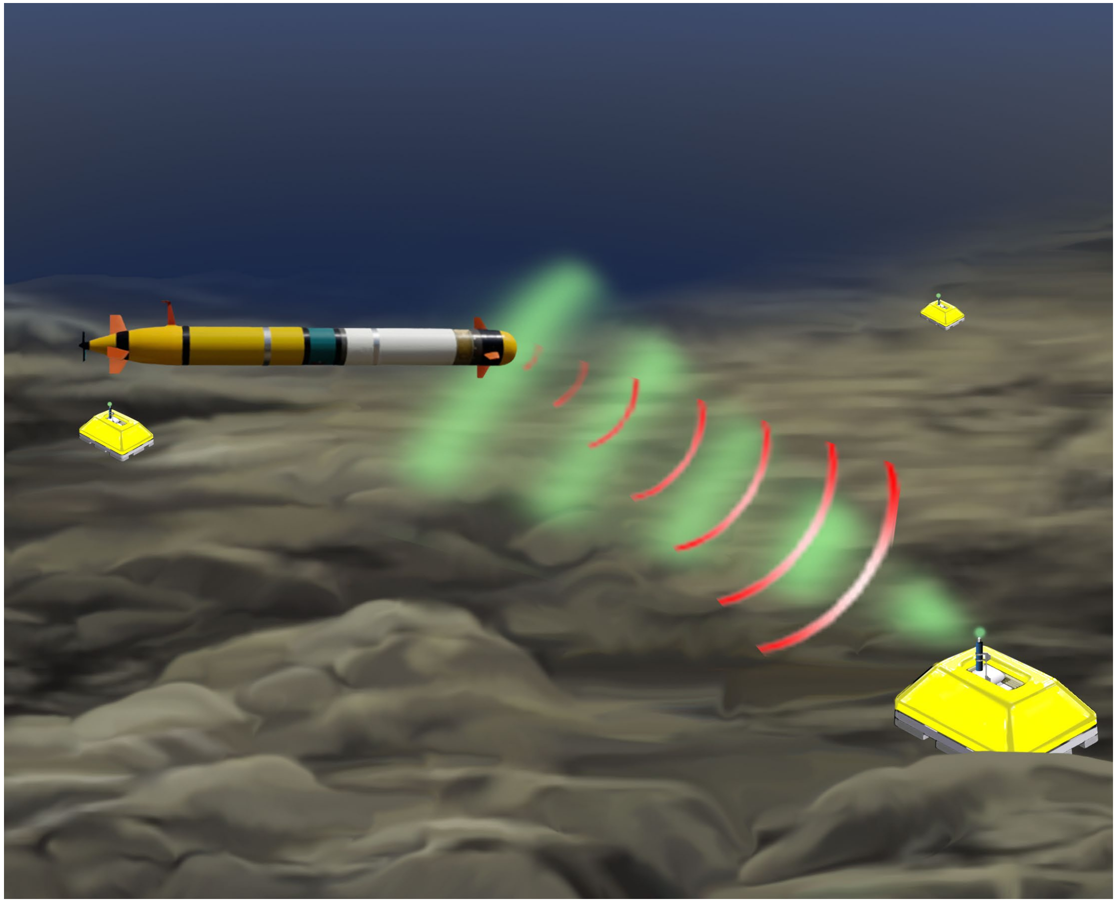
SEISMIC DATA RETRIEVAL USING AN AUTONOMOUS UNDERWATER VEHICLE AND HIGH-SPEED OPTICAL TELEMETRY

WHOI Ocean Bottom Seismograph Laboratory

OBS data access typically requires ship-based instrument recovery. Recent advances at WHOI in optical telemetry and marine robotics, coupled with the availability of COTS low-power seismic sensors, data loggers and atomic clocks offer the capability for multi-year deployments of OBS arrays that are capable of delivering high-frequency, accurately-timed seismic data to shore with data latencies of hours to days without OBS recovery.

In 2015, NSF funded a group of WHOI scientists and engineers (Collins, Farr, Ware, Purcell, and McGuire) to develop such a system by integrating a WHOI-designed optical modem capable of telemetry rates of 20 Mbits/second with an OBS and with a long-range (up to 286 nautical miles) REMUS Autonomous Underwater Vehicle (AUV).

These data rates rates allow telemetry of a week of high-rate (100 Hz) seismic data on 4 channels (ground motion and pressure) in minutes (or a year of data in less than 2 hours).

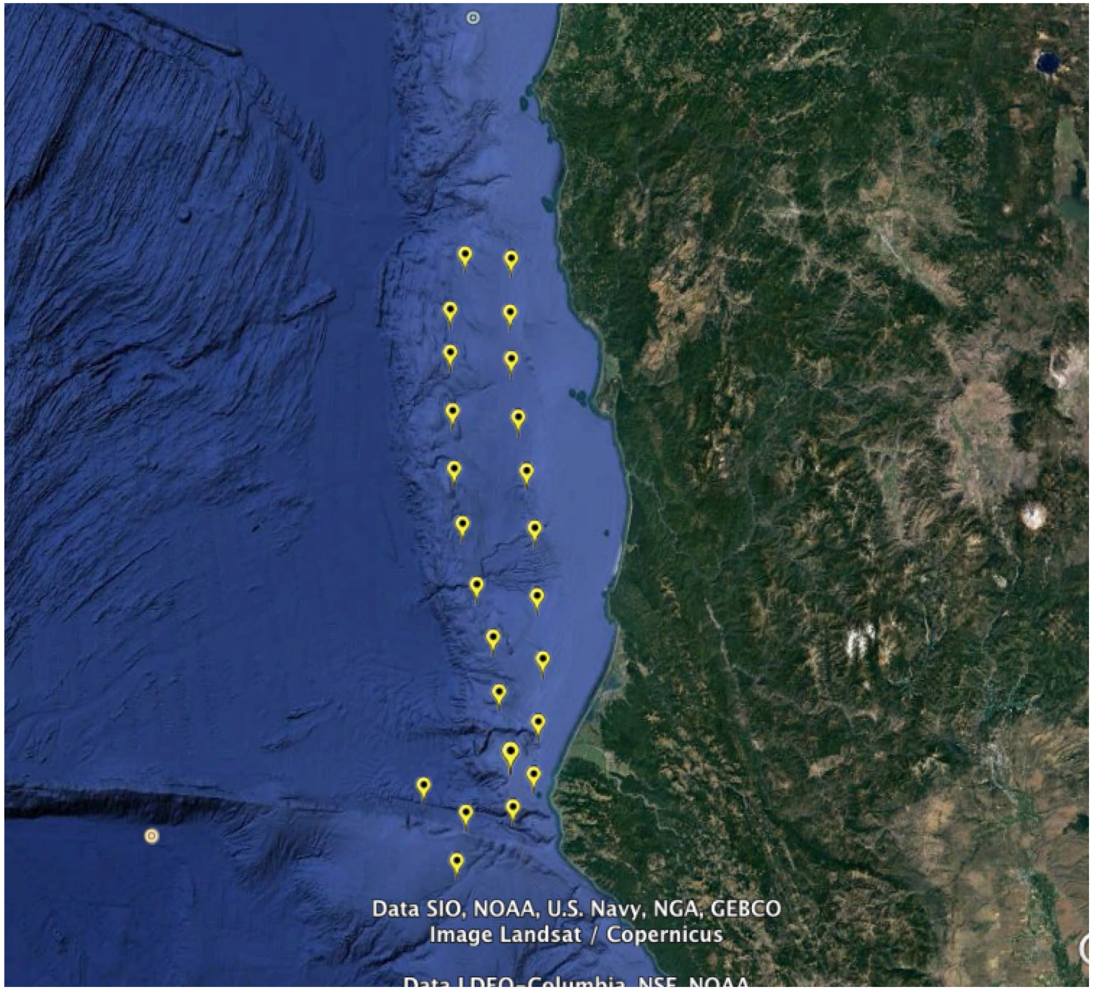


Accurate timing is critical for earthquake location but OBS lack GPS timing. The optical link will also allow measurement of the offset of the OBS clock relative to a GPS-synchronized time signal carried by the AUV to a precision of ~1 microsecond.

A Possible Southern Cascadia Observatory

These technologies will make possible multi-year deployments of OBS arrays with on-demand data offload and clock-check without the need for annual recovery/re-deployment cruises, saving hundreds of thousands of dollars per experiment. This capability will be particularly suitable for the dense near-shore arrays needed in subduction zones.

The figure shows one possible seismic array offshore northern California and southern Oregon of 24 OBS at a spacing of 20 km. This geometry would require an AUV mission of 300 nm (556 km). Offload rates of 20 Mbits/s means that a week of high-rate data would be downloaded in ~2 minutes. Total mission duration would be < 120 hours.

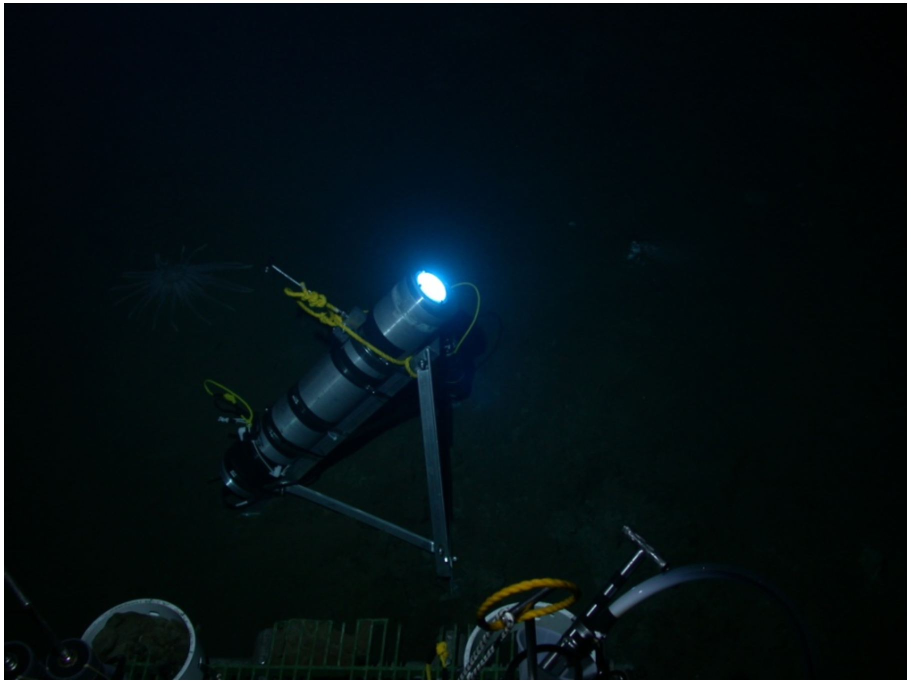


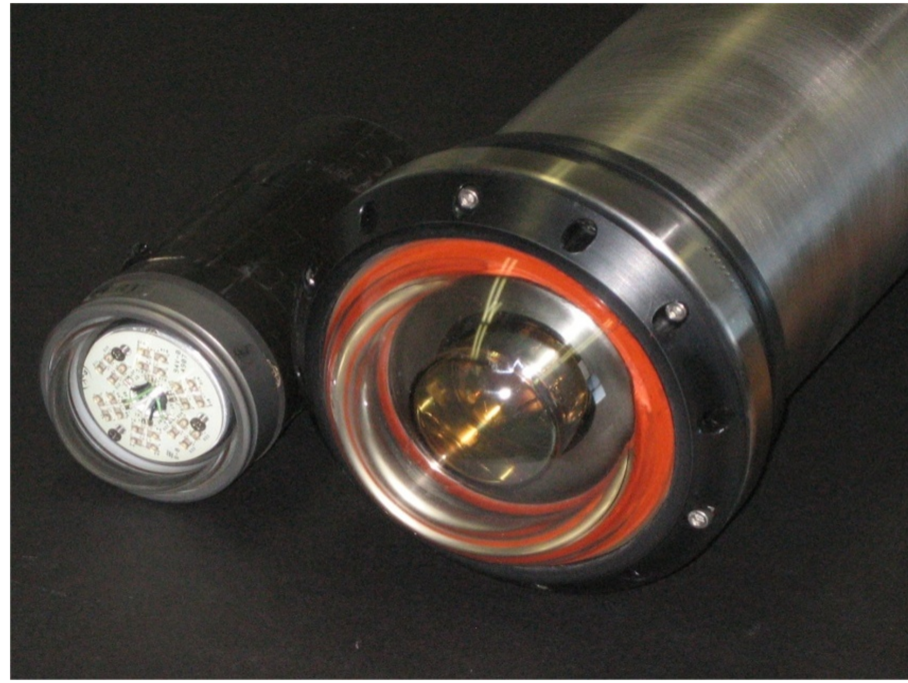
Acoustic vs. Optical Telemetry Comparison

	Optical	***Acoustic***
Data rate	10-20 Mbits/sec.	5 kbits/sec.
Range	150 meters	kilometers
Latency	micro sec	msec to sec
Efficiency	300k bits/J	1k bits/J

Acoustic and optical telemetry are complementary. The optical modem is a clear winner over short distances, while the acoustic modem is necessary for telemetry over distances exceeding a couple of hundred meters.
The WHOI OBS will be equipped with both acoustic and optical telemetry capability.

Optical Technology





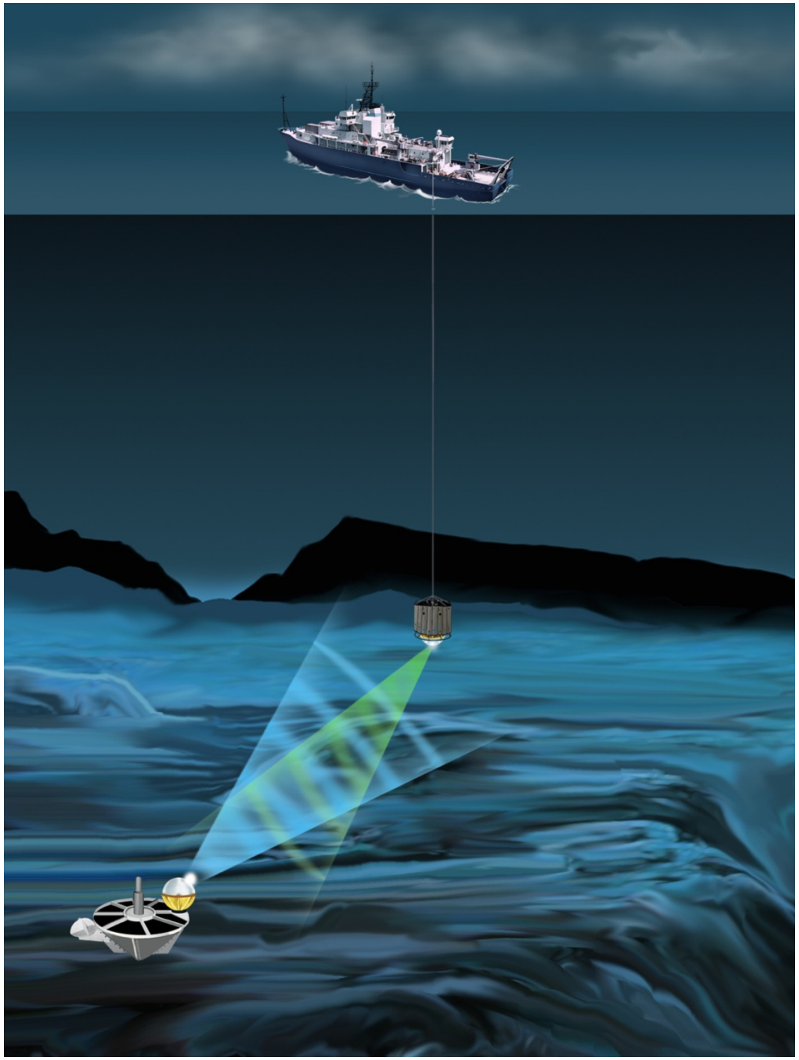
High power hemispherical transmitter

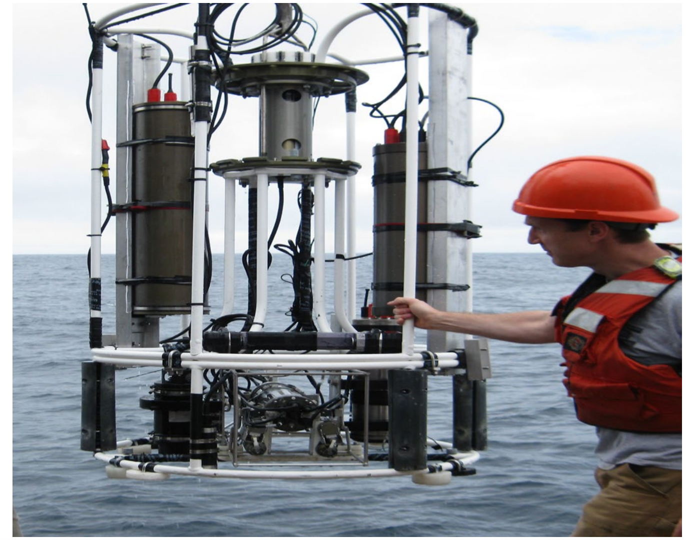
- 24 commercial light-emitting diodes
- 6 W avg. optical power

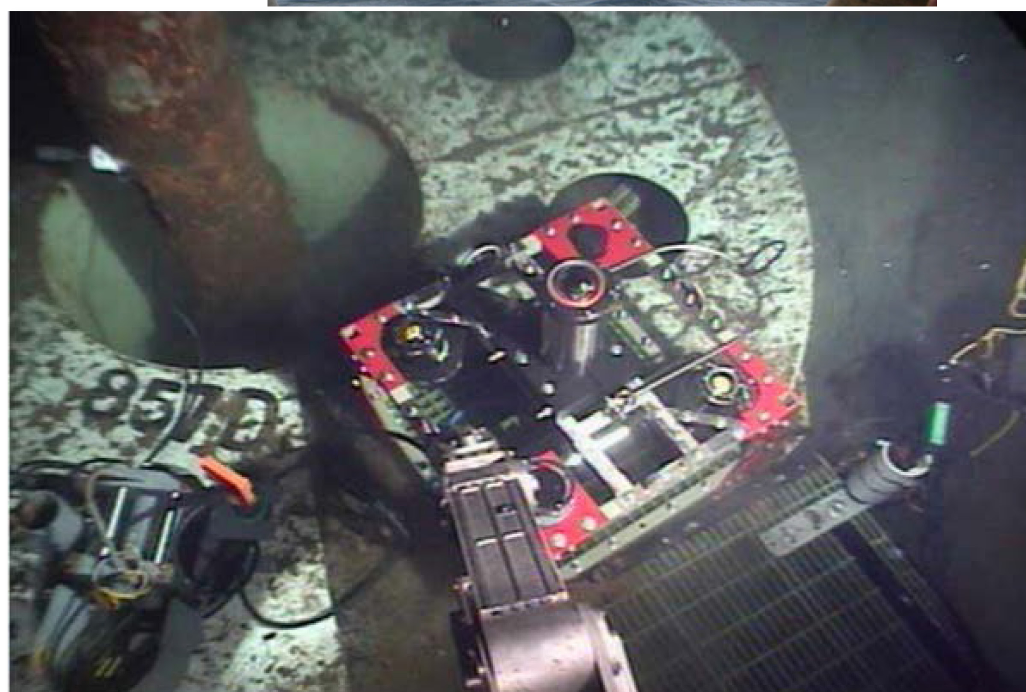
Sensitive hemispherical receiver

- 2-inch photo-multiplier tube
- Wide field of view gathers out-of-plane light
- AGC with blanking circuit
- Dynamic range Ws to 100s-nW

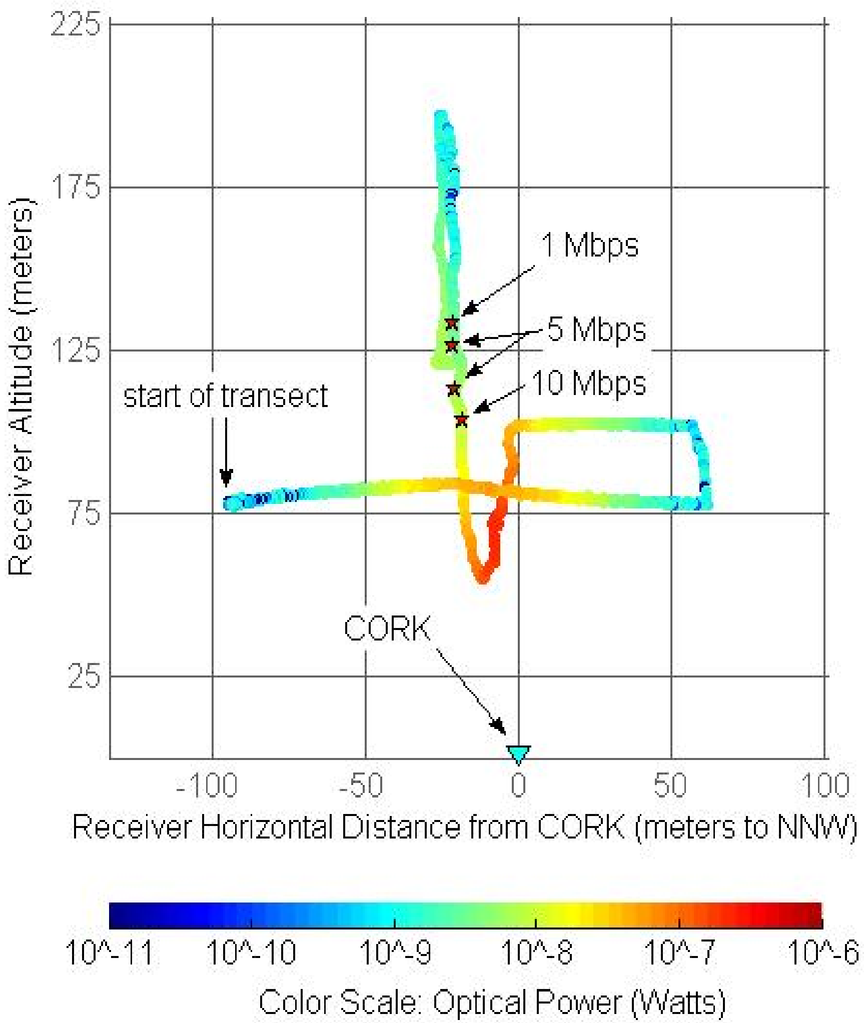
Data delivery via optical modem lowered on ship's CTD-wire.



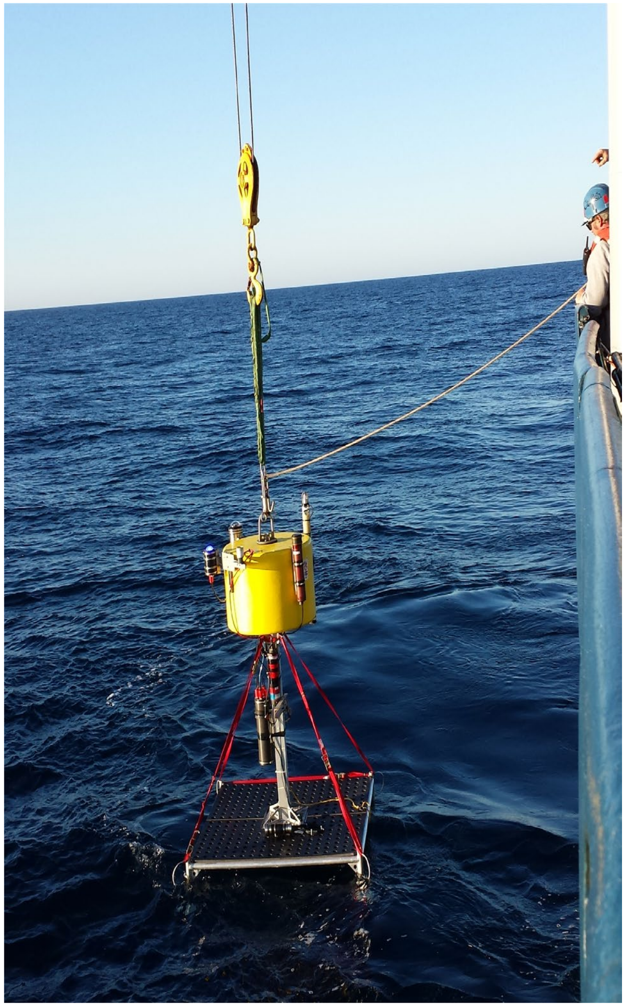


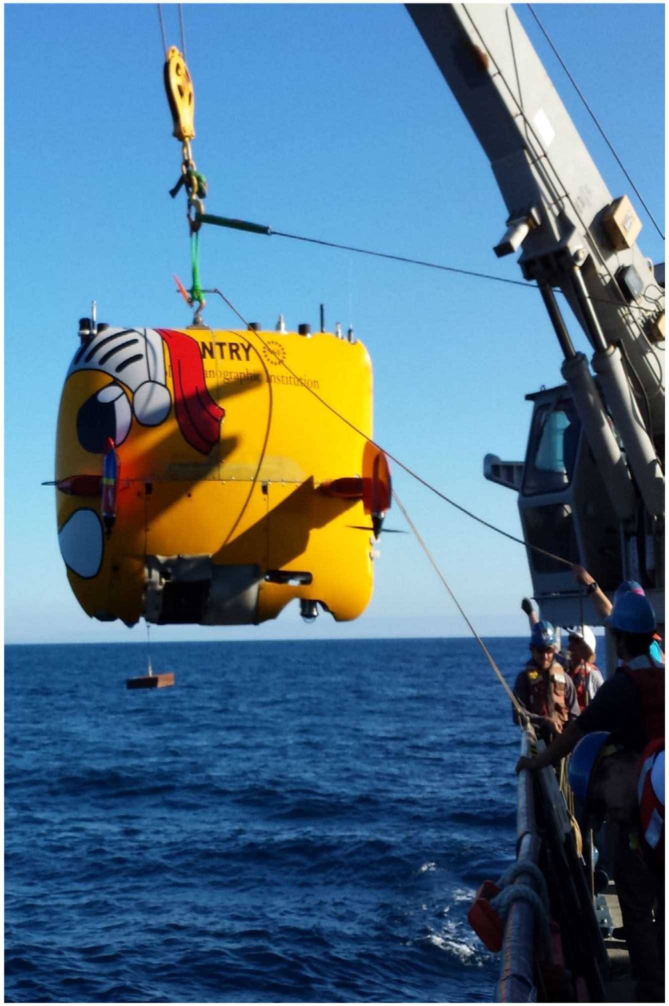


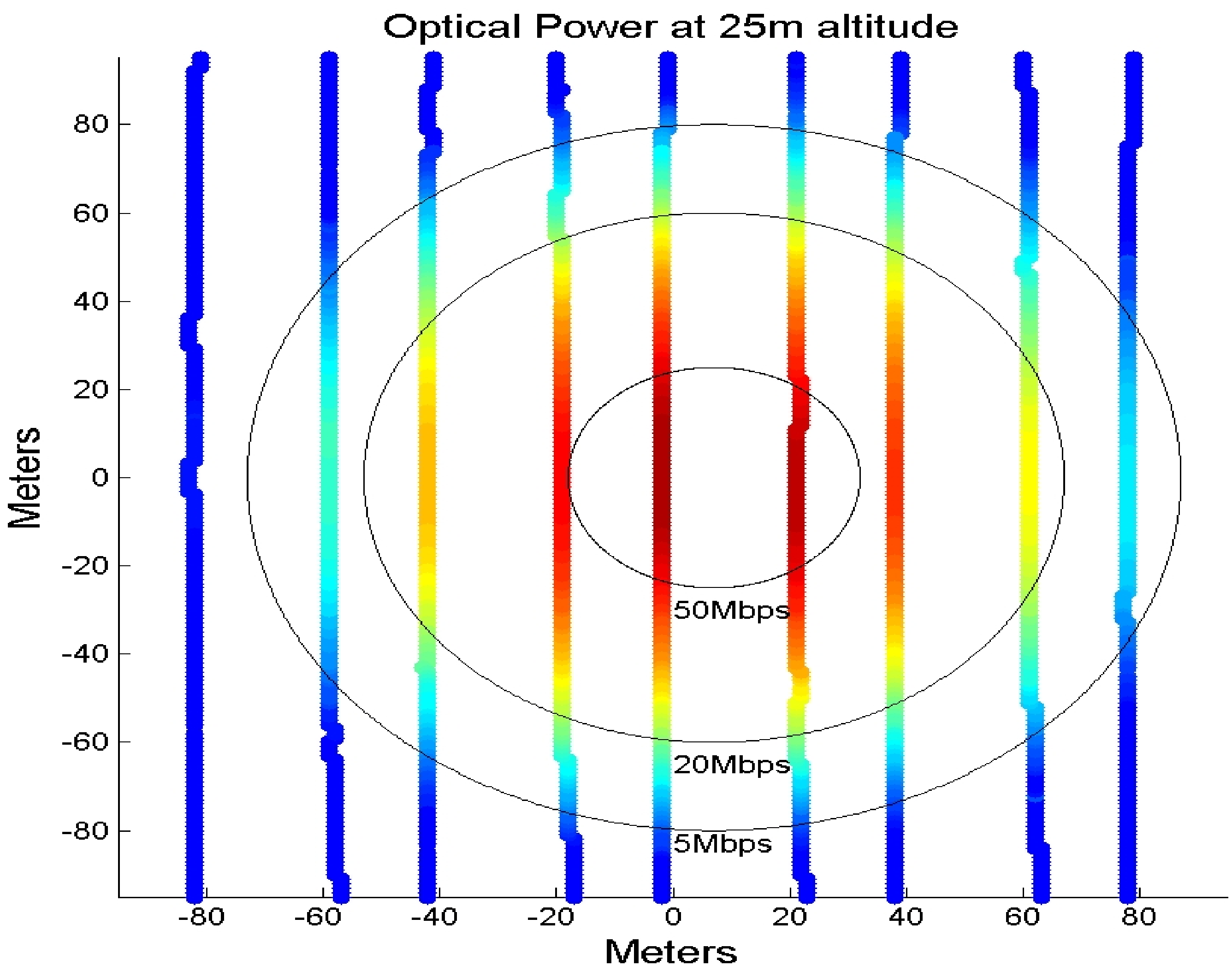
Range (meters)	Data transfer rate (mbps)
108	1, 5, 10
118	1,5
128	1,5
138	1



Beam field mapping using AUV





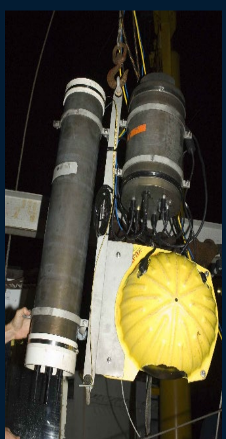


Optical modem power at 25 m altitude measured with the Sentry AUV. Circles of constant data rate are shown and labeled. These define the size of the loiter circle that an AUV needs to maintain to ensure the given data rate.

Milestones

2006 - 2008

8” receiver for long range omni directional 1Mbps

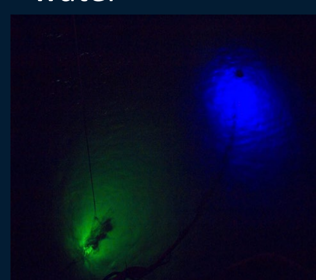


2008

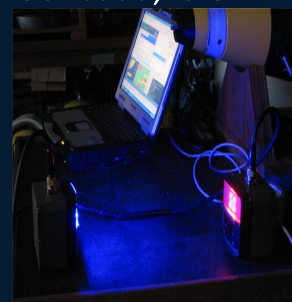
2’ receiver for long range omni directional 10Mbps

2009

Video through water



2009
Soft Docking System
Full daylight operation
56Kbaud, 0-5



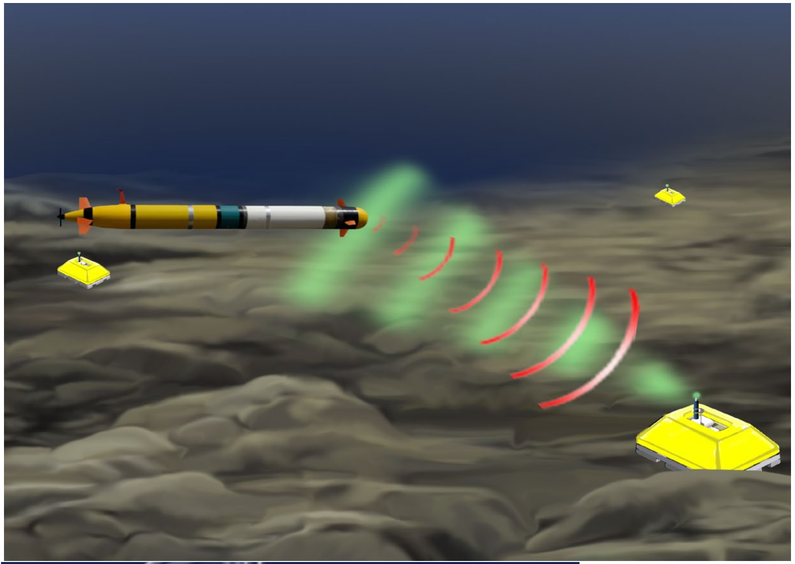
2012

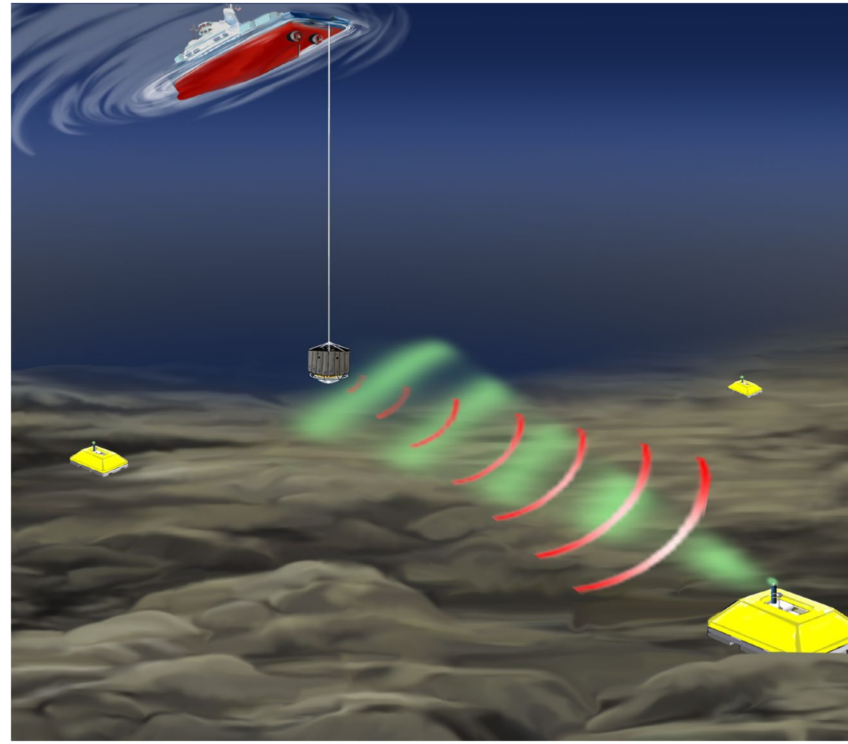
Remote vehicle control

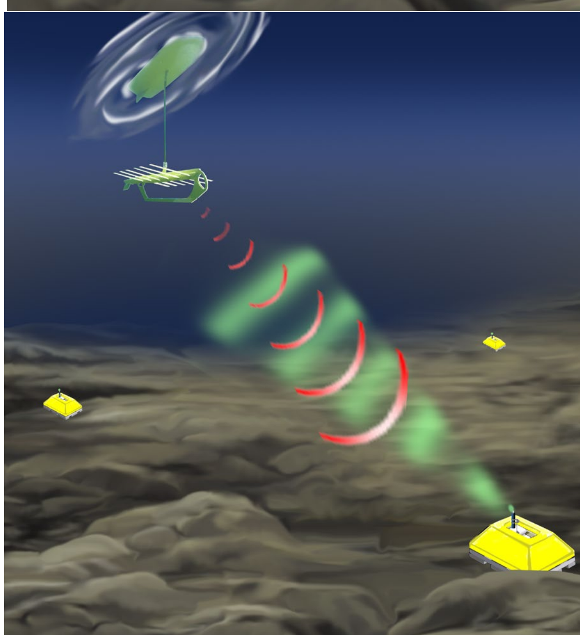
2013
High Ambient Light (HAL)
Hemispherical coverage
LED/PD transceiver
6Mbps data rate

2014
REMUS AUV integration
40 meter range
20Mbps throughput

2015
High rate
500 to 1000 Mbps
0 to 10 meters





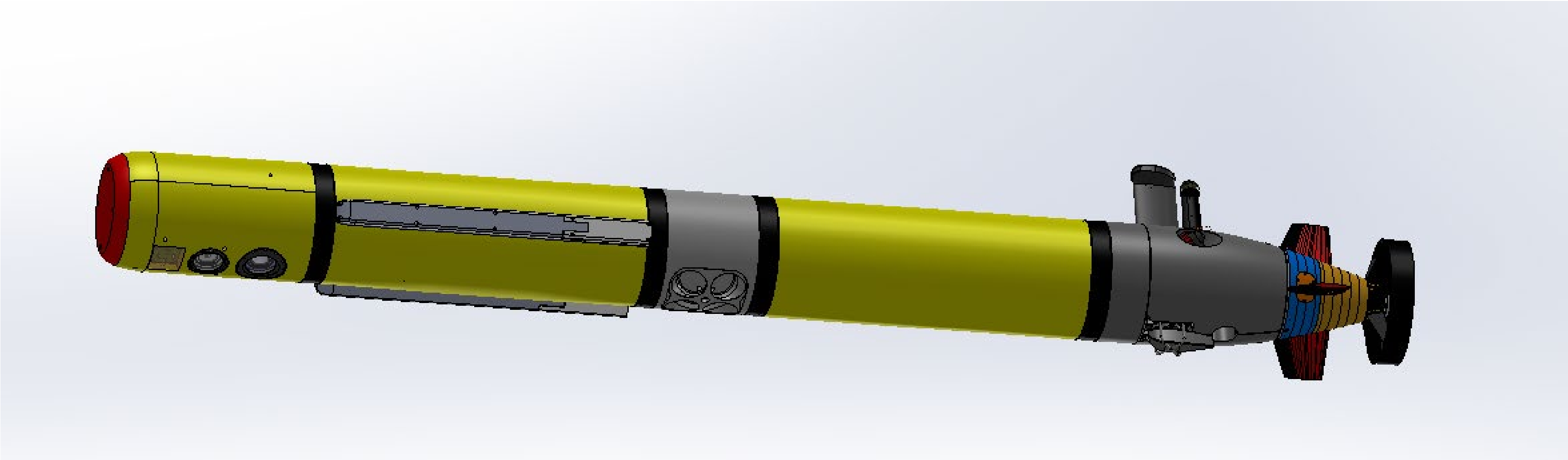


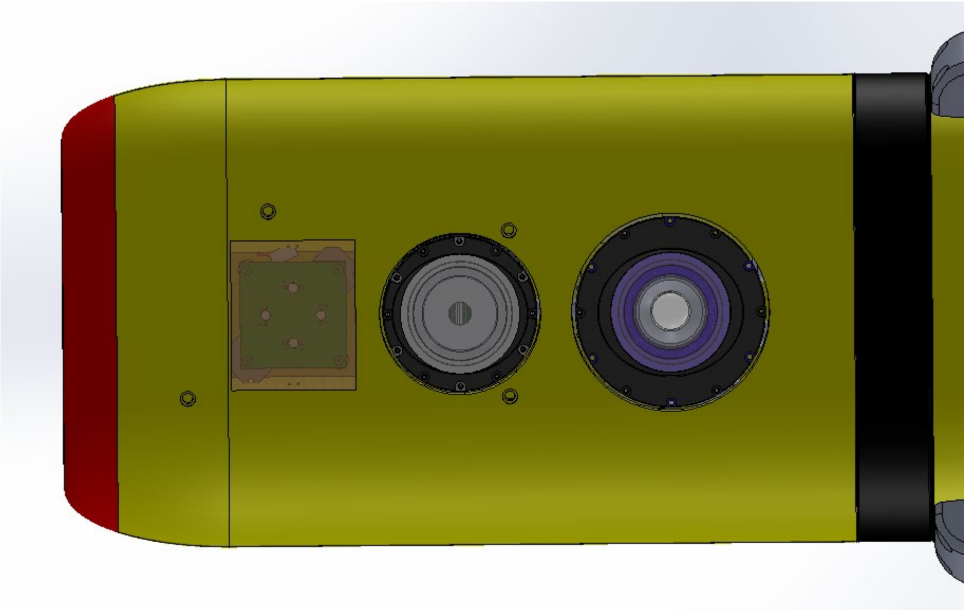
The optical modem is a versatile instrument that can be used from a variety of platforms. In addition to using an AUV (top left), the modem can be lowered on a ship's standard CTD wire to within ~100 m of the OBS (top right). Dynamic positioning is not necessary. Finally, Liquid Robotics® is now developing a winch system for their glider that will be capable of lowering the modem to ~150 m depth while providing 10 W of power and 10 Mbits/s Ethernet at the end of the wire.

The REMUS (Remote Environmental Monitoring UnitS) family of autonomous underwater vehicles (AUVs). From front to back: REMUS-100, REMUS Tunnel Inspection Vehicle, REMUS-600, REMUS-3000, and a REMUS-6000. The numbers indicate maximum operating depth in meters.

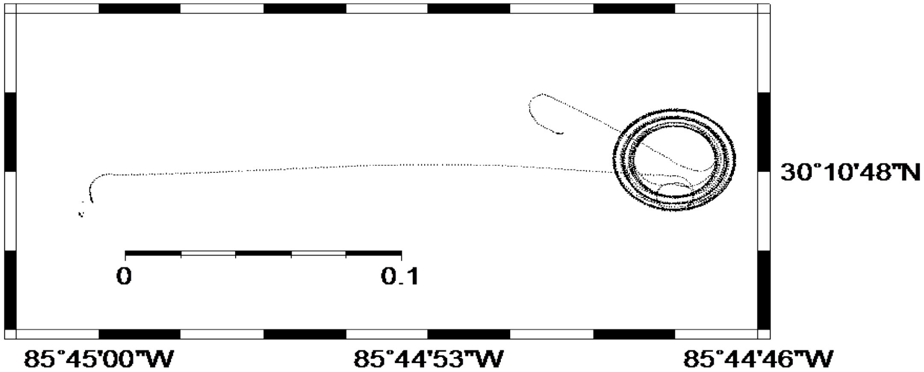
REMUS-600

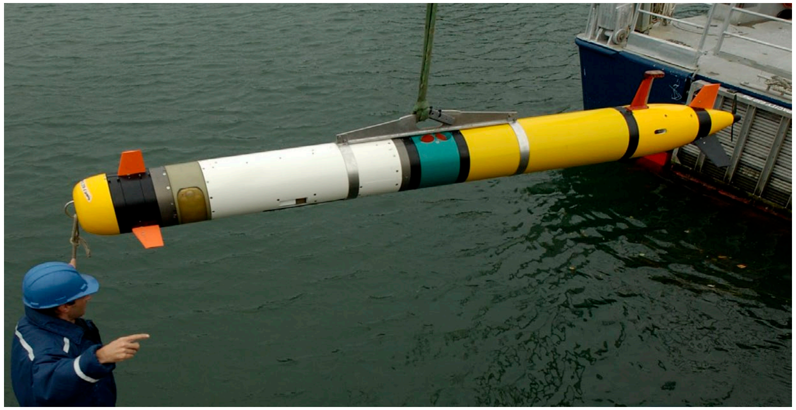
- Endurance: 72 Hours at 3 knots
- Range: 286 nautical miles
- Depth: 600 meters
- Length: 10 feet
- Weight: 530 lb
- Speed: Up to 5 knots
- Communications: OTH Iridium

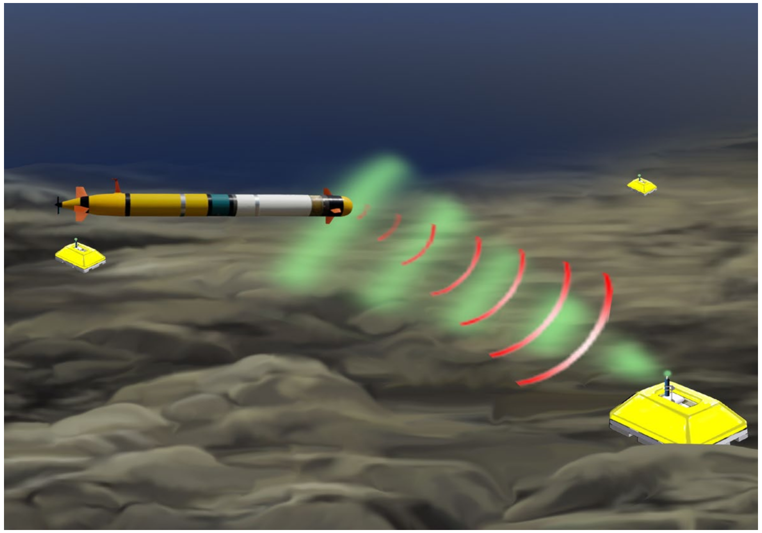


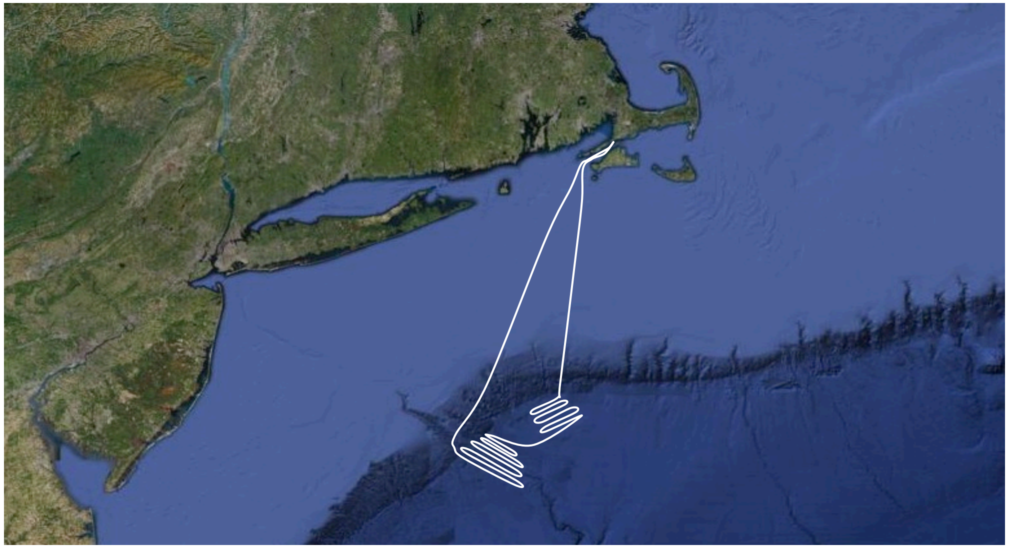


CAD drawings of how the optical modem will be mounted on the belly of the REMUS 600



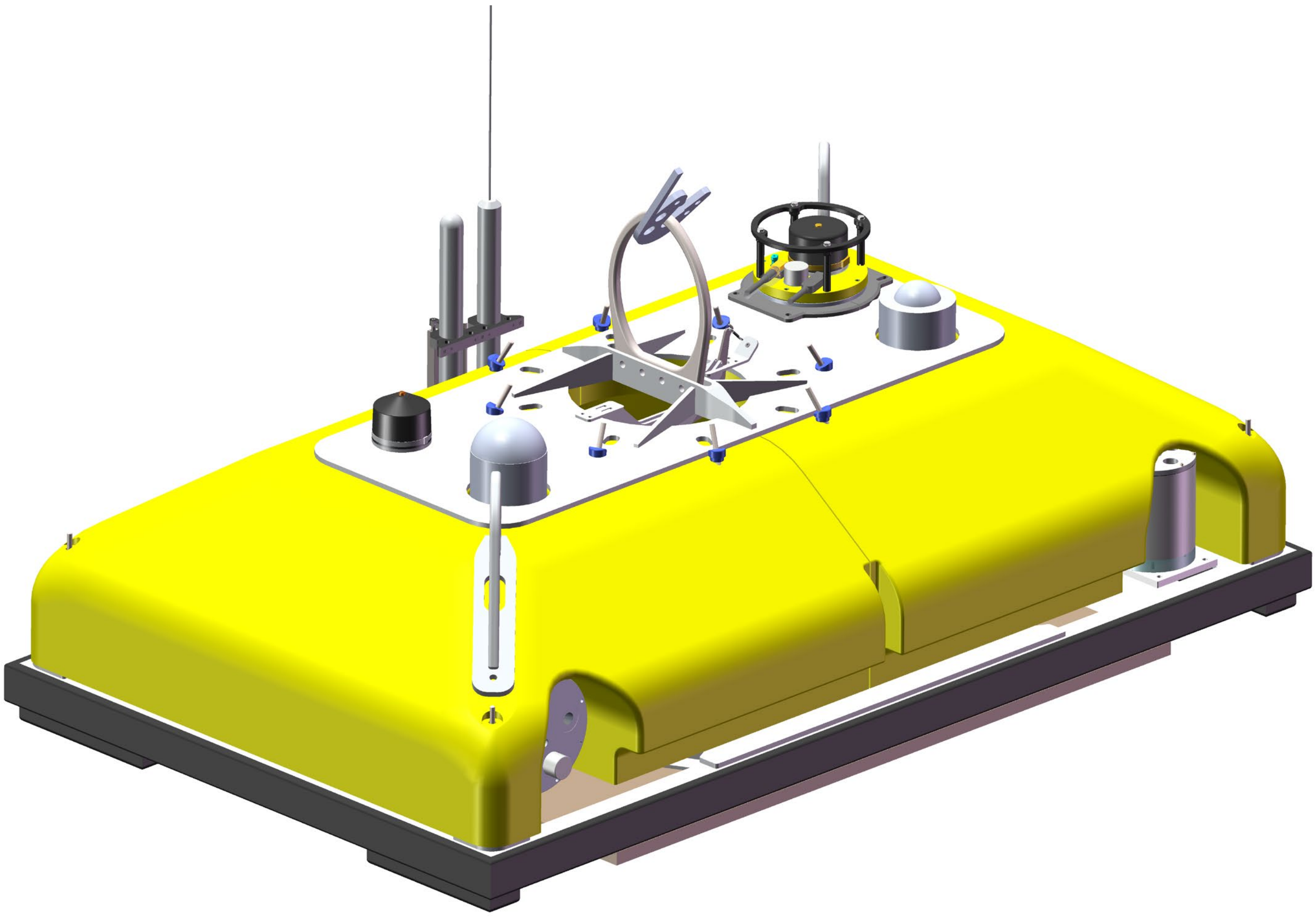


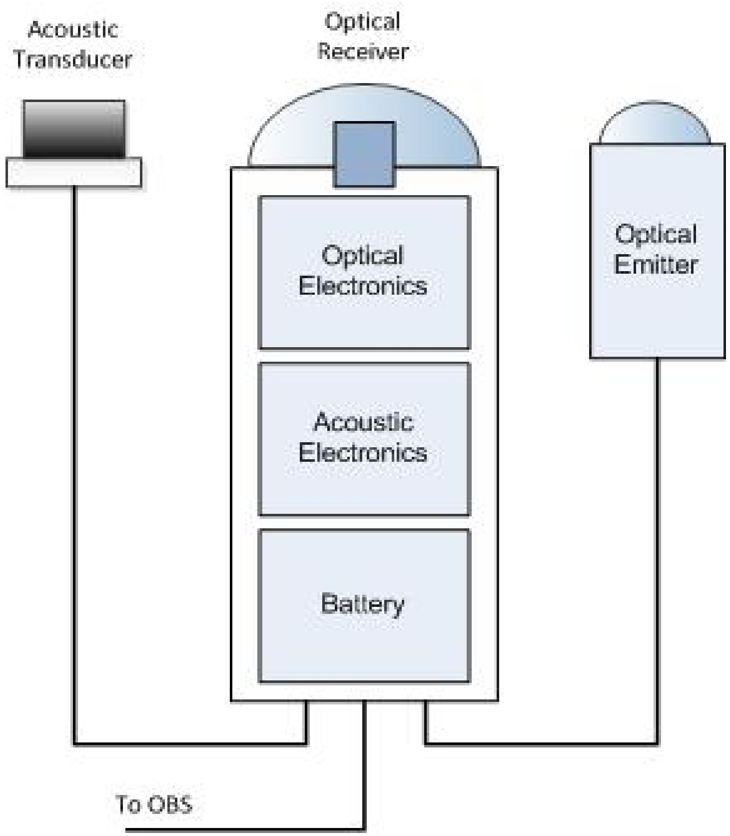




The REMUS AUV cannot hover over the OBS while retrieving data. Rather it loiters by steaming around the OBS. The figure at the top left shows the results of a field test of this capability. The scale bar is 100 m. The diameter of the circles that REMUS swims is ~20 m. Future development plans for REMUS include building a Long Endurance REMUS 600. Goal is speeds of 3 knots and an endurance of 6 days. The design target is transit to the shelf edge, data collection for multiple days, and then return to near-shore for recovery. Mission endurance would be doubled by going to a primary Li battery pack.

WHOI Shielded Two-Year Capable OBS with Integrated Optical and Acoustic Modems





Block diagram of communications system designed for integration into the OBS. The main optical receiver housing also contains an acoustic modem and batteries for the communications system for more than 2 years of data offload.