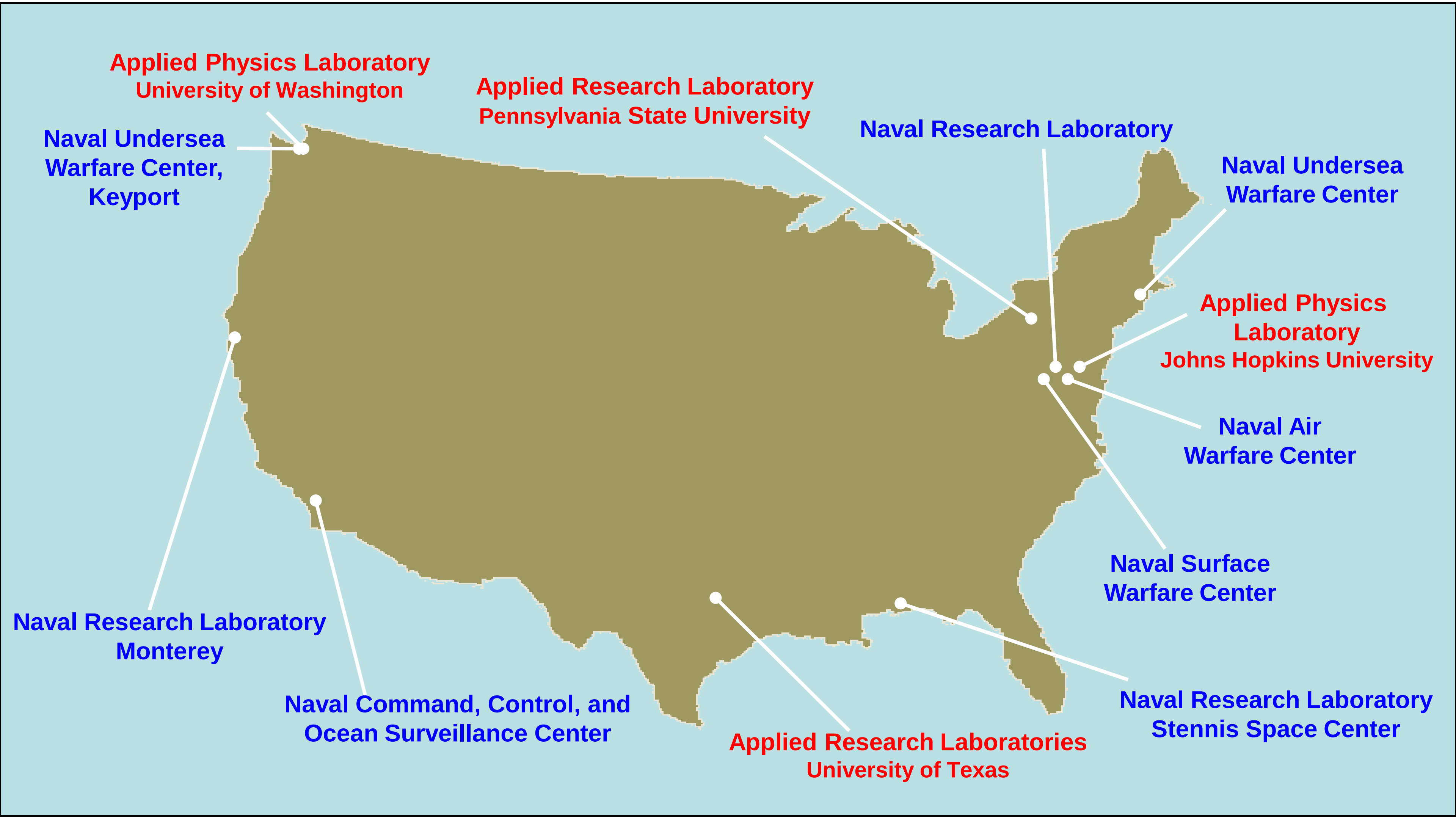
Autonomous Platforms in Persistent Littoral Undersea Surveillance: Scientific and Systems Engineering Challenges

David L. Martin, Ph.D., CAPT, USN (Ret.)

Associate Director
Applied Physics Laboratory
University of Washington
October 6, 2005

MAJOR NAVAL LABORATORIES, WARFARE CENTERS, AND UNIVERSITY LABORATORIES



AT A GLANCE

R&D Program

Ocean Acoustics – MCM, ASW, Acoustical Oceanography

Sonars – Imaging, Mine, Ship

Submarine Acoustic Systems – ACINT

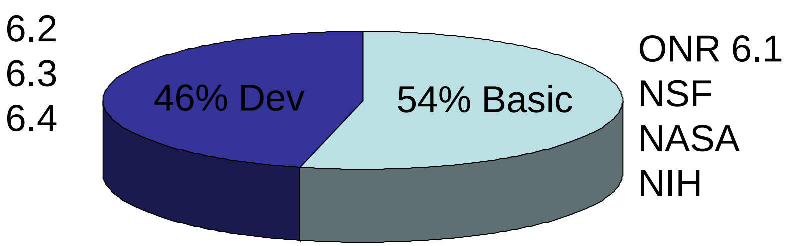
Arctic/Polar Science – Global Climate Change, SHEBA, SEARCH, SUBICEX

Ocean Physics – Turbulent Mixing, Electromagnetic Sensing

Satellite Remote Sensing - air/sea fluxes, aerosols, sea surface height, waves

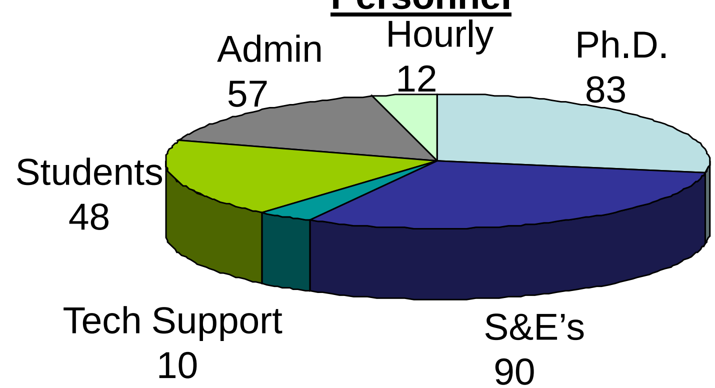
Medical Ultrasound - Acoustic Hemostasis, Imaging, High Intensity Focused Ultrasound, Lithotripsy

R&D Budget



$43M FY04
62% Navy Derived

Personnel



300 Total

Navy ASW CONOPs

TASK FORCE ASW

Anti-Submarine Warfare

Concept of Operations for the 21st Century

BACKGROUND

As we sail deeper into the 21st century, Anti-Submarine Warfare (ASW) will remain a core mission area for the United States Navy. Execution of that vital mission will be critical to protecting the strategic speed and operational agility of joint and coalition forces across the largest maneuver space in the world – the sea. The ASW capabilities we possess today when confronting potential enemies are based largely on skills developed during the Cold War. To sustain our operational advantage, we must develop additional skills, implement them in an innovative manner, and rapidly leverage advanced technologies to swiftly defeat enemies wherever they may be found.

This 21st Century ASW Concept of Operations (CONOPs) is intended to guide the development of a comprehensive ASW Master Plan that will be forthcoming shortly. It details operational principles and force attributes that we seek to develop in the years ahead. Our goal in the near term is to maximize our undersea advantage anywhere in the world by leveraging advances in acoustic processing, data collection and sharing, communications, collaborative real-time planning, reachback support, rapid maneuver, and precision engagement. These tactical advantages will allow friendly forces to take the fight to the enemy. In the far-term, we will build on these advances to fully leverage an integrated network of sensors coupled to stand-off weapons, thereby maximizing our advantages in persistence, speed, and precision as the conceptual framework for our future.

21st CENTURY OPERATING ENVIRONMENT

The 21st century environment is one of increasing challenges, due to the littoral environment in which we operate and advanced technologies that are proliferating around the world. Operations in the future will be centered on dominating near-land combat, rapidly achieving area control despite difficult sound propagation profiles and dense surface traffic. The operating environment will be cluttered and chaotic, and defeating stealthy enemies will be an exceptional challenge.

Operating Environment

- High traffic density
- Poor sound propagation
- High technology enemies
- Asymmetric challenges

- Near-term, leverage
  - *Data collection/sharing*
  - *Collaborative real-time planning*
  - *Reachback support*
  - *Precision engagement*
- Smart planning & precision execution in Hold at Risk and Secure Friendly Maneuver Area operations
- Far term, shift from "platform-intensive" to "sensor-rich" operations
  - *Networks of sensors coupled to standoff weapons*

Themes

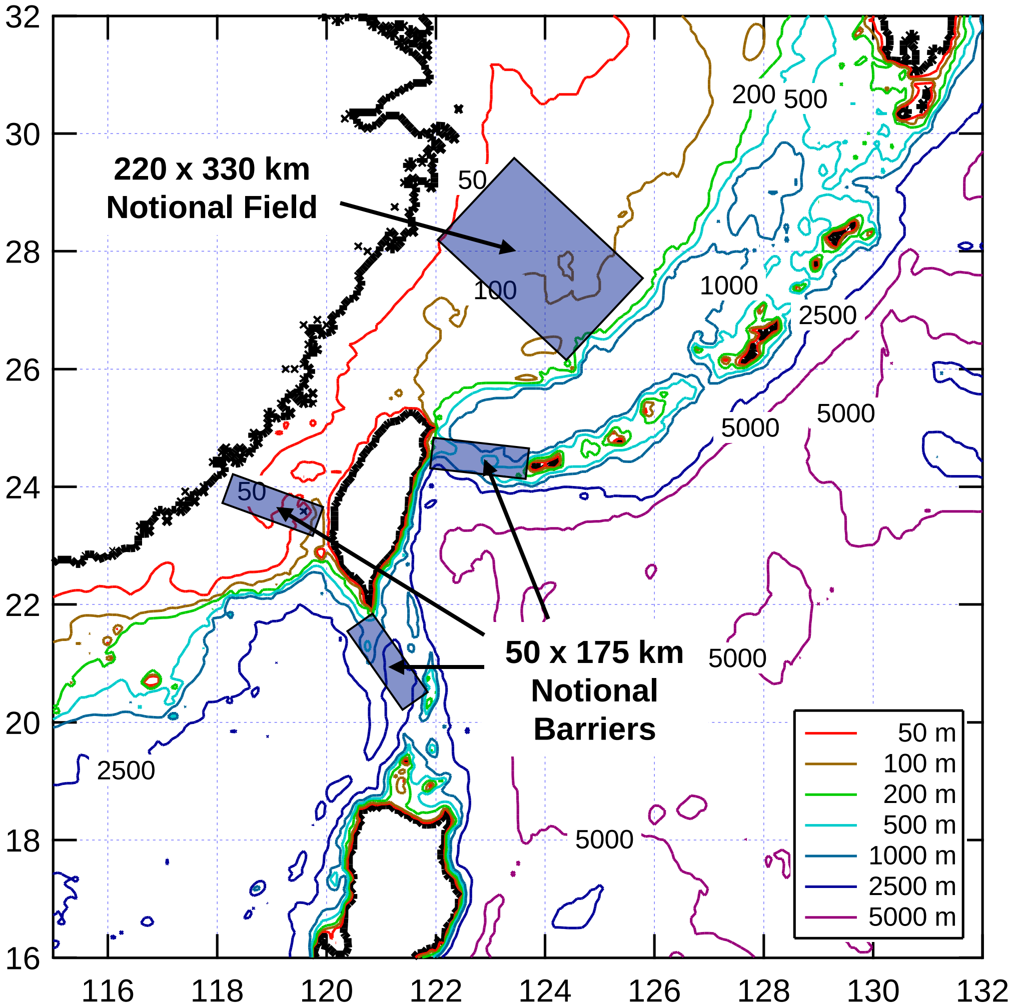
Persistence

Pervasive Awareness

Speed & Operational Agility

Technological Agility

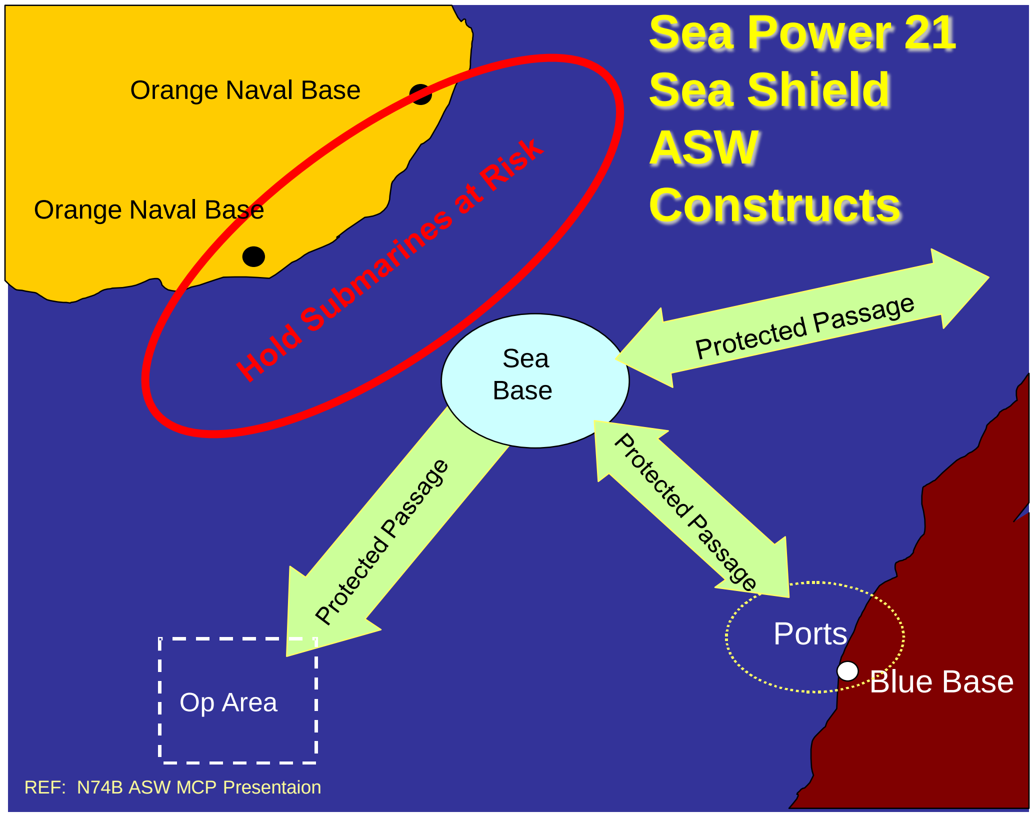
Background

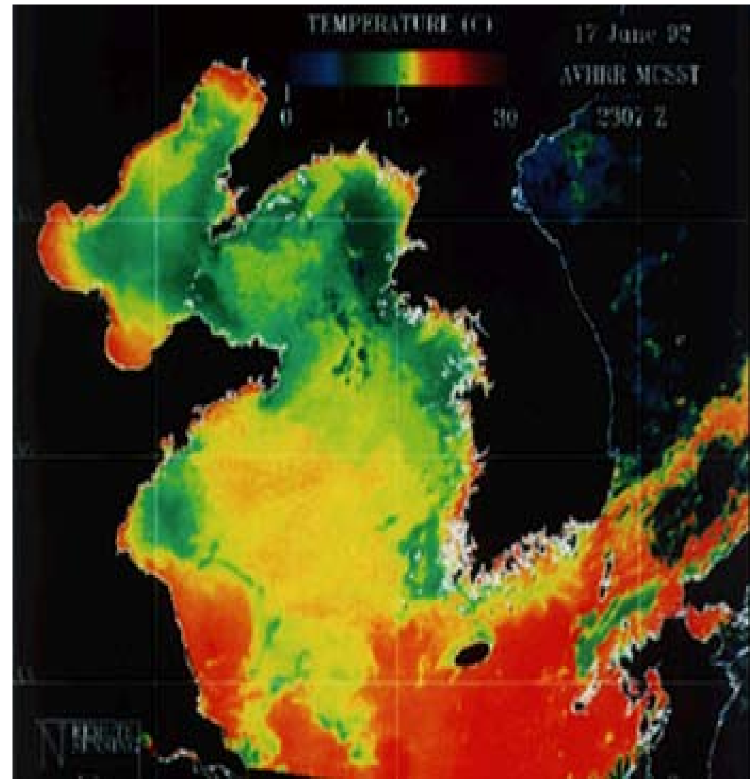


- The Navy's Hold-at-Risk ASW strategy requires operation in choke points, port areas, and open ocean areas.
  - Environments are harsh and changing
  - Required areas of coverage are large
  - Time frames of operational effectiveness are long (weeks to months)
  - Desired effectiveness is high with low risk to blue forces
- **Current systems do not support this ASW strategy.**

Undersea Persistent Surveillance

Provide accurate, persistent submarine surveillance in complex environments





Reduce the “detect-to-engage” timeline

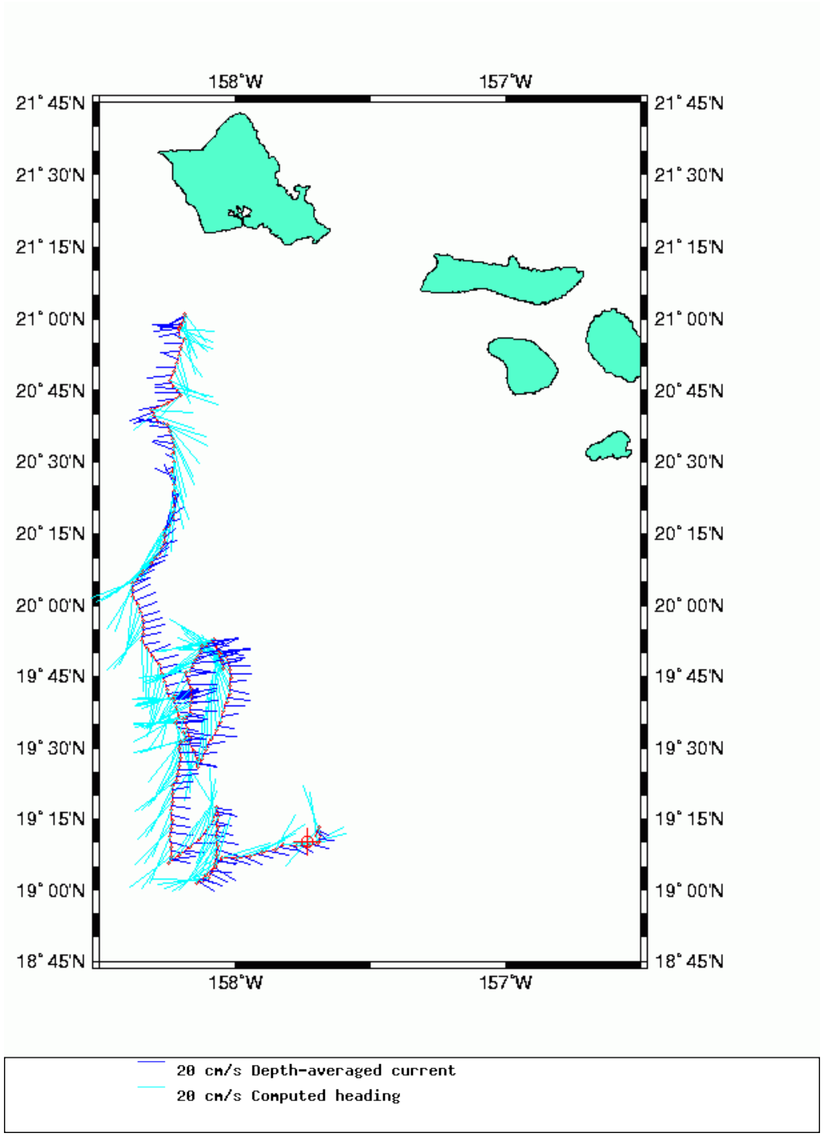
Undersea Gliders for Navy Applications

- APL-UW Investigators:
  - **Marc Stewart (mstewart@apl.washington.edu)**
  - **Bob Miyamoto (rtm@apl.washington.edu)**
  - **Jim Luby (jcl@apl.washington.edu)**
  - **Craig Lee (craig@apl.washington.edu)**
  - **Bruce Howe (howe@apl.washington.edu)**
- UW School of Oceanography
  - **Charlie Eriksen (eriksen@u.washington.edu)**
- Office of Naval Research
  - **Tom Swean (sweant@onr.navy.mil)**
  - **Tom Curtin (curtint@onr.navy.mil)**
  - **Theresa Paluszkiewicz (theresa_paluszkiewicz@navy.mil)**
  - **Mike Traweek (mike_traweek@onr.navy.mil)**
- Program sponsors: ONR, DARPA
- ONR RIMPAC04
- ONR TASWEX04
- Future Glider Technologies
  - ONR Xray flying wing glider
  - FutureGlider concept
- Role in Persistent Littoral Undersea Surveillance

RIMPAC June-July 2004

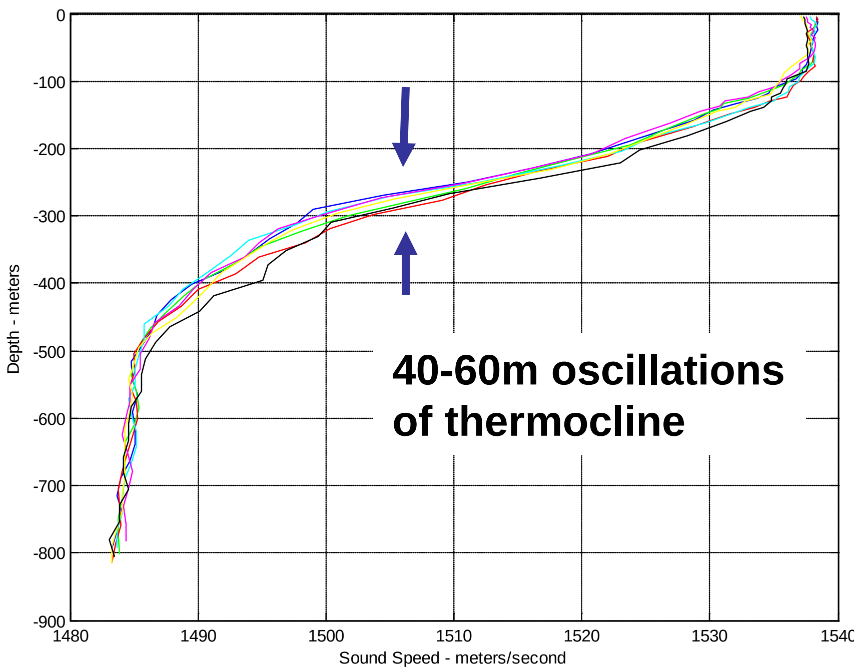
RIMPAC June-July 2004

RIMPAC June-July 2004

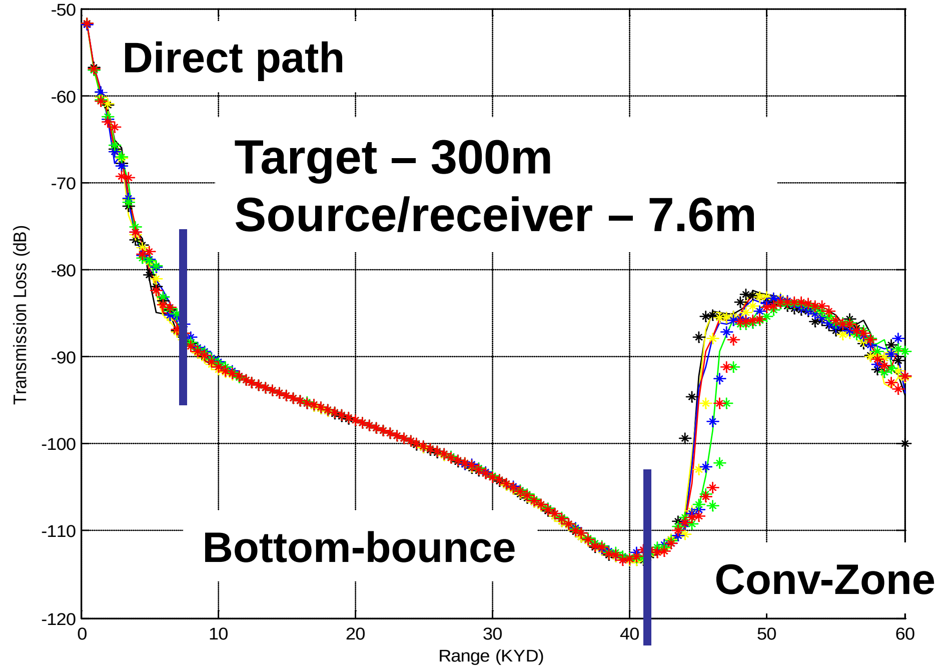


Acoustic effects of internal waves

Profiles 139-145



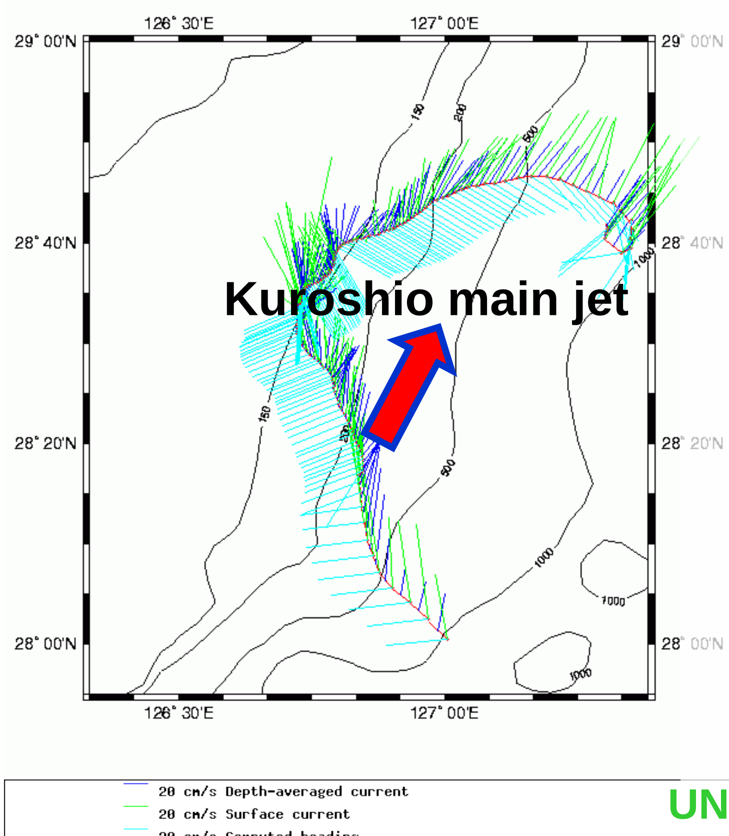
CASS Transmission Loss



TASWEX04

14 – 22 October SG017 Track

Red = glider track
Turquoise = glider heading
Blue = depth-averaged current
Green = surface current



SUCCESSES:

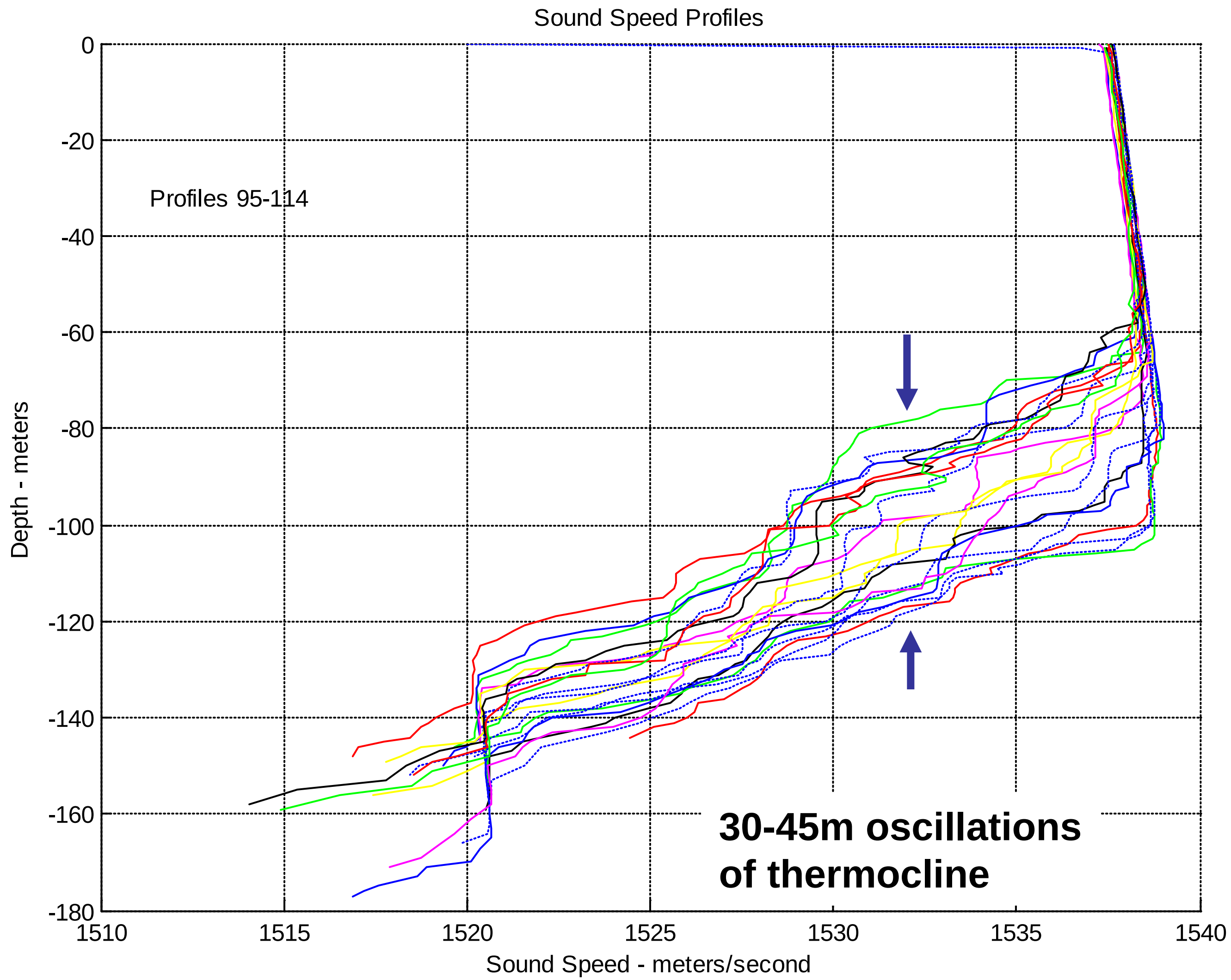
- **Research glider borrowed for Navy exercise**
- **JJVV & KKYY message auto-generation**
- **100% data reliability despite typhoon**
- **Mixed layer depth pegged (70m deeper than model)**
- **Tide-induced internal wave effects Evaluated (and made a difference!)**
- **Seamless rendezvous with Bowditch**

CHALLENGES:

- **Glider data rate vs. model capabilities**

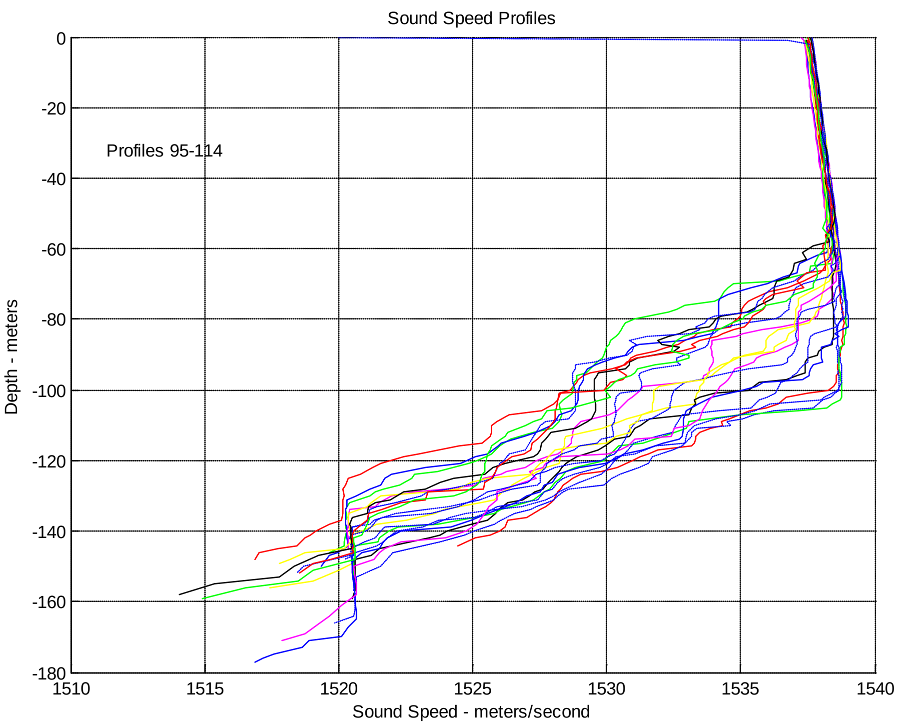
Internal Waves on ECS Shelf

Profiles 95-114, 19 October '04

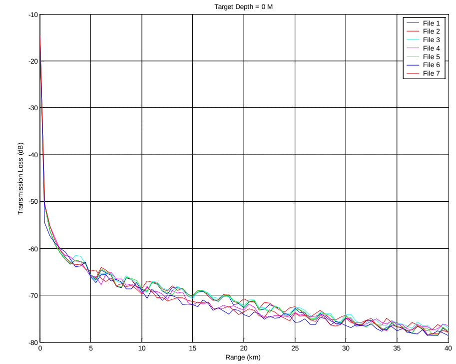


CASS Transmission Loss

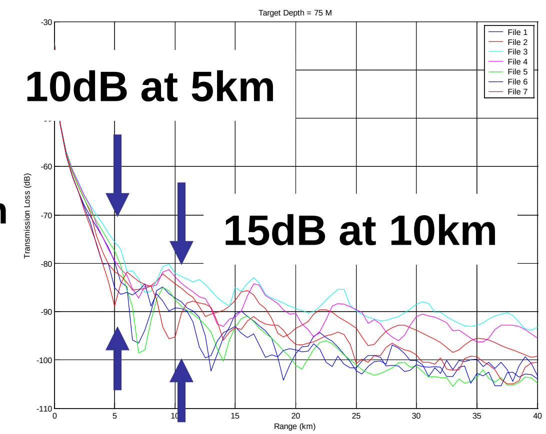
Source = 7.6m



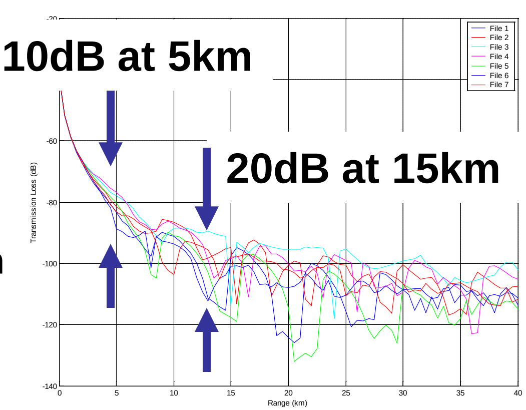
Receiver – surface



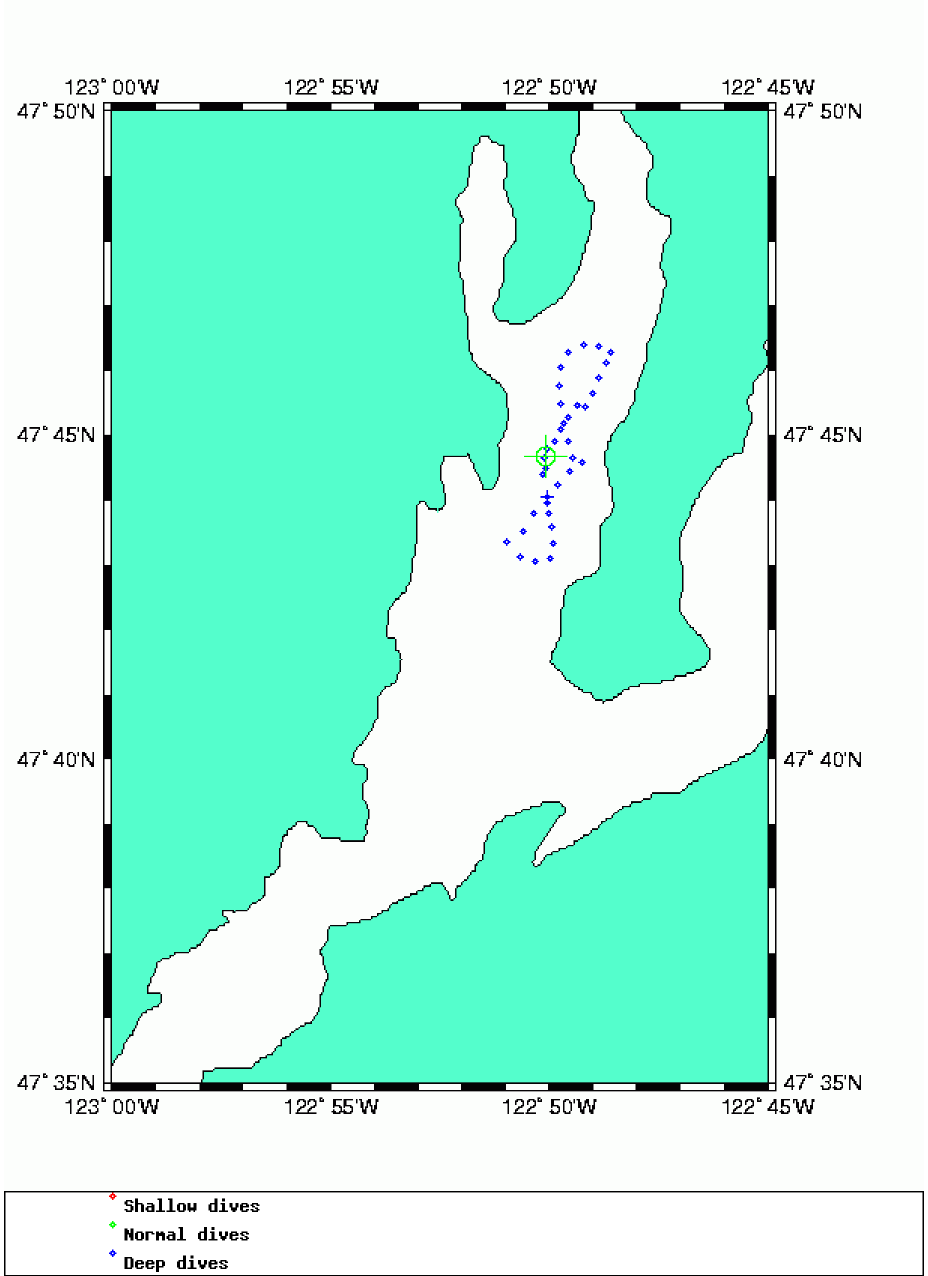
Receiver – 75m



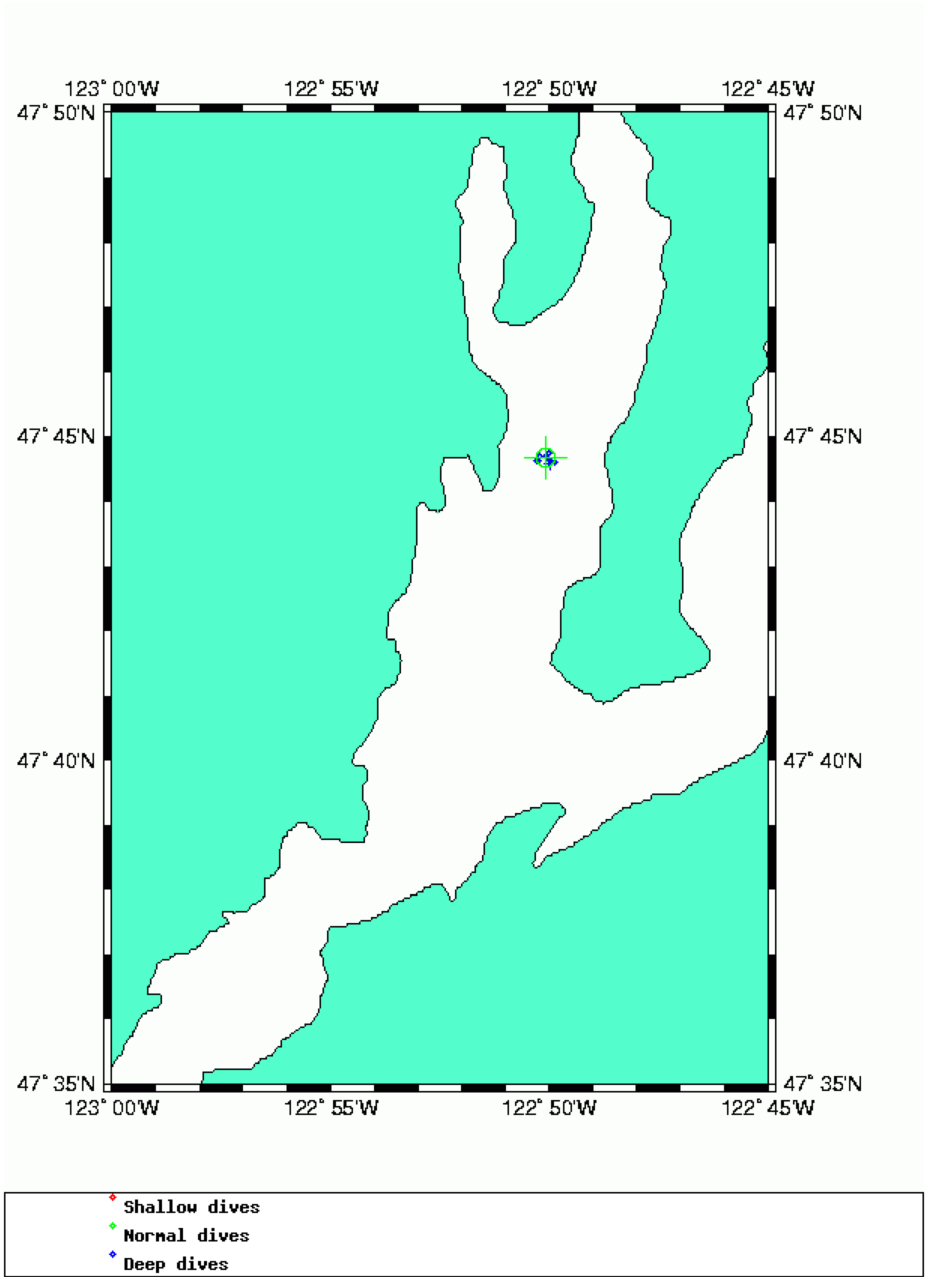
Receiver – bottom



SG022 Double Bow-Tie Pattern (Dabob Bay)



SG022 Station-keeping (Dabob Bay)

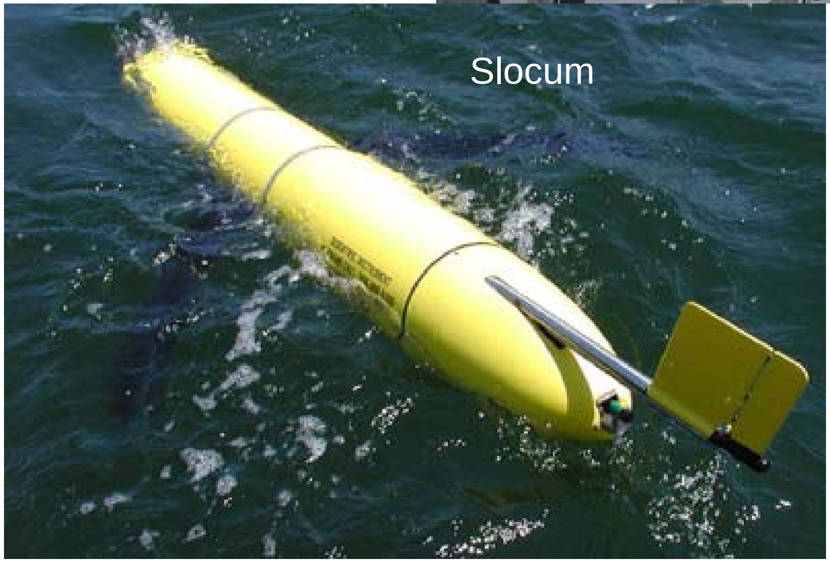


Cumulative UW Glider Results

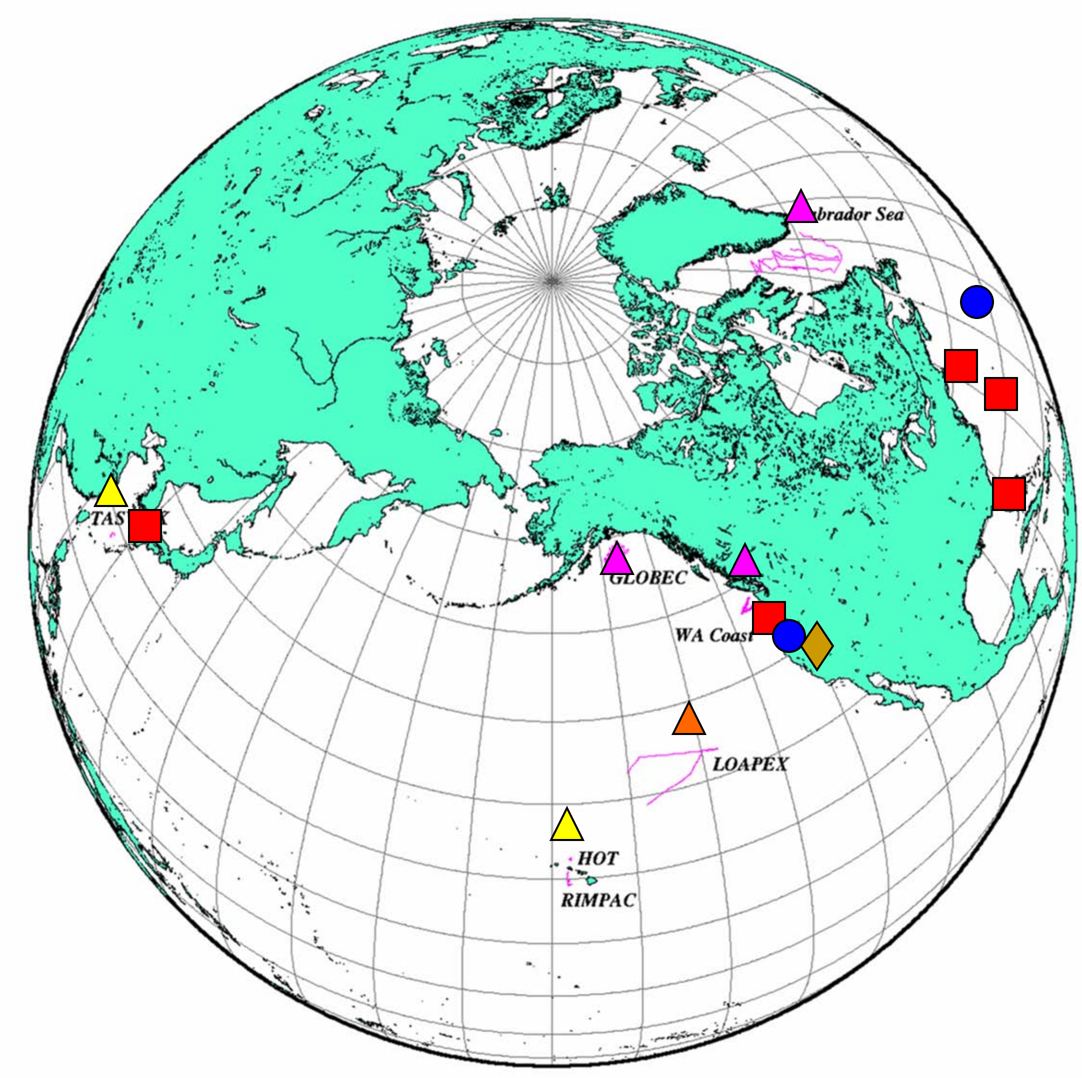
- 22 gliders built, 15 ordered
- 4 flying today: Hawaii, Washington Coast (1), Labrador Sea** (2)
- 8 Four-, 7 Five-, and 6 Six-month missions
  - April 05, SG022 & 023 finished 6+ month, ~600 dive, 3000+ km voyages - new record
- 2500 glider-days of operation

  (~75% of total by all gliders)
- Over 32,500 kilometers traveled through water
- 9 lost at sea, 1 recovered (SG004)

There is a Broad Glider Effort

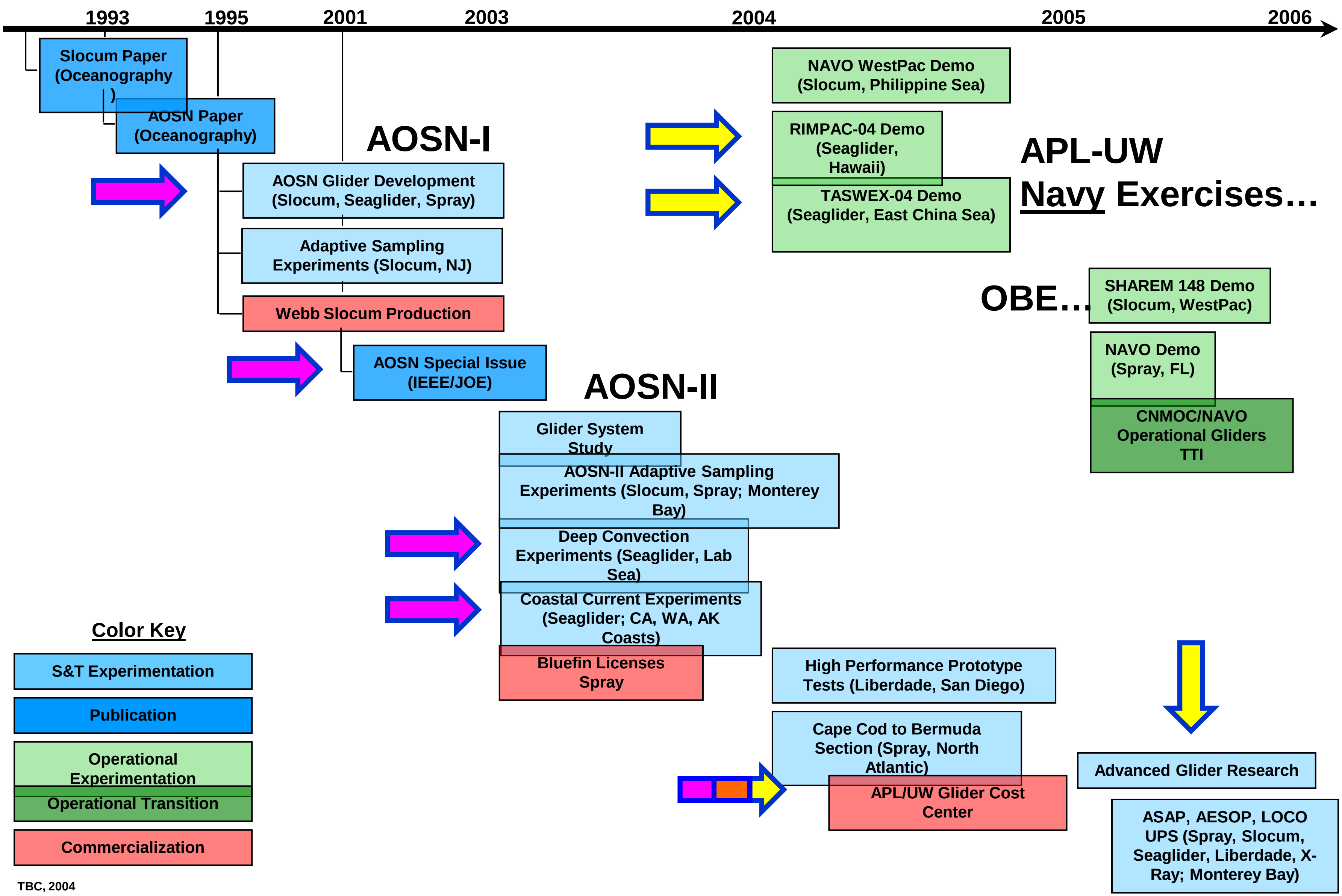


A Snapshop of the Overall Glider Program
Global Deployment, (very) Remote Control



Seaglider | Slocum | Spray | Liberdade

Undersea Glider Milestones

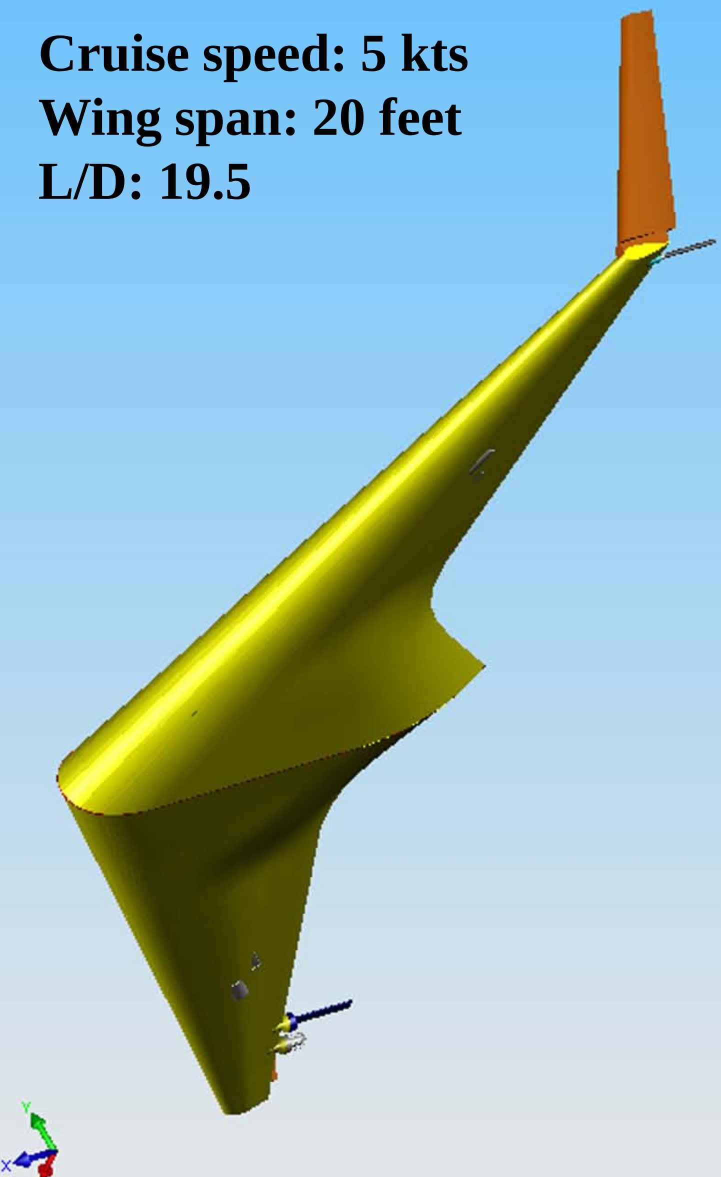


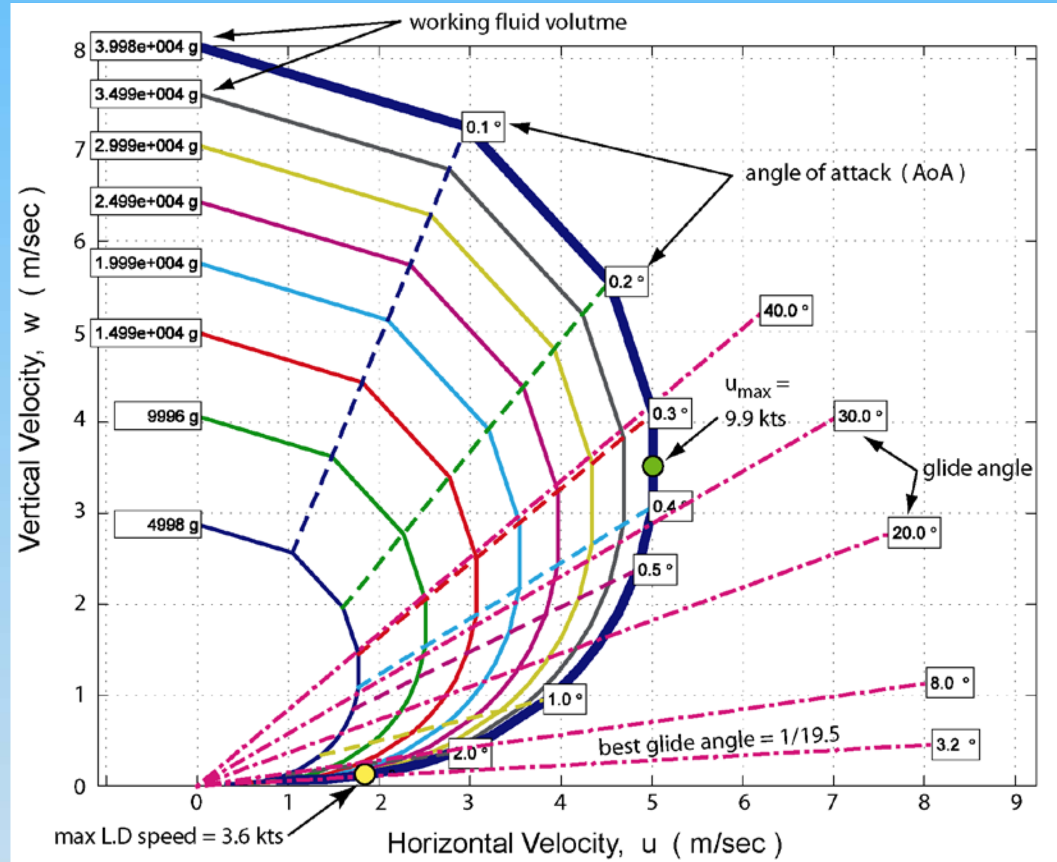
ONR X-RAY Flying Wing Glider

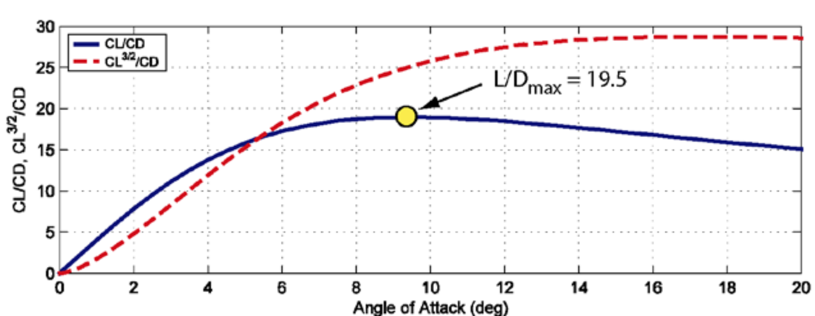
- Funded by Office of Naval Research (Dr. Tom Swean)
- Collaboration with Marine Physical Laboratory, Scripps Institute of Oceanography (San Diego, CA)
- High efficiency blended wing/body concept
- Designed to operate in efficient Reynolds number regime
- High lift to drag ratio will permit long duration energy efficient operations
- Acoustic and EM sensors
- Navy interested in potential for long range, autonomous surveillance

Xray Glide Polar

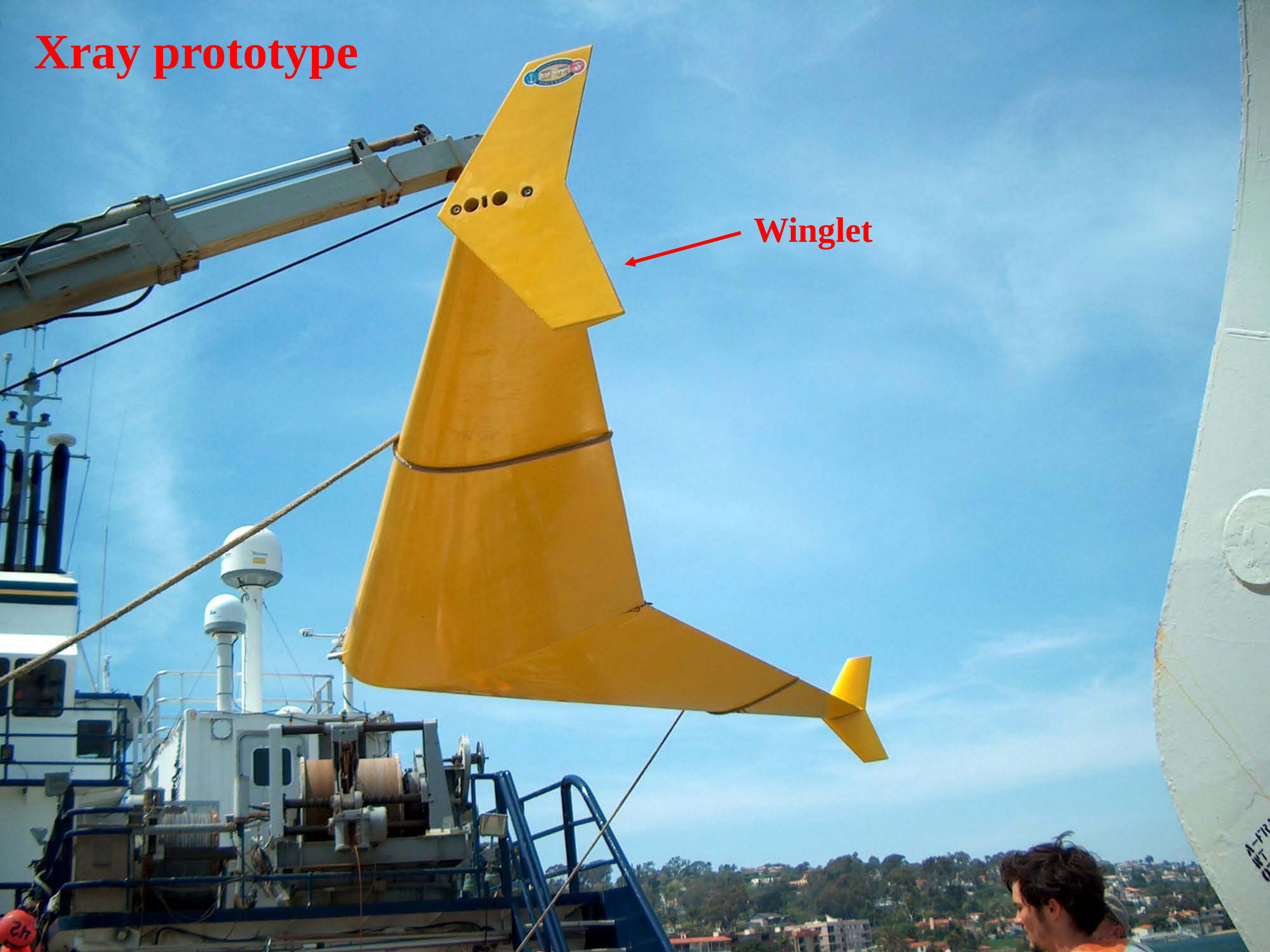
Cruise speed: 5 kts
Wing span: 20 feet
L/D: 19.5







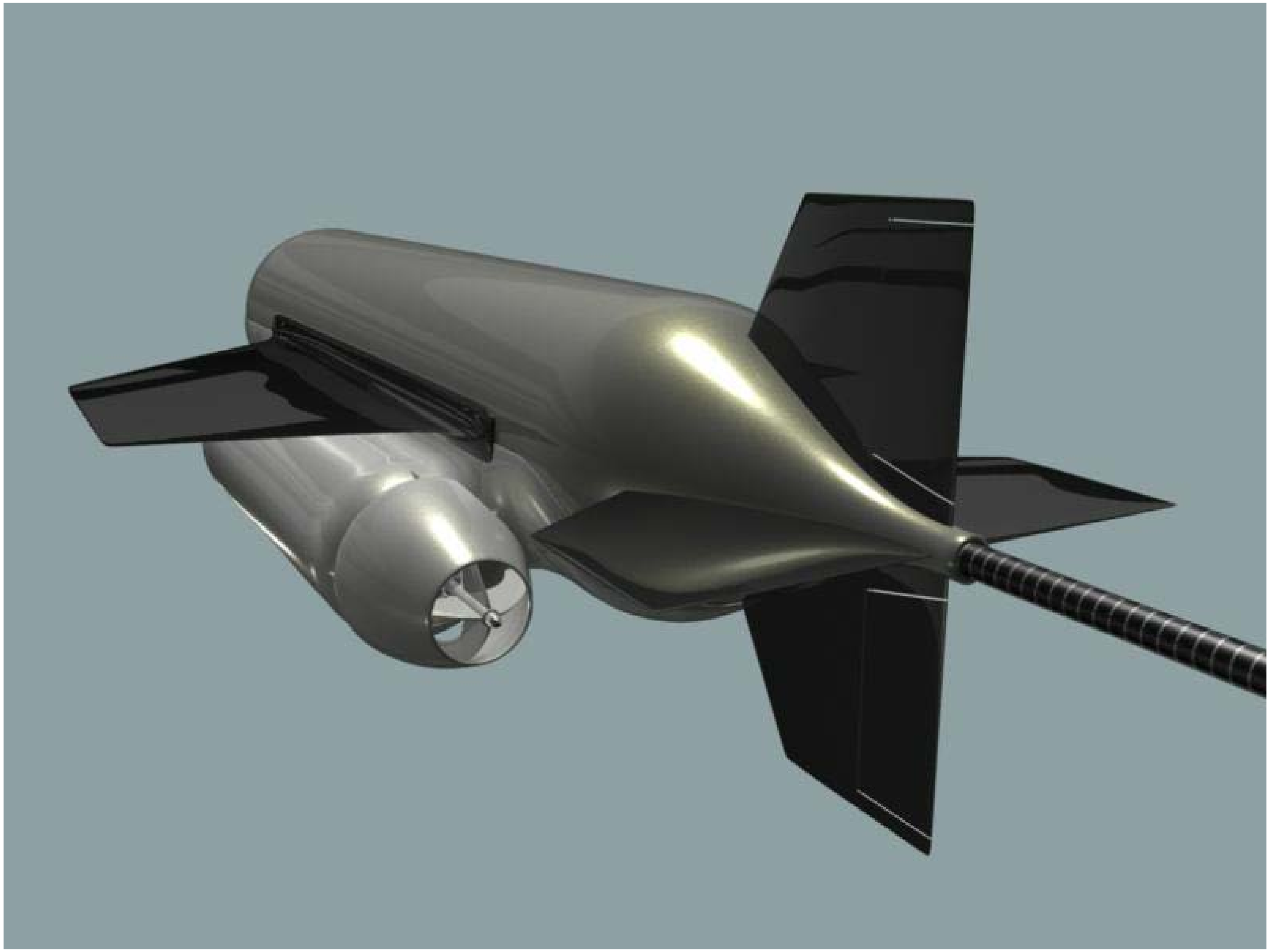
Xray prototype



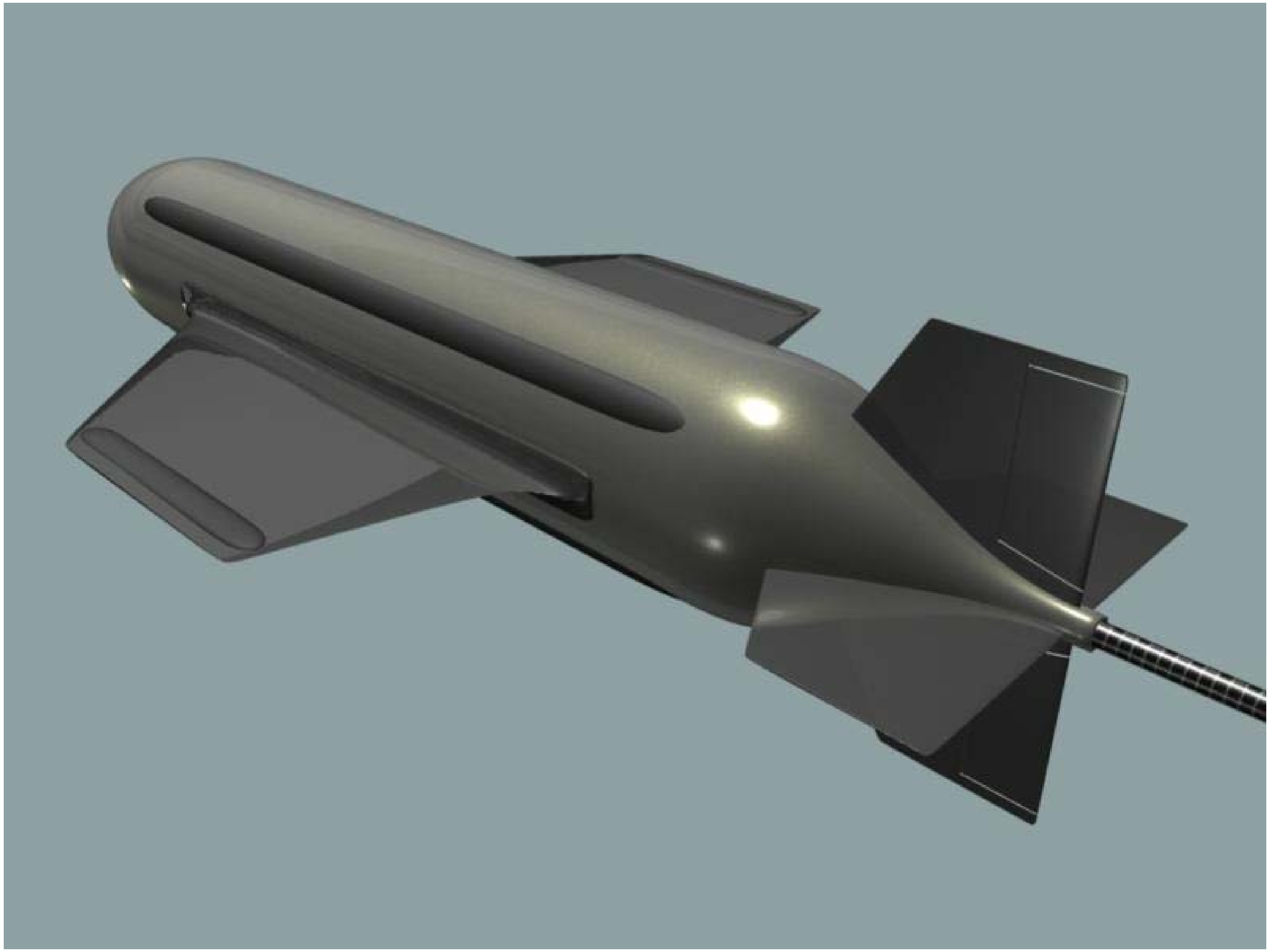
FutureGlider Concept

- Primary mission: Surveillance of far-forward, littoral areas
- Design goals
  - Low cost
  - Autonomous operations
  - Persistence
  - Stealth
  - Ease of launch/recovery (2 people, variety of platforms)
  - Over the horizon launch with rapid transit to operating area
  - Recoverable and reusable

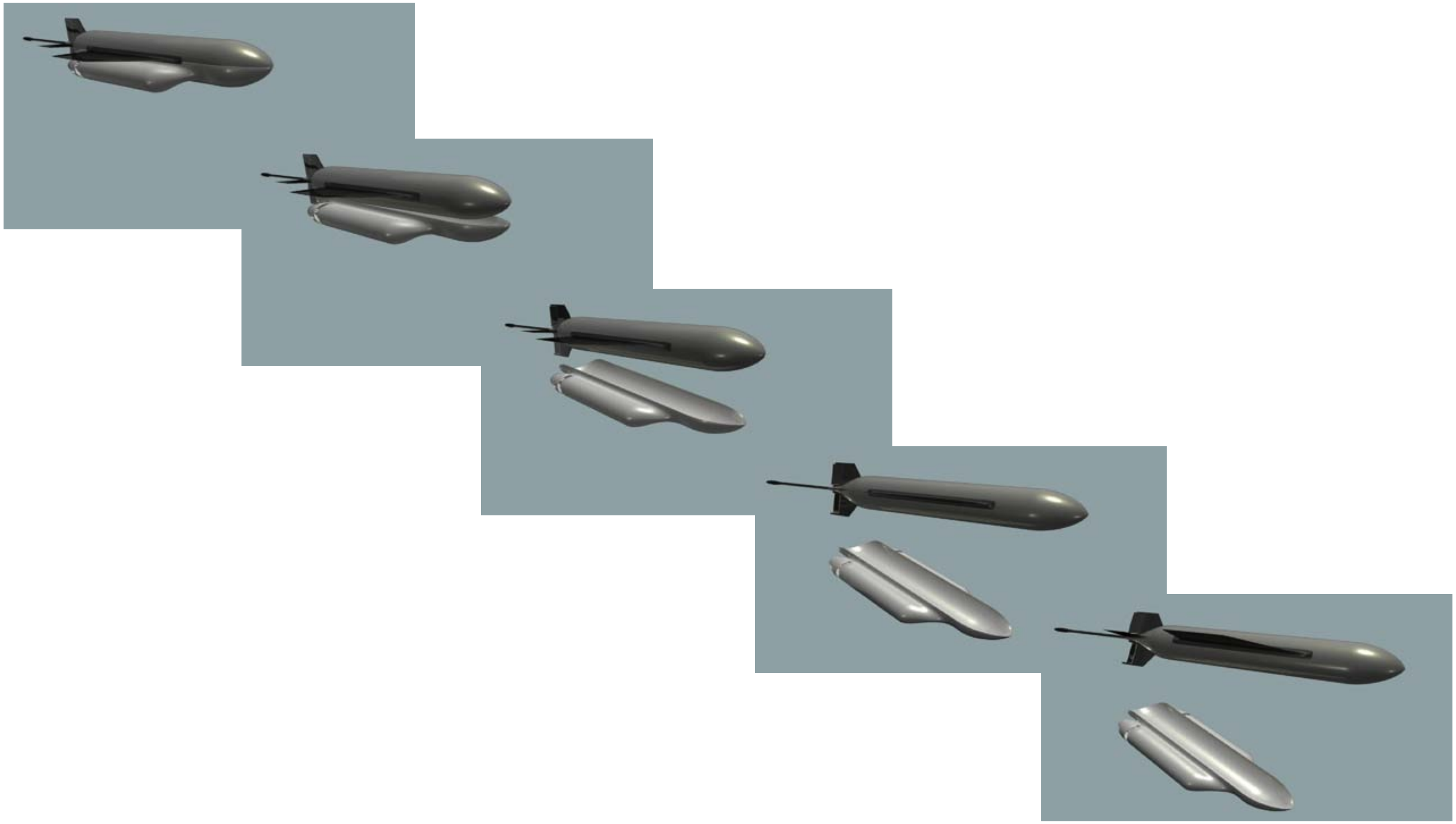
FutureGlider: Booster/Glider

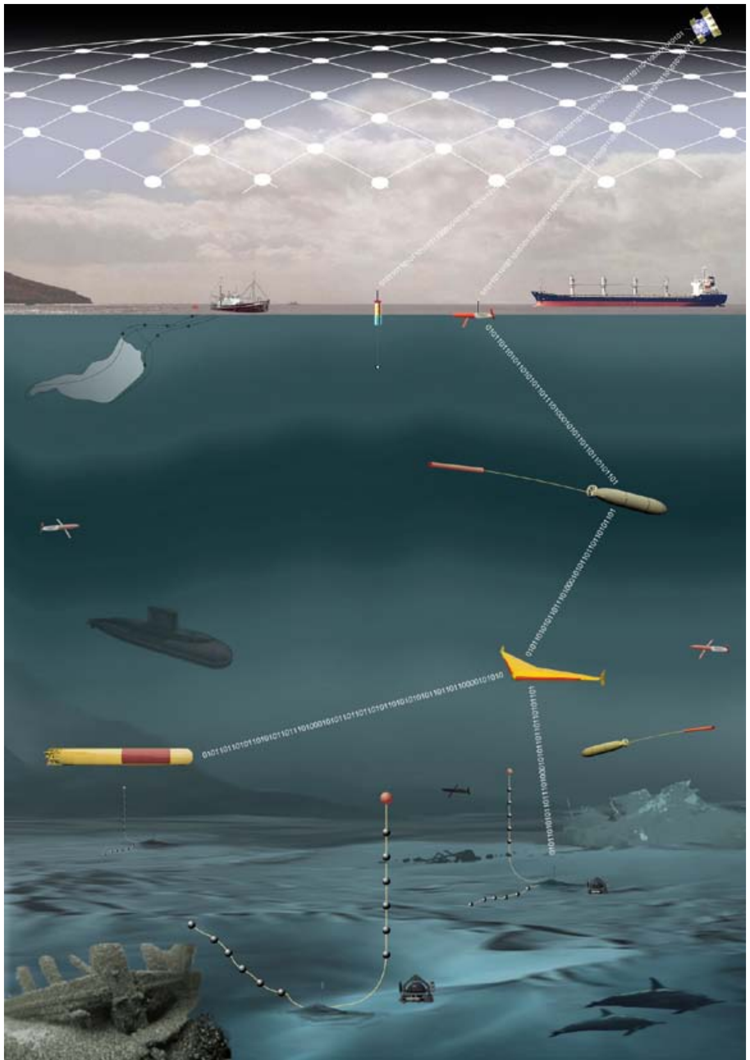


FutureGlider: Conformal Sensors



FutureGlider: Booster jettison





Multi-Institution Effort in Persistent Littoral Undersea Surveillance Network (PLUSNet)

PLUSNet Concept

- **Unmanned Systems Approach to Distributed Sensor ASW Surveillance**
- **Use mature (enough) technologies to field a scalable system demonstration**
- **Environmentally and tactically adaptive, cable-free sensor network**
  - **Fixed sensor nodes**
  - **Mobile sensor nodes**
    - **Assess environment**
    - **Redeploy (adapt)**
    - **Directed as sensor "wolfpacks"**
  - **Autonomous processing**
  - **Nested communication structure**

Defining Parameters

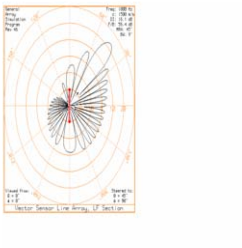
- **Clandestine undersea surveillance for submarines in far-forward and/or contested waters of order 10^3 - 10^4 square nautical miles, shallow and deep water, operating for months.**

- **Innovative technologies integrated into scalable systems.**

- **Systems at all scales that are deployable, affordable and effective for large area, persistent coverage.**

Acoustic Vector Sensor Arrays

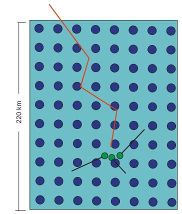
E-Field sensors

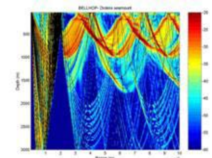


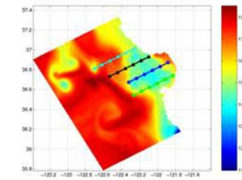
Directional Sensitivity

Acoustic and Ocean Models

Targeted Observations





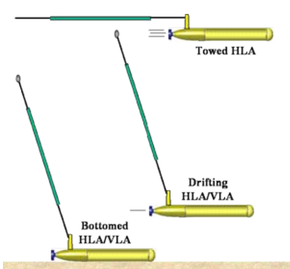


Adaptability, Feedback

UPS

Cornerstones

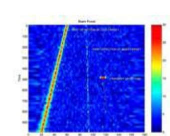
Mobility, Persistence

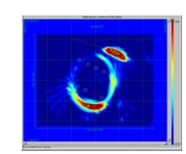


Autonomous Underwater Vehicles

Acoustic modems

Autonomy

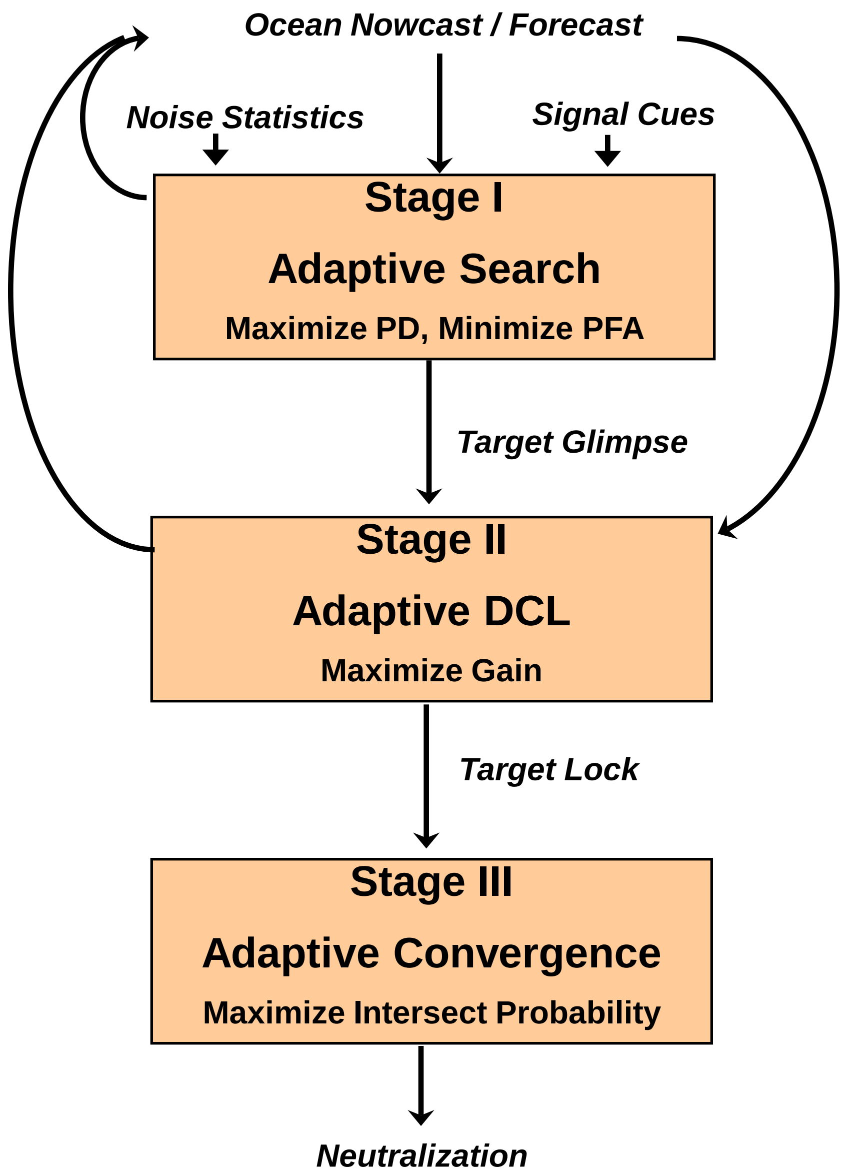




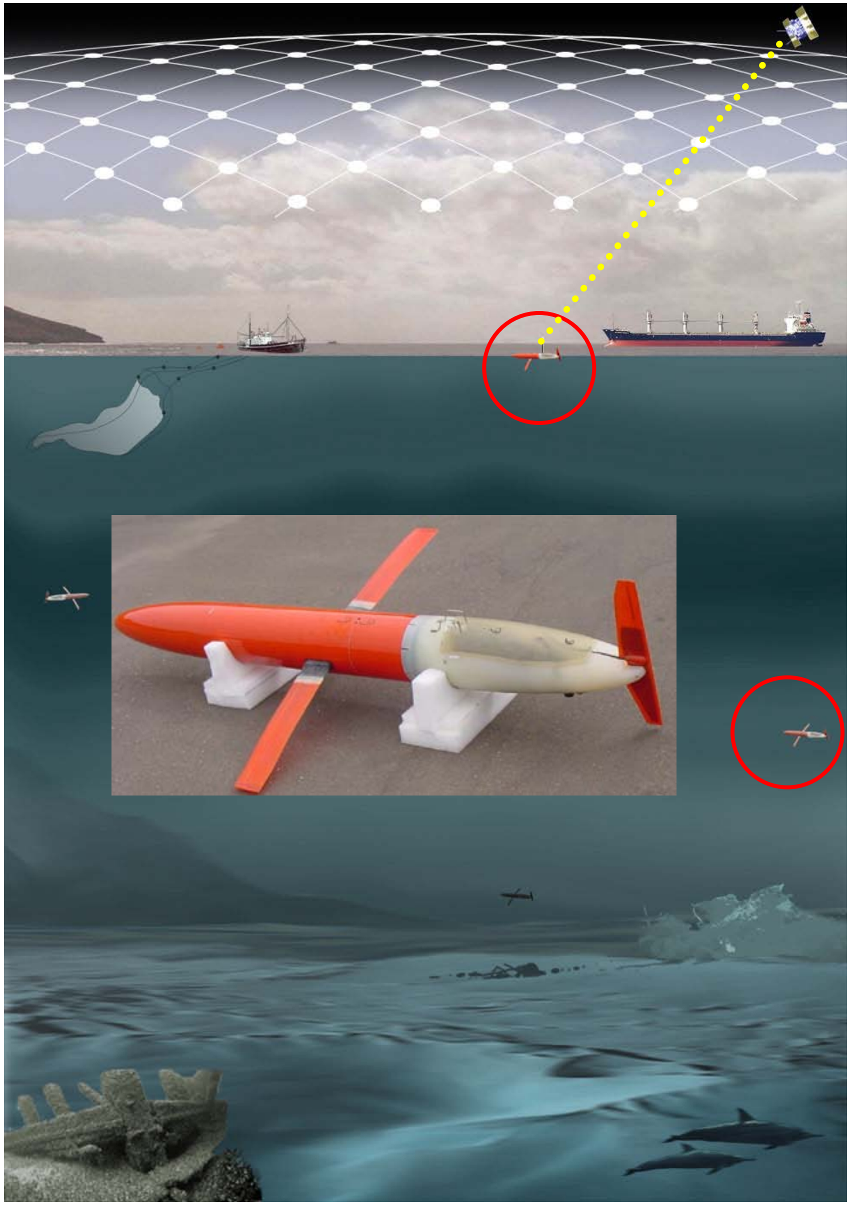
Autonomous DCL

Automated Tracking

Stages of Undersea Persistent Surveillance

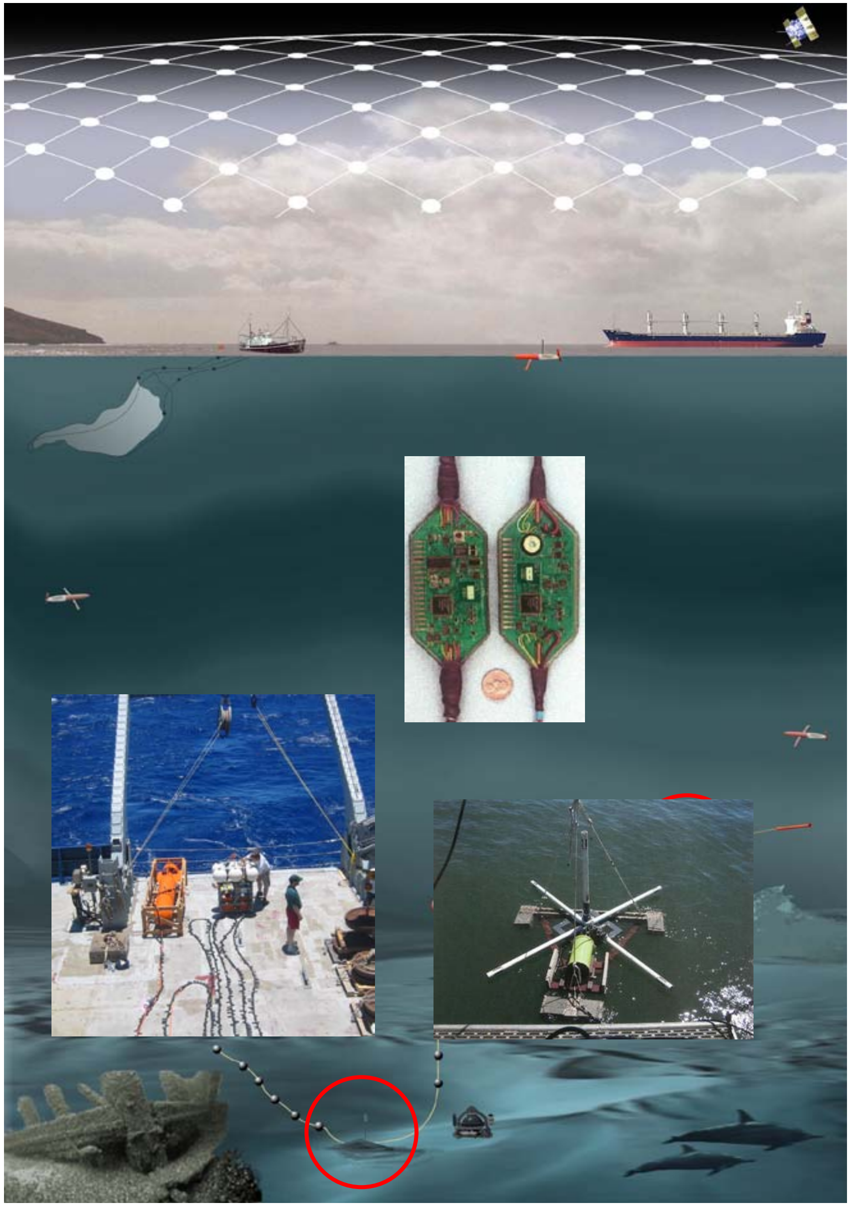


Environmental Assessment



- Environmental acoustic assessment – e.g., bathymetry, SVP, detection ranges…, finalize network cluster topology and fixed/mobile mix

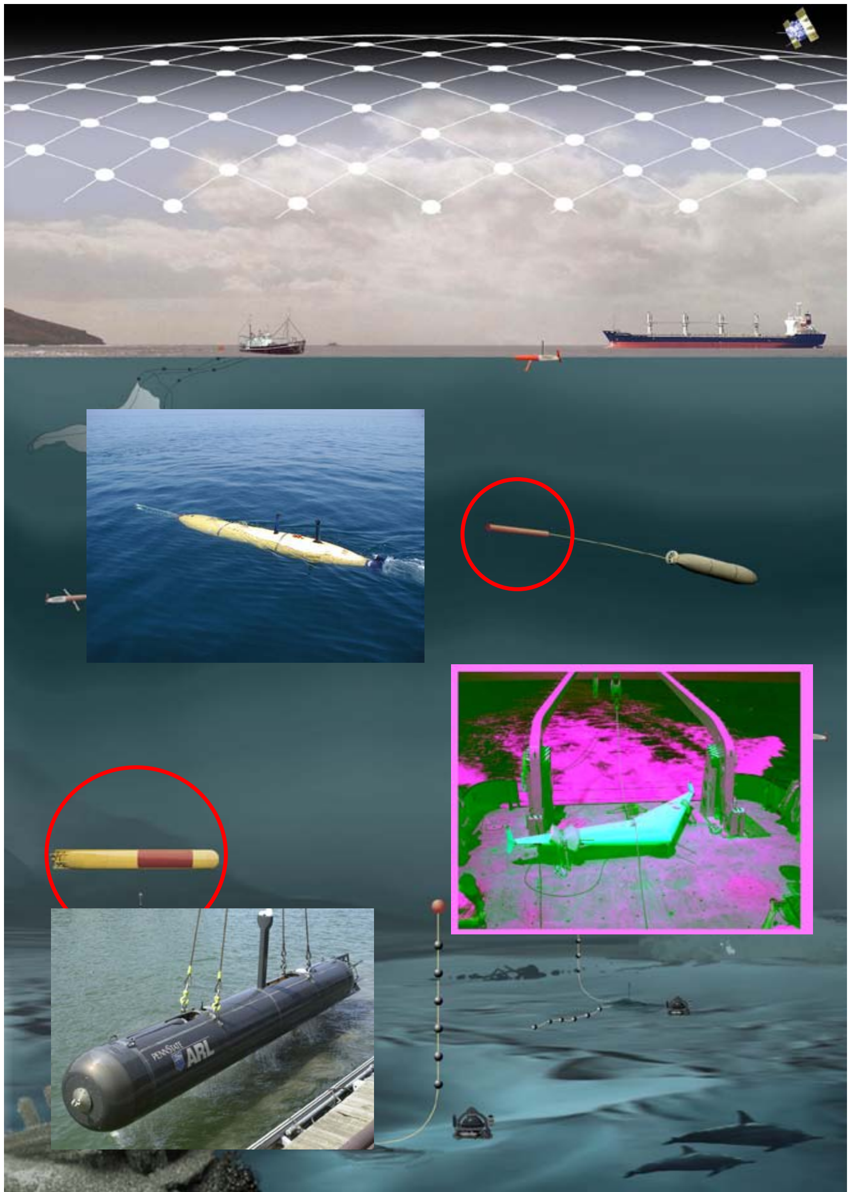
Sensor Deployment



- Environmental acoustic assessment – e.g., bathymetry, SVP, detection ranges…, finalize network cluster topology and fixed/mobile mix

- **Fixed and mobile sensor nodes launched from SSGN, LCS, USV and deploy for optimum surveillance coverage. AUV's enter semi-dormant state as temporarily fixed or drifting nodes**

Reconfigure Network

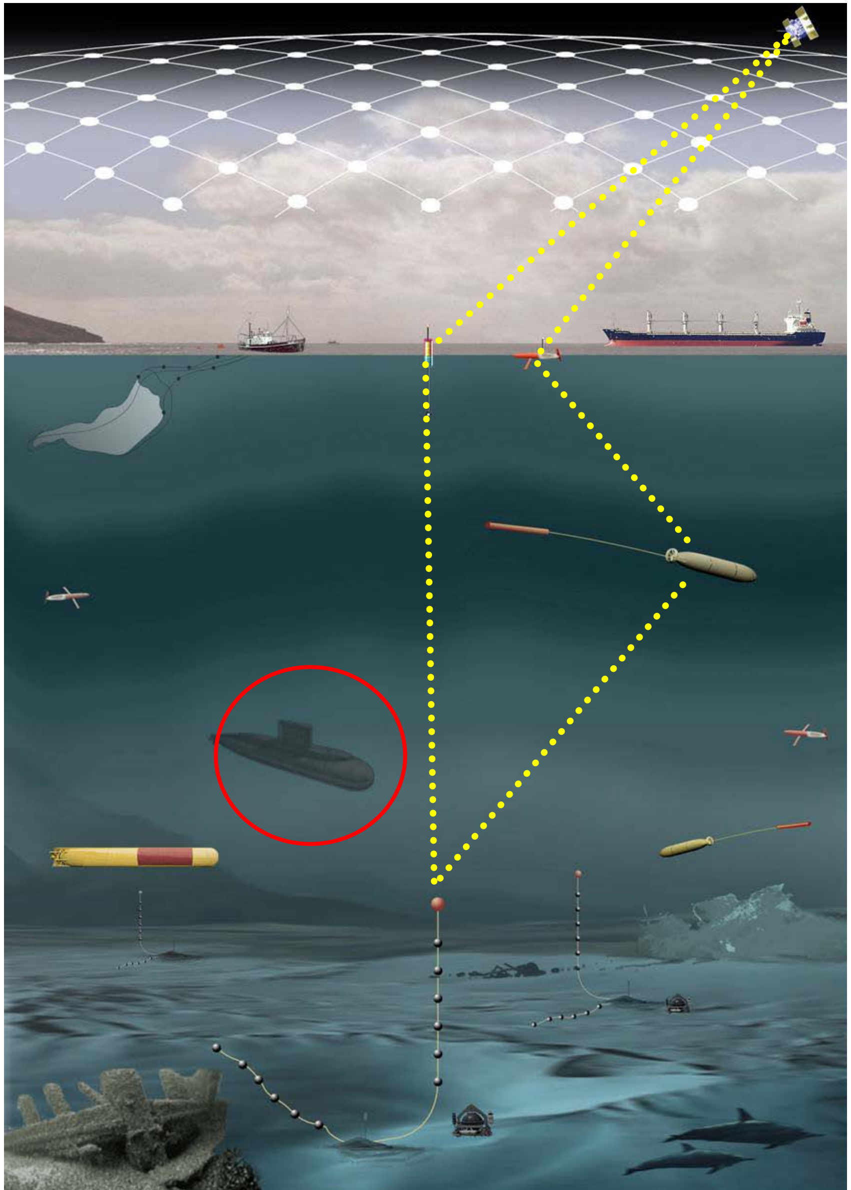


- Environmental acoustic assessment – e.g., bathymetry, SVP, detection ranges…, finalize cluster topology and fixed/mobile mix

- Fixed and mobile sensor nodes launched from SSGN, LCS, USV and deploy for optimum surveillance coverage. AUV's enter semi-dormant state as temporarily fixed or drifting nodes

- **Reconfigure mobile sensors nodes based on current tactical or environmental situation**

Target Detection



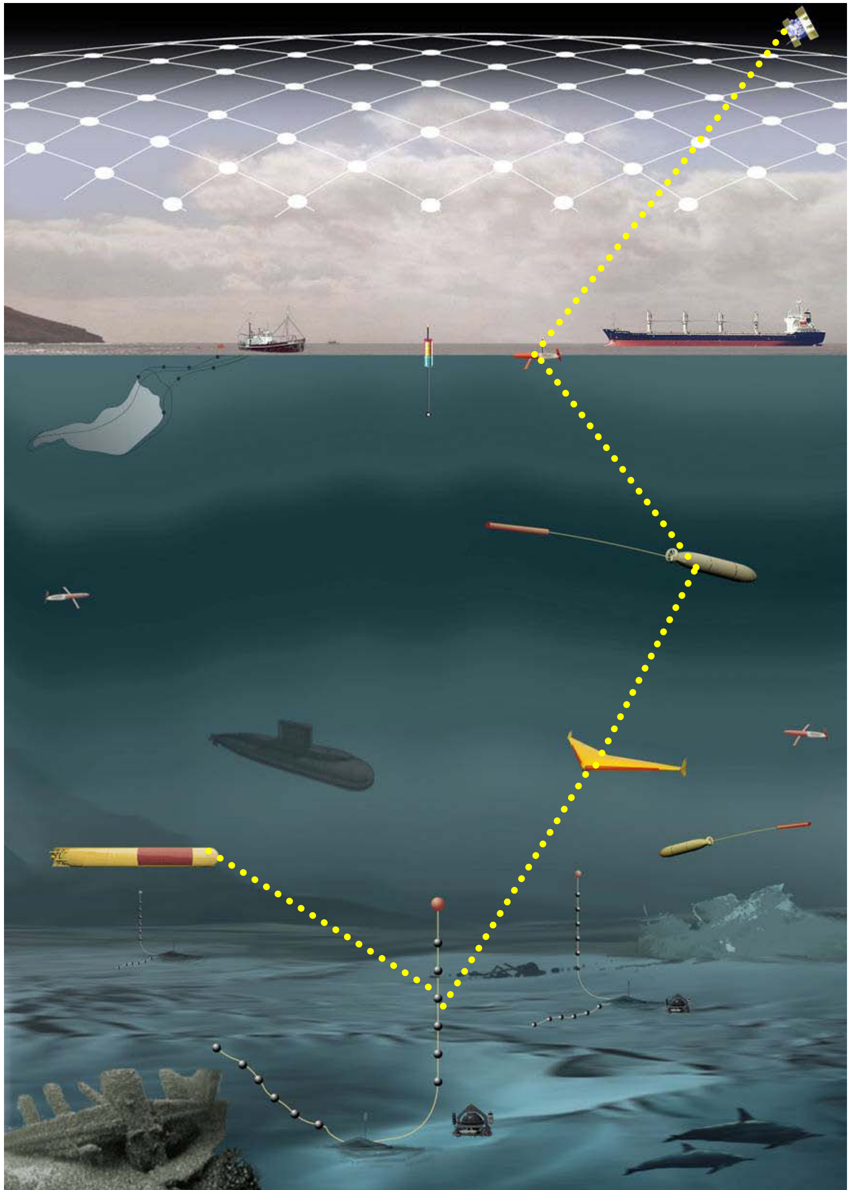
- Environmental acoustic assessment – e.g., bathymetry, SVP, detection ranges…, finalize cluster topology and fixed/mobile mix

- Fixed and mobile sensor nodes launched from SSGN, LCS, USV and deploy for optimum surveillance coverage. AUV's enter semi-dormant state as temporarily fixed or drifting nodes

- Reconfigure mobile sensors nodes based on current tactical or environmental situation

- **Target initial detection communicated to network (ACOMMS or RF)**

Wolfpack Response



- Environmental acoustic assessment – e.g., bathymetry, SVP, detection ranges…, finalize cluster topology and fixed/mobile mix

- Fixed and mobile sensor nodes launched from SSGN, LCS, USV and deploy for optimum surveillance coverage. AUV's enter semi-dormant state as temporarily fixed or drifting nodes

- Reconfigure mobile sensors nodes based on current tactical or environmental situation

- Target initial detection communicated to network (ACOMMS or RF)

- **Mobile asset "wolfpack" responds to detection to achieve weapon firing criteria DCL**

Undersea Surveillance Seascape

ONR 31/32/33/35/NRL Team Efforts

6.1 — Adaptive Mobile Networks

Sensors
Energy
Comms
Navigation
Control
Modeling

Adaptive Sampling and Prediction Using Mobile Sensing Networks (ASAP)

Targeted observations
Cooperative behavior

Autonomous Wide Aperture Cluster for Surveillance (AWACS)

Adaptive gain
Clutter/Noise suppression

6.2 — Adaptive Mobile nodes

Undersea Persistent Surveillance (UPS)

Undersea Persistent Glider Patrol / Intervention (Sea Sentry)

Four dimensional target discrimination
Mobile sensor environmental adaptation

Undersea Bottom-stationed Network Interdiction (CAATS)

Target interdiction with mobile sensors

Persistent Ocean Surveillance (POS)

Fixed surface nodes

Congressional Plus-ups

Component technologies

ONR/DARPA/NAVSEA SBIR efforts

6.3 — Trip wires, track and trail

Littoral Anti-Submarine Warfare (FNC)

Fixed bottom nodes

Autonomous Operations (FNC)

Adaptive path planning

Persistent Littoral Undersea Surveillance (PLUS) (INP)

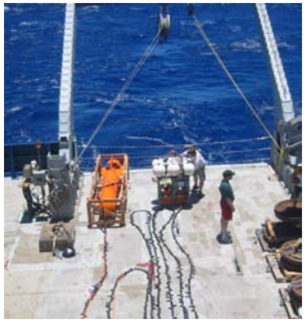
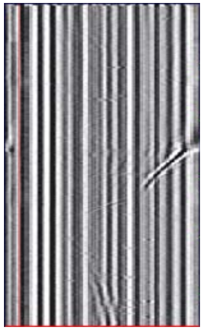
Prototype system integration and testing

PMS-403
PEO-LMW
Submarine T&T

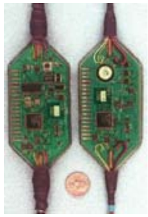
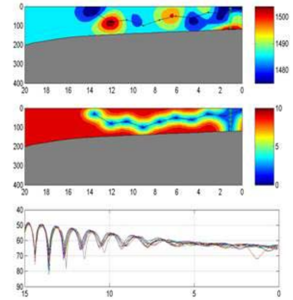
Task Force ASW
PEO-IWS
Theater ASW BAA

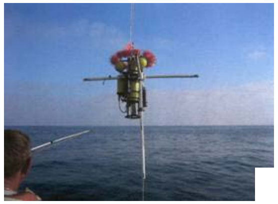
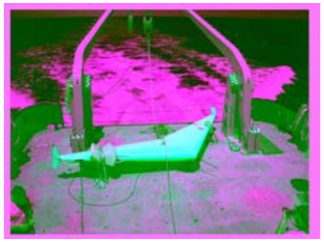
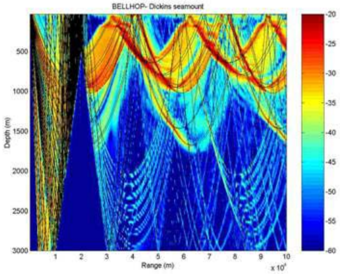
ONR
DARPA
NAVSEA
Italics: potential new program

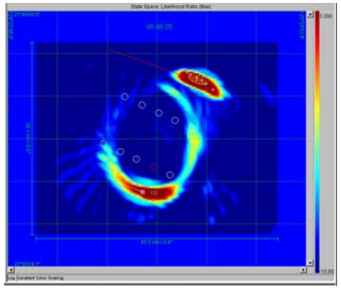
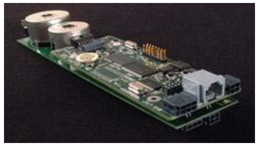
Critical Mass Team Experience



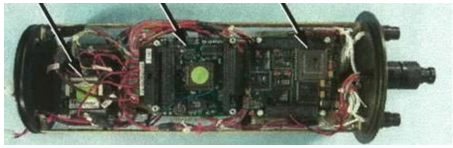



Field Efforts

FY05

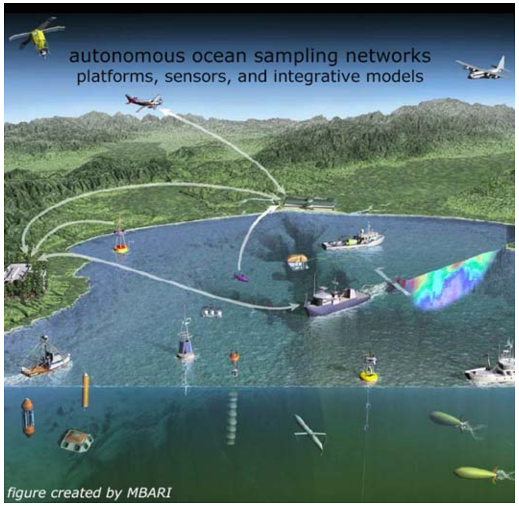
Collaborative Vehicles (SACLANT)

Liberdade / X-Ray



ACOMMS

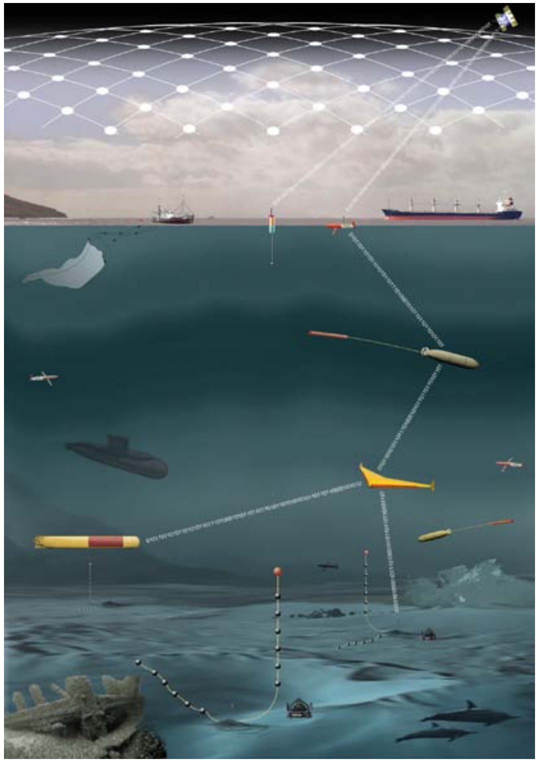
FY06



ASAP MURI (Monterey Bay)

SeaHorse / LCCA

FY07



Final Demo ONR Acoustic Observatory – Systems Level Concept Demonstration (Ft. Lauderdale)

PLUSNet Steps Toward Future Systems Capabilities –

- Elimination of bottom cable enables rapid deployment and survivability of cueing system.
- Persistence through power saving sensing technology and intelligent AUV behaviors
- Advanced communications technologies enable both remote control and autonomous operations.
- Autonomous, adaptive network control exploiting changes in tactical and environmental picture for improved DCL.
- Use of coordinated AUV wolfpack operation reduces need to send tactical platforms in harm’s way and increases likelihood of successful target prosecution.

A “System of Systems” Systems Engineering Approach

Embedded Research and Systems Engineering Issues

- Shallow water environment
  - Acoustics
  - Oceanography
  - Modeling and Inversion
  - Performance prediction under uncertainty
- Environmental Adaptivity
  - Signal processing (including multiplatform, MFP, invariants)
  - Autonomous signal processing
  - Sensing and Network control
  - Acomms/channel capacity
- Data fusion-Heterogeneous sensor data assimilation
- Sensor technology
  - Vector sensors
  - E-field sensors
  - Synthetic apertures
- AUV Technology
  - Intelligent behavior
  - Collaborative behavior
  - Quieting
  - Sensor integration
  - Power
  - Navigation approaches
  - Integrated sensing and control

Summary

- Distributed sensor field of *networked* unmanned fixed and mobile sensors for ASW surveillance
- Tactical and oceanographic environments sensed in real time, with sensor network *reconfigured* to improve target DCL
- Substantive research and systems engineering issues in this highly complex systems-of-systems effort must be addressed.