Mapping Coastal Dead Zones Through Collaborative Remote Sensing and *In Situ* Observations

Virginia Institute of Marine Science Seminar

David Spencer
Professor of the Practice
School of Aerospace Engineering
Georgia Institute of Technology

July 23, 2010

Georgia Tech Center for Space Systems

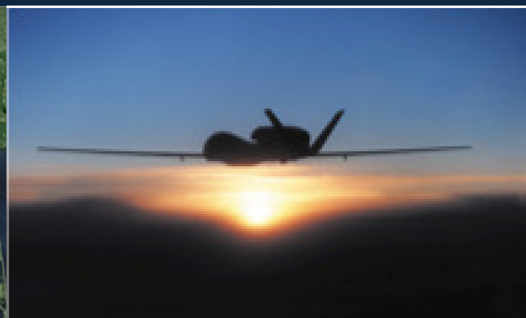
NASA

VIMS
Virginia Institute of Marine Science

Scope of Summer Research

- Definition of Coastal Science Application
- System Architecture for Collaborative Observations
  - Definition of observing platforms, observation strategies, communication paths, system-level requirements
- System modeling
  - Vehicle trajectory modeling, observational coverage
- Instrument selection
  - Sensor identification for selected application, instrument requirements
- System performance evaluation
  - Expected data return, measurement resolution, response times, mission duration

Coastal Observing With Collaborative Remote Sensing & In Situ Observations

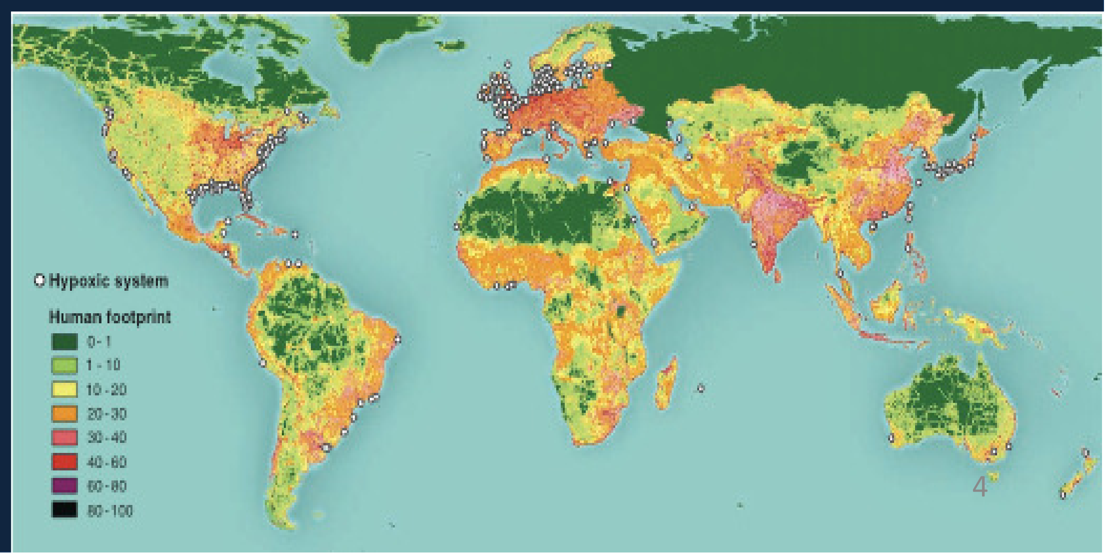


- Aerial remote sensing provides chemical distribution to limited depth, providing initial parameters for underwater vehicle mapping
- A network of underwater vehicle systematically maps and tracks the chemical distribution in three dimensions
- Network control strategy is defined by mission control and carried out autonomously by underwater vehicles

Selected Application: Mapping of Coastal Dead Zones

- Currently, hypoxia (< 2 mL of O_2, per L of seawater) and anoxia (zero levels of O_2) represent the most widespread of human-induced impacts on estuarine and marine environments.
- The frequency and extent of hypoxic and anoxic zones in the coastal oceans have increased exponentially over the past four decades, with major consequences to coastal ecosystems.*
- The worldwide distribution of coastal oxygen depletion zones are correlated with population centers and watersheds that deliver large quantities of nutrients to the coastal oceans

* Diaz, Robert and Rosenberg, Rutger, "Spreading Dead Zones and Consequences for Marine Ecosystems," *Science*, Vol. 321, 15 August 2008.

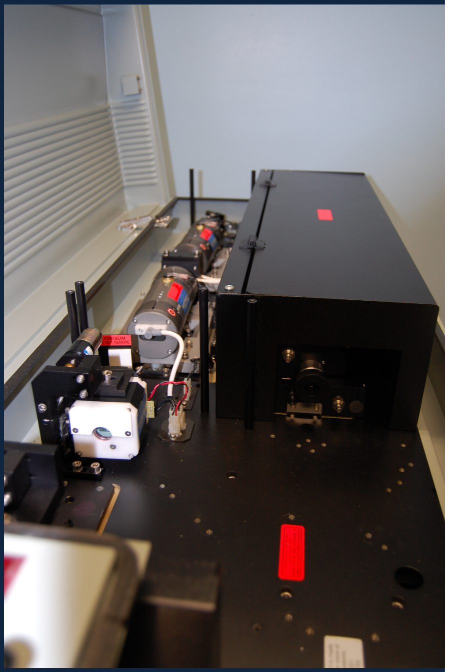


Remote Sensing via Raman Scattering

- Traditional Light Detection and Ranging (LIDAR) systems use a pulsed laser and receiving optics to measure the round-trip light-time of elastically backscattered photons (Rayleigh scattering), allowing range measurements to be made.
- Raman scattering differs from traditional LIDAR range measurements in that it is based upon the measurement of the *inelastic* scattering of photons.
  - When light is scattered by a molecule, a small fraction of the incident light is scattered via excitation.
  - As the molecule is energized by the incident laser photons, it is promoted to an excited state with an electron transitioning to a higher energy orbit. When the molecule returns to the ground state, a quantum of energy in the form of a proton is spontaneously emitted, or scattered.
  - The difference in energy between the incident and scattered photons corresponds to the energy between two energy levels of the molecule. The energy level of the emitted (scattered) photon is therefore characteristic of the impacted molecule.

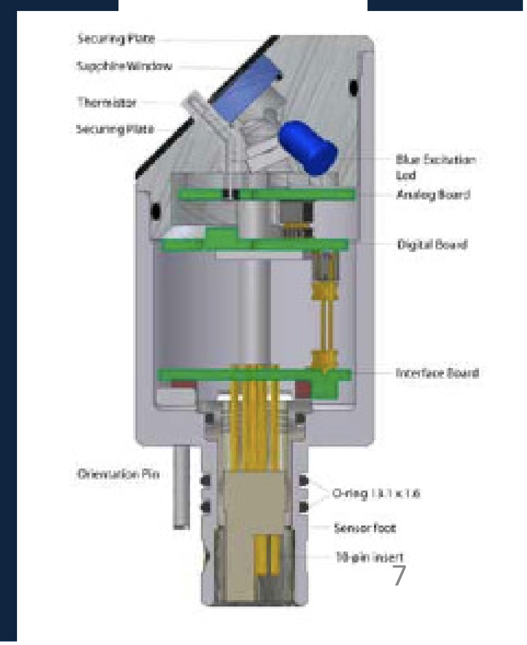
Raman Scattering for Detection of DO_2 Technology Advancement Plan

- Raman scattering system for detection of DO_2 is currently at TRL-2 (Technology concept and application formulated)
- Lab-based demonstration of system at NASA Langley Research Center will advance technology to TRL-4 (Breadboard validation in a laboratory environment) in July-August 2010
- Field testing of system on a fixed platform will advance system to TRL-6 in fall 2010 (System prototype demonstration in a realistic environment)
  - At TRL-6, system will be at a readiness level that will enable its selection for NASA and DoD applications



In Situ Measurement of Dissolved Oxygen

- Optode sensors optically measure oxygen concentration based on the ability of selected substances to act as dynamic flourescence quenchers
  - A chemical film is adhered to an optical fiber. The flourescence properties of the film depend upon the oxygen concentration; flourescence is at a maximum when no oxygen is present
  - When oxygen molecules collide with the film, the photoluminescence of the film is quenched
  - Optodes can operate across the full range of oxygen concentration (anoxic to full saturation)
- Commercially available optodes suitable for integration with underwater vehicles are produced by Aanderaa Data Instruments
- Optode technology is at TRL-9 (Operationally proven through successful mission operations)
  - Successfully utilized on gliders and AUVs

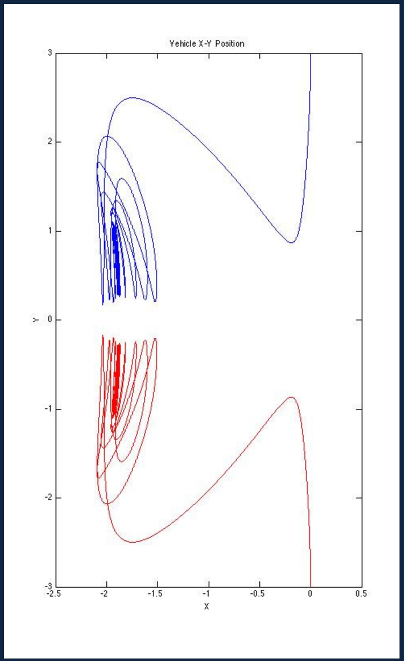


Underwater Network Control Strategies

- Objective:
  - Determine the time-varying *extent* and *concentration levels* of a chemical distribution in three dimensions
- Strategy Evaluation Criteria:
  - Geometric accuracy of chemical plume map over time
  - Accuracy of chemical concentration distribution
  - Number of underwater vehicles in network
  - Response time to reach required levels of plume tracing accuracy

Network Control Strategies (cont.)

- Initial work is focused on developing coordinated and distributed control of multiple autonomous vehicles
  - Schooling: Center of mass of the group translates
  - Flocking: Vehicles circle center of mass of the group; center of mass remains stationary
- Artificial potentials define interaction control forces between neighboring vehicles, using attraction and repulsion to enforce desired inter-vehicle spacing*
- Virtual leaders are moving reference points that can that can influence group behavior through artificial potentials
  - No ordering among the actual vehicles; approach is robust to loss of vehicles
- Behaviors will be integrated into MOOS-IvP for simulation



* Leonard, Naomi, and Fiorelli, Edward, "Virtual Leaders, Artificial Potentials and Coordinated Control of Groups," Proceedings of the 40th IEEE Conference on Decision and Control, Orlando, Florida, December 2001.

Potential Funding Source

- NASA Earth Venture Missions
  - $30M-class airborne missions as part of Earth System Science Pathfinder program
  - Subject: Seasonal variations and long-term trending of dead zone evolution in coastal oceans
  - 2010 awardees:
    - Airborne Microwave Observatory of Subcanopy and Subsurface. Principal Investigator Mahta Moghaddam, University of Michigan
    - Airborne Tropical Tropopause Experiment. Principal Investigator Eric Jensen, NASA Ames Research Center
    - Carbon in Arctic Reservoirs Vulnerability Experiment. Principal Investigator Charles Miller, Jet Propulsion Laboratory
    - Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality. Principal Investigator James Crawford, NASA Langley Research Center
    - Hurricane and Severe Storm Sentinel. Principal Investigator Scott Braun, NASA Goddard Space Flight Center

NASA Earth Venture Organizational Partnership

Principal Investigator

- Virginia Institute of Marine Science: Robert Diaz

Project Management, LIDAR Development, Aerial Systems

- NASA Langley Research Center: Stephen Sandford, Chris Webster, Russell DeYoung

System Engineering, Underwater Systems, Mission Operations

- GT-Atlanta: David Spencer
- GTRI ELSYS: Mick West, Carlee Bishop
- GT-Savannah: Fumin Zhang