include the full depth of the water column down to 6,000 meters.

Fig. 4　Controller Housing

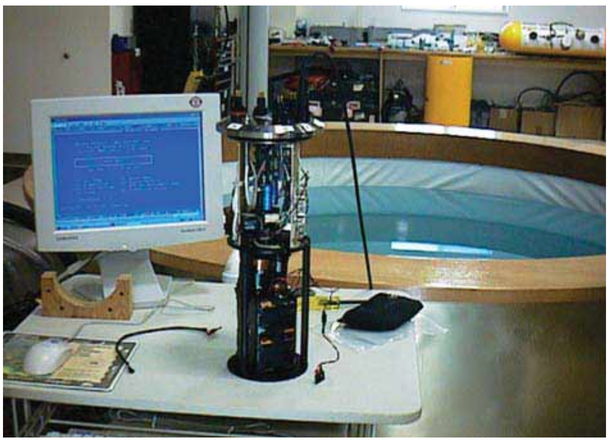


Fig. 5　Communicate the computer by RS232C cable

4. Data strage

Data from the instrument suite are stored on non-volatile PCMCIA flash cards (Fig. 6). The cards are MS-DOS compatible and can be read and copied at bus speeds on PCMCIA equipped PC's for data analysis and archiving. Binary to ASCII conversion software is provided with a MMP. This card can hold up to 440 Mbytes of data. The data from the CTD and ACM described below occupy approximately 200 Mbyte for million meters of travel during a deployment.

5. Source of power

MMP are normally deployed with a 24 cell lithium battery pack. The standard pack has a capacity of 240 Ahr and operates at 10.8 Volts. of the dichotomy are striking (Fig. 7).

The CTD requires 12.5 mA while logging internally (profiling) and 30 mA while moving data onto the flash card at the end of a profile. The comparable drains for the ACM are 25 mA and 40 mA. The micro-controller requires 2 mA while active and 0.5 mA in low power sleep. Most of a deployment is spent in the latter condition. On average this means a total drain from the battery

Fig. 6　Data strage

while profiling of 180 mA to 200 mA under field conditions. During data storage, 10% to 15% of the elapsed profile time, the drain averages 50 mA. As based on previous measurements test, that the endurance of a MMP equipped with a 240 Ahr lithium battery is 1.1 to 1.2 million meters.

6. Vehicle movement

The vehicle was ballasted to be neutrally buoyant at the mid-point of the profiling range (Fig. 8). The MMP sensor suite includes a CTD and a 4-axis acoustic current meter. The profiling schedule of the MMP can be tailored, within limits, to fit the requirements of a particular investigation. Typically, the profiler is programmed with a periodic schedule of single profiles or up/down pairs of profiles. Paired profiles reduce the effects of bio-fouling by parking the vehicle at the bottom of the profiling range during periods of inactivity. The system can also be set for continuous profiling or for burst sampling. The excursion limits of a profile, shallow and deep pressure levels are set by the operator.

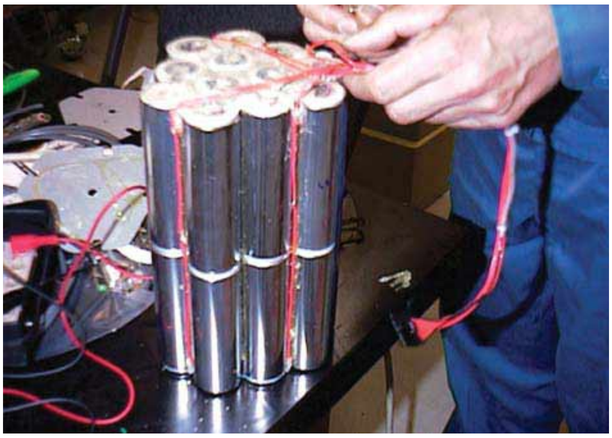


Fig. 7 Lithium battery pack V1-V8: 11.68

The profiler normally terminates a profile when the target pressure is reached, however, pressure rate, depth relative to physical stops on the mooring, elapsed time, and several engineering parameters are also monitored and used to control profiler actions.

7. Kuroshio Extention deployment

We deployed this MMP on May 21, 2001 in the northwestern Pacific Ocean as a contribution to the Kuroshio Extension System Study (KESS) (Fig. 9). The mooring was placed in 5,754 meters of water at lat. 35.08 degrees North, lon.146.46 degrees East.

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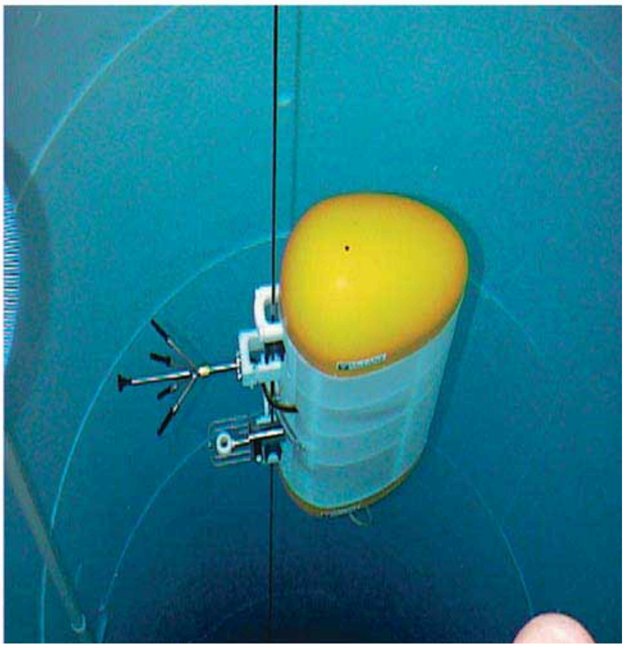

Fig. 8 Vehicle movement. The vehicle was ballasted to be neutrally buoyant at the mid-point of the profiling range.

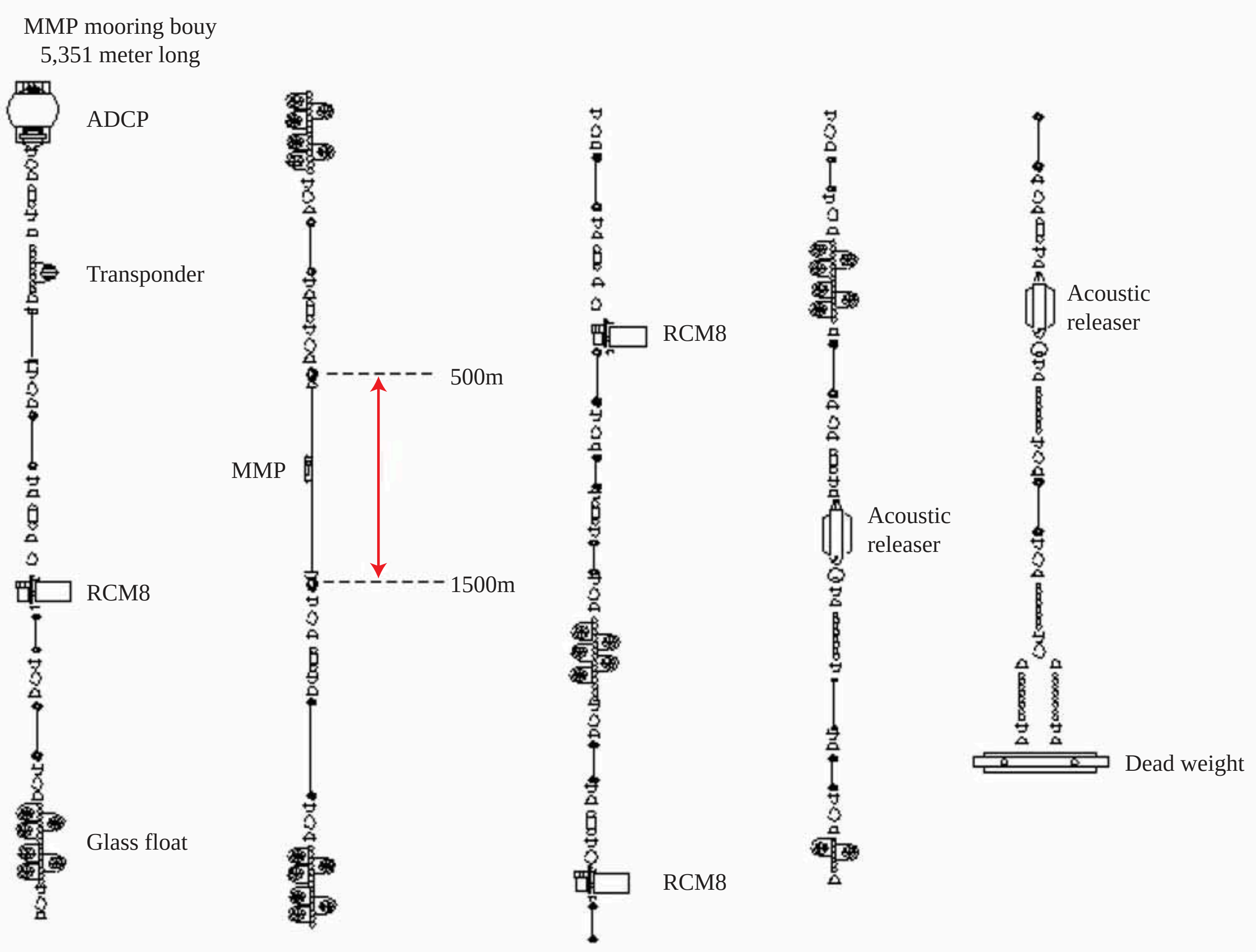

Fig. 9 Kuroshio Extention deployment. We deployed this MMP on May 21, 2001 in the northwestern Pacific Ocean as a contribution to the Kuroshio Extension System Study (KESS). The mooring was placed in 5,754 meters of water at 35.08° N, 146.46° E.

with a periodic schedule of single profiles or up/down pairs of profiles. Paired profiles reduce the effects of bio-fouling by parking the vehicle at the bottom of the profiling range during periods of inactivity. The system can also be set for continuous profiling or for burst sampling. When burst sampling is selected, profiles are conducted in regular bursts of periodic profiles or profile pairs. The ability to conduct more complex patterns is planned for a later revision of the operating software.

In this mode profiles begin as soon as the data collected during the previous profile have been stored. The short anticipated duration of the deployment permitted use of this mode without exceeding data storage or battery capacity limits. The 440Mbyte flash card is sufficient for more than two million meters of travel with the standard suite of instruments. The excursion limits of a profile, shallow and deep pressure levels, are set by the operator. The profiler normally terminates a profile when the target pressure is reached, however, pressure rate, depth relative to physical stops on the mooring (Fig.10), elapsed time, and several engineering parameters are also monitored and used to control profiler actions [1), 2), 3), 4), 5)].

The profiling schedule called for initiation of an up-going/down-going pair of profiles every 6 hours. For this deployment the MMP was programmed to travel between 500 dbars and 1500 dbars pressure, an interval determined by the available length of mooring wire.

The mooring was recovered on October 14, 2001. The system successfully completed 1008 profiles (503 paired profiles plus the first down-going profile and a final up-going profile) before its battery was exhausted on September 26 and the system executed a controlled shutdown (Fig.11, 12). Even numbered profiles proceed

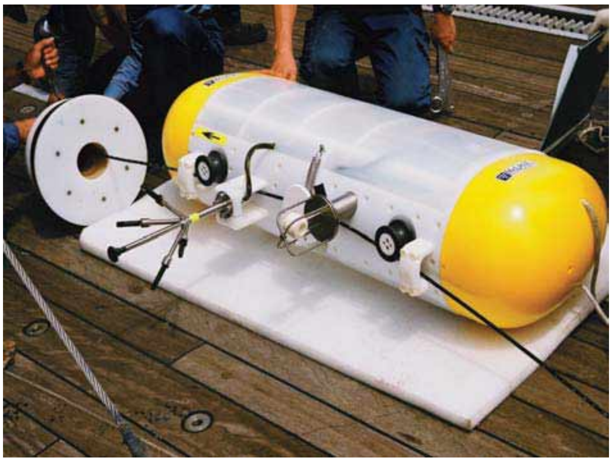

Fig.10　Bumper: physical stops on the mooring

Fig.12　Open the end cap

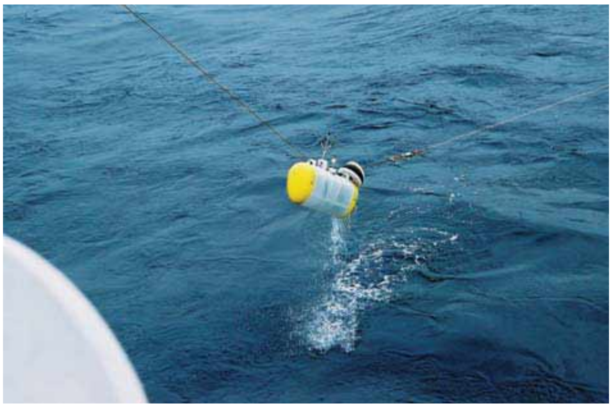

Fig.11　MMP Recovery. The mooring was recovered on October 14, 2001.

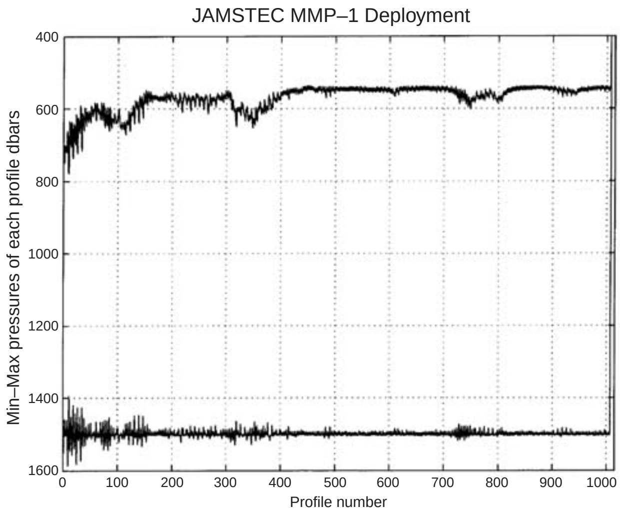

Fig.13　Min-Max pressure of each profiles Average motor current

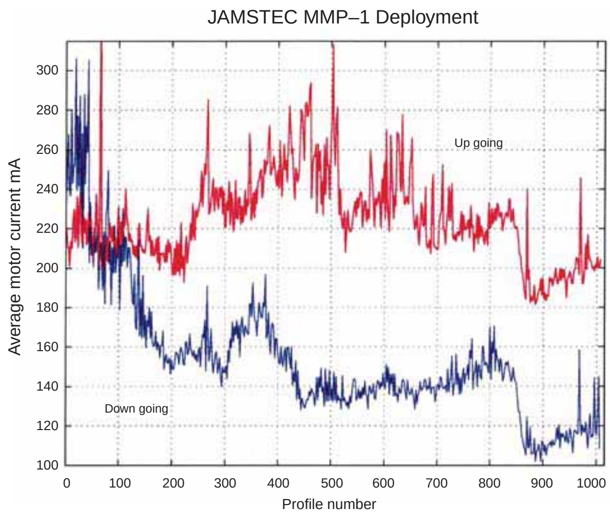

Fig.14　Average motor current

from shallow to deep. Profile 0 begins after a programmable delay to allow for deploying the mooring. It ends at the deep pressure limit, but has an arbitrary start depth that depends on the actual setting of the mooring and on vehicle ballasting (Fig.13).

Average motor current showed Fig.14. Note that the profiler was able to continue the mission, albeit with a greater drain on the battery. The motor current varies over the course of a profile because of changing buoyancy forces; the MMP is less compressible than seawater.

Average battery voltage showed Fig.15. Profiling speed depends on battery voltage. At the beginning of the deployment the lithium pack was able to deliver 10.4 V under load and the average profiling speed was 25.8 cm/s. By the end of the deployment the voltage under load had dropped to 8.0 V and the profiling speed was 25.5 cm/s. The standard lithium pack supplies a steady voltage under load of 10.4 V for 90% or more of

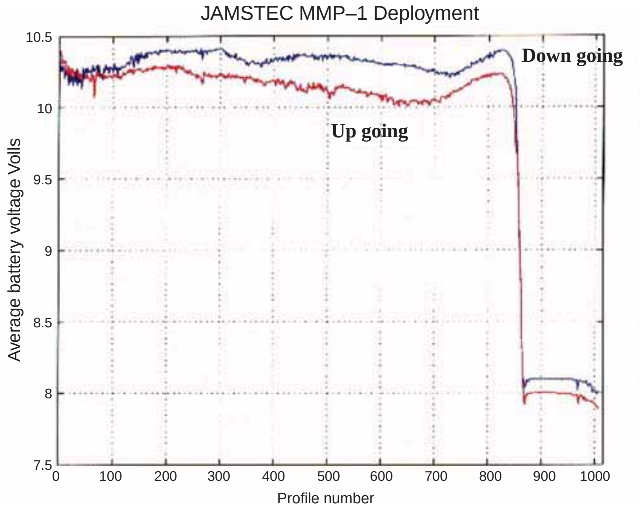

Fig.15 Average battery voltage

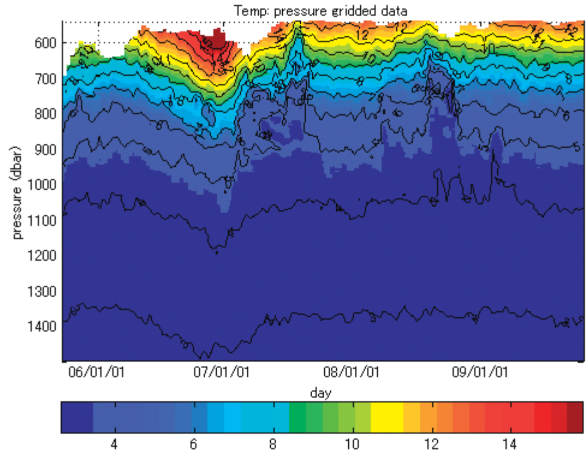

Fig.17 Time variation in vertical distribution of temperature

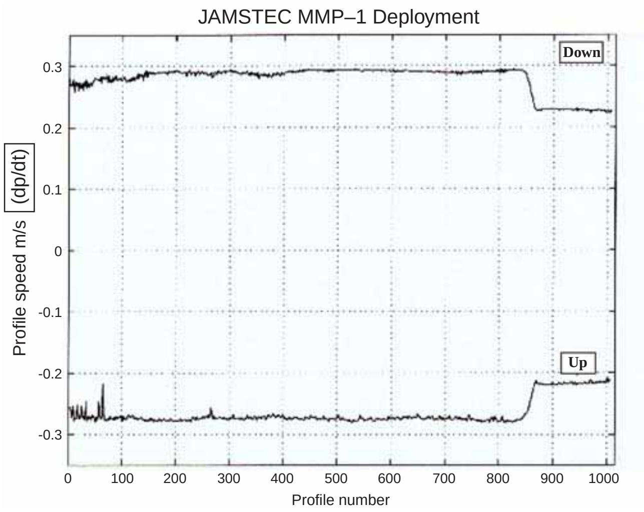

Fig.16 Profile speed

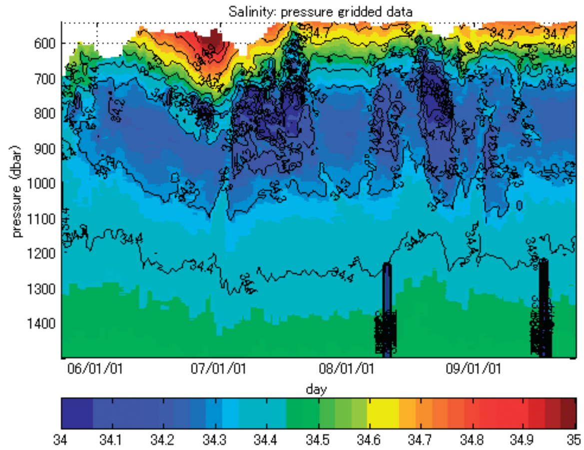

Fig.18 Time variation in vertical distribution of salinity (PSU)

its life. The nominal profiling speed at that voltage is 25.5 cm/s. Motor current depends, largely, on the hydrodynamic drag, which is proportional to the square of profiling speed.

Profile speed showed Fig.16. On average, it required 1 hour to complete each one-way profile and 11 minutes to transfer the data from the sensors to the non-volatile storage on the flash card. Our profiler logged a complete record of conductivity, temperature, pressure, ocean current, and system engineering information. The total profiling distance was 934,750 meters, which is a record for MMP operation in the world ocean.

8. Profiling data output

8.1. Time variation in vertical distribution of temperature at mooring site from May 21, 2001 to September 25, 2001. (Fig.17). In particular, the baroclinic structure of a cold eddy and the Kuroshio Extension are examined. These data are averaged at every 10 db at each cast. This profile interval is with respect to each 8 section. The beginning in June, this mooring system was leaned by strong current. In July and August, cold water mass pass through this area.

8.2. Time variation in vertical distribution of salinity (psu) at mooring site from May 21, 2001 to September 25, 2001 (Fig.18). This profile interval is with respect to each 8 section. The blackened area under this figure failed the data. The end-June, this mooring system was leaned by strong current. In July and August, low salinity mass pass through this area.

8.3. Correction for horizontal velocity calculation

1) Magnetic correction
2) Compass bias correction
3) Apparent velocity due to the inclination of the system and autonomous MMP movement

We have the original data for the inclination of MMP which are T(X) and T(Y) unit degree) (Fig.19). We also have the vertical velocity which includes the autonomous movement of MMP (which is V(Z)). Where (X,Y,Z) are coordinates reference to the MMP and (x,y,z) are reference to the geographical coordinates (longitude, latitude, and vertical).

Apparent horizontal velocity arises from the inclined mooring system and autonomous vertical movement of MMP. We named it as 'tilt velocity' (Vt(x) and Vt(y)). Tilt velocity should be corrected (Fig.20).

After we convert T(X) and T(Y) into T(x) and T(y) (unit: radian) because MMP can spin horizontally, we can calculate tilt velocity as

$Vt(x) \sim V(z)\sin\{T(x)\}$

$Vt(y) \sim V(z)\sin\{T(y)\}$.

(Here, $V(Z) \sim V(z)$)

8.4. Eastward and northward velocity (Fig.21, 22, 23, 24)

Time variation in vertical distribution of eastward velocity at mooring site (i.e., from 500 db to 1500 db). Apparent velocities caused by tilt of the mooring system and by autonomous movement of MMP are removed by clinometric data and vertical velocity data. Axes are transformed from x^- and y^- axes of MMP to the geographical latitude and longitude.

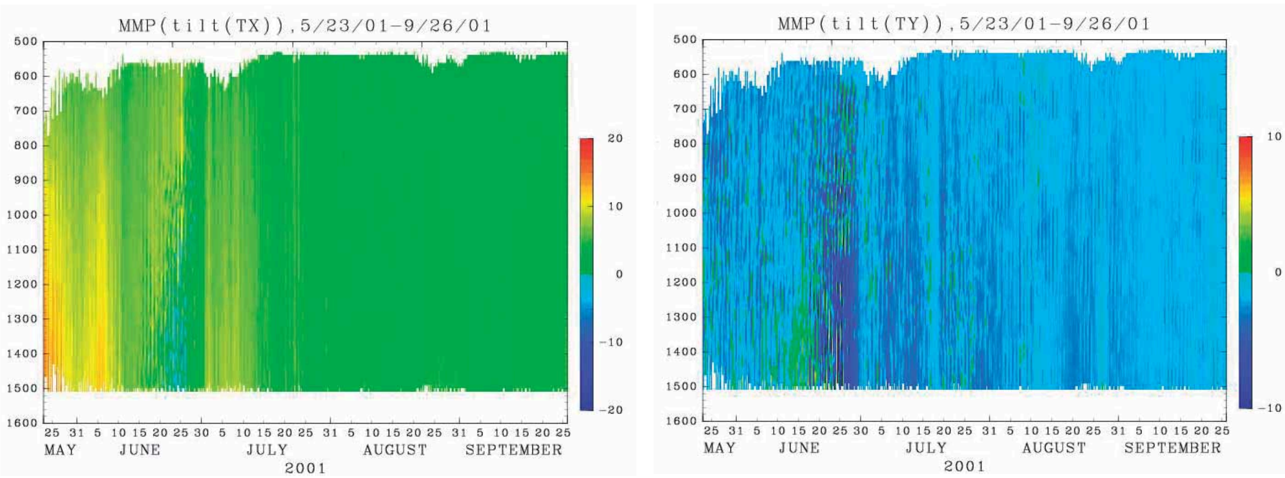

Fig.19 Time variation in vertical distribution of tilt (tx) at mooring site. Color bar shows degree of the angle.
Time variation in vertical distribution of tilt (ty) at mooring site

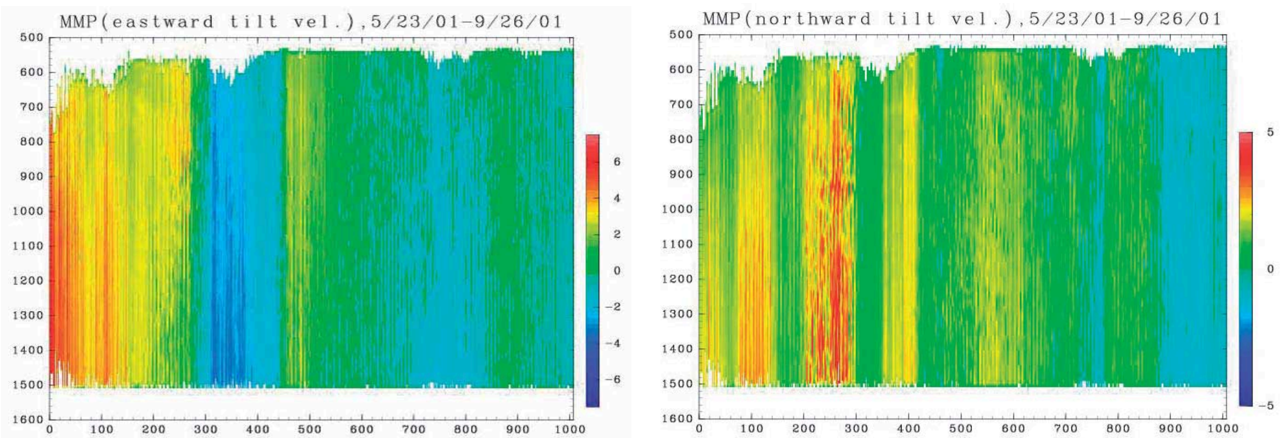

Fig.20 Eastward tilt velocity (left) and northward tilt velocity (right). Color bar shows velocity (cm/sec).

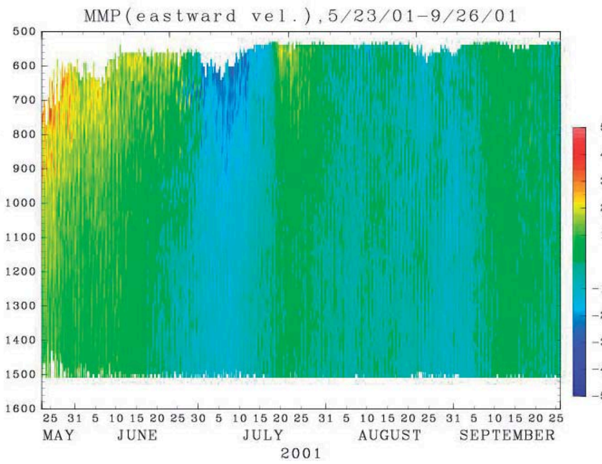

Fig.21 Eastward velocity. Color bar shows velocity (cm/sec).

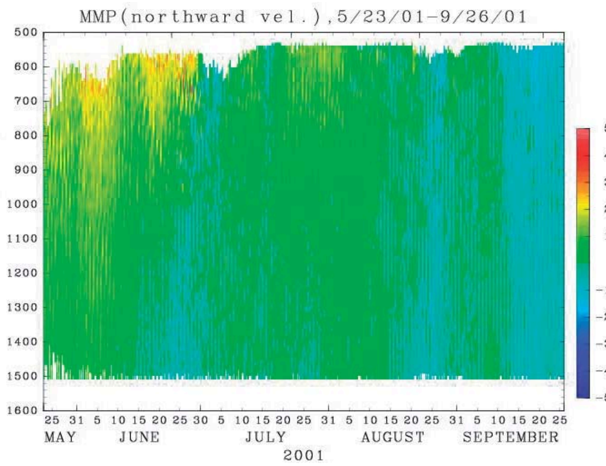

Fig.23 Northward velocity. Color bar shows velocity (cm/sec).

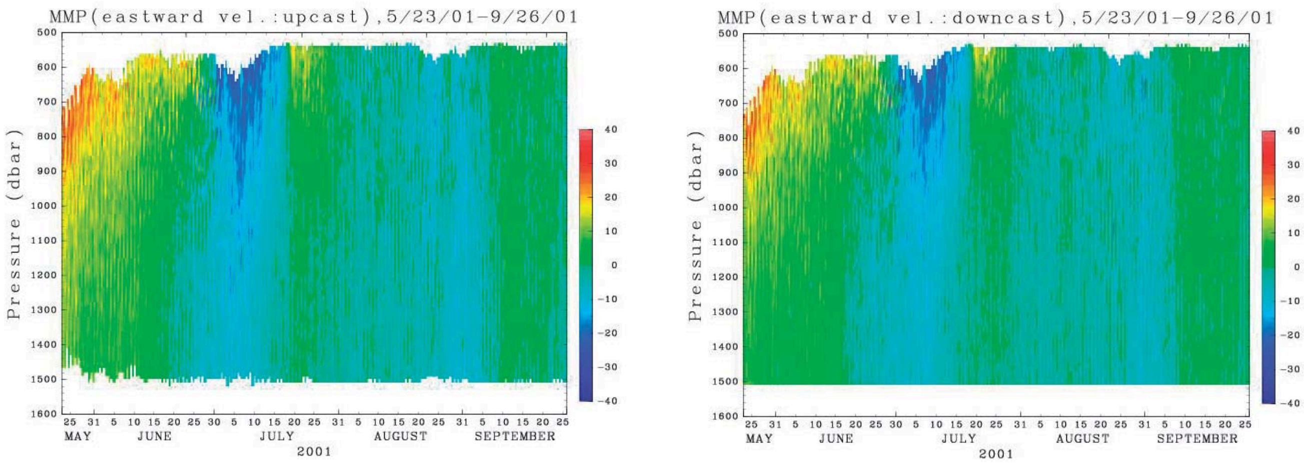

Fig.22 Time variation in vertical distribution of eastward velocity (upcast, downcast) at mooring site (i.e., from 500 db to 1500 db). Color bar shows velocity (cm/sec).

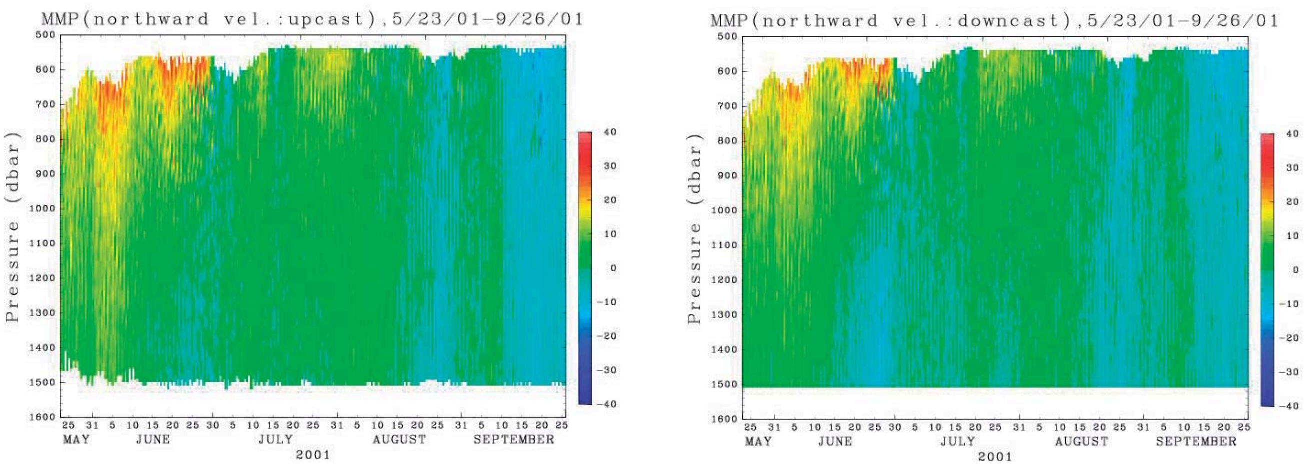

Fig.24 Time variation in vertical distribution of northward velocity (upcast, downcast) at mooring site (i.e., from 500 db to 1500 db). Color bar shows velocity (cm/sec).

8.5. The Stability of MMP data

We calculated the stability of MMP data using the Richardson Number. This method of calculated as blow.

$$\text{Stability} = -(g/\rho\_0)\times(d\rho/dz) / (dU/dz)^2$$

U: total velocity(sqrt(u^2+v^2)), (calculated the magnetic correction, compass bias correction tilt velocity)

ρ : potential density

ρ_0=1.020

dz: pressure

These data are averaged at every 10 db at each cast. This stability are averaged at every 10 db at each cast, too.

Ri<0	: convective instability (density stratification is instability)
0<Ri<0.25	: shear instability (Kelvin-Helmholtz instability)
Ri>0.25	: stability

As this stability rate(Ri) come up, vertical direction diffusion inhibited better than horizontal direction diffusion by buoyancy effect. We showed the stability data on Fig.25.

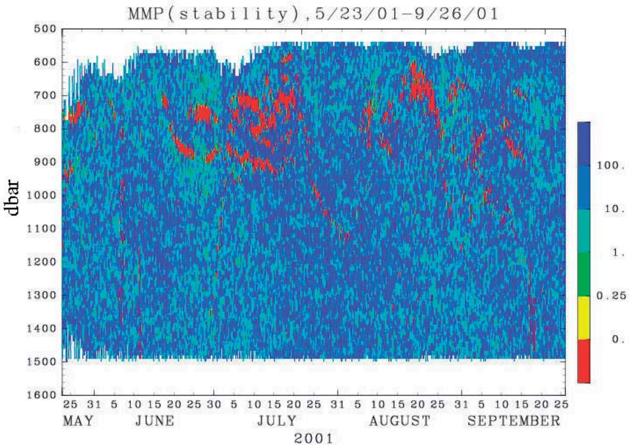

Fig.25 The fraction of velocity shear and stratified stability. It shows upper density is bigger than lower area in red area. The vertical mixture come into these area.

9. Summary

This was a very clean and largely successful this deployment. The MMP and the sensors performed well, providing greater confidence for the year-long scientific deployments now being conducted by other investigators.

Our profiler logged a complete record of conductivity, temperature, pressure, ocean current, and system engineering information. The total profiling distance was 934,750 meters, which is a record for MMP operation in the world ocean. In this paper we present an overview of the system's engineering performance and a preliminary scientific analysis of the temperature, salinity and ocean current data that were acquired.

These observations demonstrate the scientific value of 'seamless' data collected over several months with a moving profiler in support of oceanographic research. Given the good performance of the McLane Moored Profiler described here, we feel the Moored Profiler is now making the transition to an operational oceanographic system.

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