Autonomous and Adaptive Plume Detection and Tracking with AUVs:

Concepts, Methods, and Available Technology

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Goals

Develop methods for locating & tracking underwater plumes using AUVs

Adaptively account for the dynamic nature of hydrographic features (makes use of spatiotemporal scales of a feature to guide adaptation of AUV motion)

Collaborate between AUVs (and other marine platforms) to collect more complete data sets for feature detection

Autonomous tracking in which the AUVs determine the spatiotemporal positions or boundaries of the features

No guiding AUV operator, and all data processed onboard the AUVs

Outline

Detail characteristics of plumes:

- Hydrothermal vent plumes
- Oil spills
- Harmful algal blooms (HABs)

Detail characteristics of AUVs:

- Actively-propelled, torpedo-shaped
- Glider, generally torpedo-shaped w/ wings
- Other/in-house AUVs, usually actively-propelled

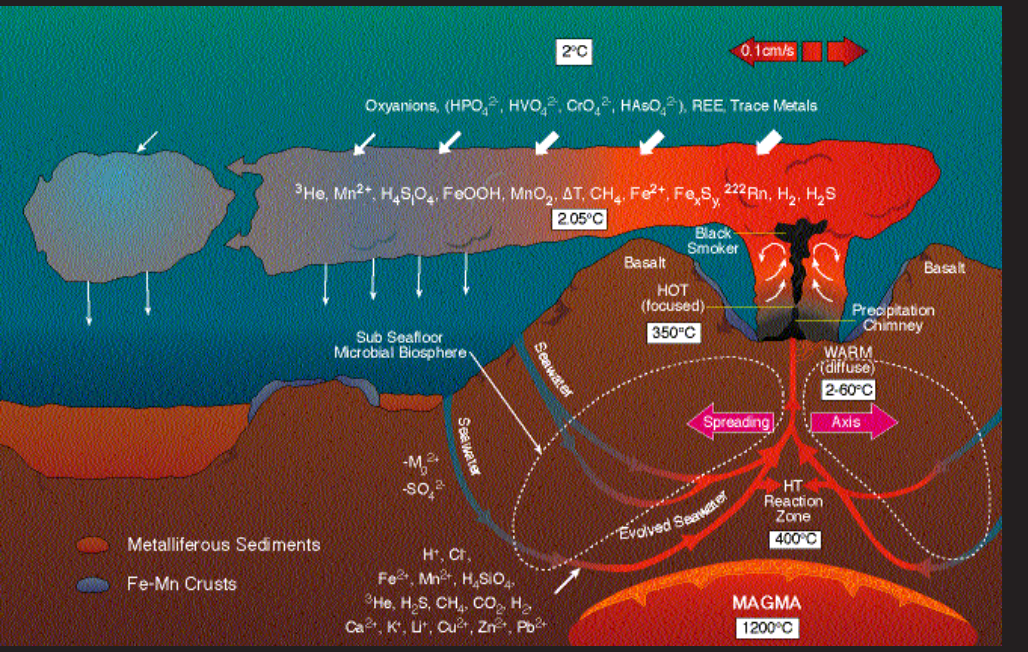
Pair AUV types with plume types for optimal plume sampling.

Present methods for detecting/tracking plumes using AUVs.

Hydrothermal Vent Plumes

Source: forced jet

Non-buoyant plume layer

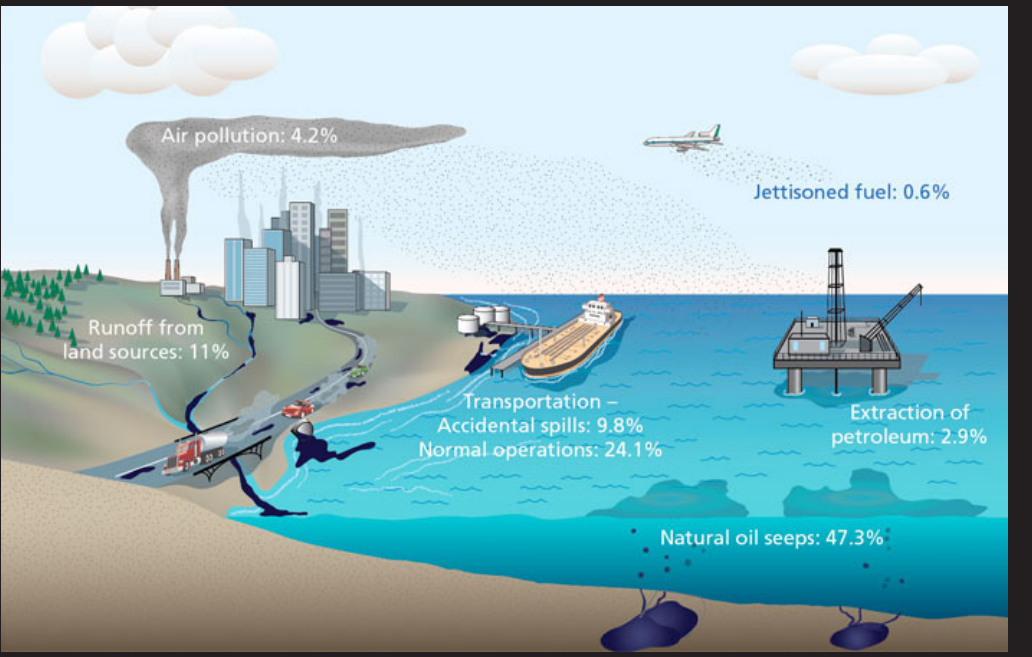


- Location: Circulation zones near underwater plate boundaries
- Scales: Non-buoyant layer extends horizontally 10s - 1000s of km from vent site (Baker et al., 1995)
- Oceanographic signatures: temperature anomaly, particle content, water velocity, chemical tracers (Fe, Mn, He, CH4, H2S), and bathymetry
- Figure: NOAA PMEL

Oil Spills

Source: forced jet or gradual outflow

Non-buoyant or surface plume layer



- Location: Surrounding the leaking source of a spill
- Scales: Oil fallout occurs over seconds - years; Horizontal extent of slick & fallout plume is highly variable, depending on source and local currents (O(1-10) km, possibly more)
- Oceanographic signature: hydrocarbon concentration
- Figure: Jack Cook, WHOI, 2011

Harmful Algal Blooms

Source: no point source

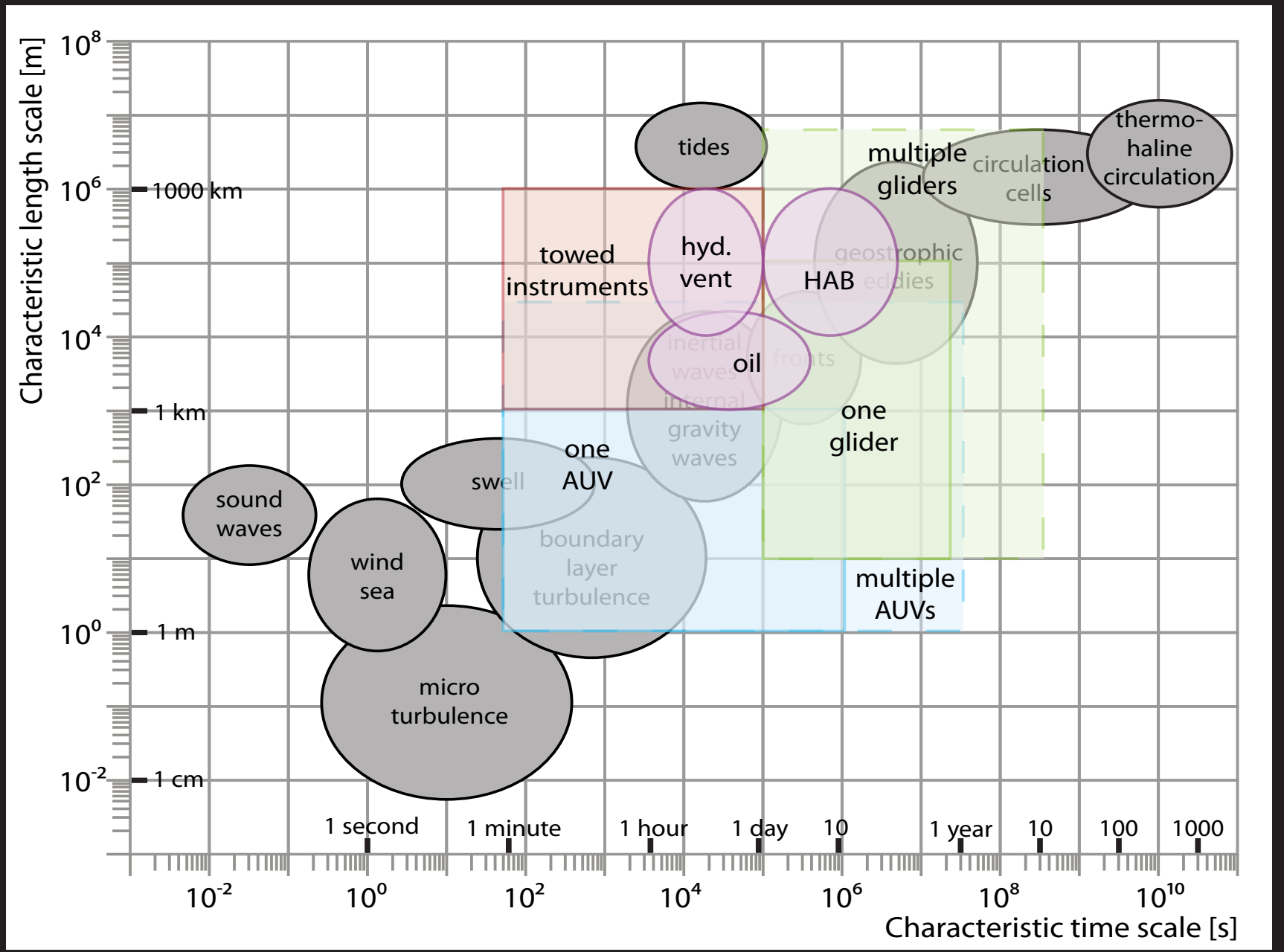
Non-buoyant plume layer near thermocline or surface

- Location: Where & when significant nutrients (N & P) and light are sustained in a region, resulting in an abundance of algal growth in a thick layer near the sea surface (often in eutrophic zones)
- Scales: Vertical extent is 10s of cm near the surface or thermocline (Gilbert, 2006); Horizontal extent is 10-1000 km (Gilbert, 2006); Time scale depends on the local currents
- Oceanographic signatures: nutrients, phosphorous-regulated proteins, chlorophyll, nucleotides, biomass

AUV Attributes

Attribute	Glider	Actively propelled, torpedo shaped
Speed	0.0-0.5 m/s	0.0-3.0 m/s
Duration	weeks to months	hours to days
Propulsion	passive	active
Vertical motion	constant yoyo	unrestrained (but most do not hover)
Horizontal motion	unrestrained	unrestrained
Depth rating	most $<$2000 m, one up to 6000 m	up to 6000 m
Navigation	dead reckoning (DR), compass, GPS	IMU (inertial measurement unit), acoustics, DR, compass, GPS
Comm. method	at surface (Iridium, RF)	at surface (Iridium, RF), underwater (acoustic)
Hotel load	$<$10 Watts	$<$100 Watts
Autonomy	possible, not fully implemented	implemented frequently
Shape	torpedo with wings	torpedo
Original sensors	CTD (or CT), pressure, bottom ranger, compass	CTD (or CT), pressure, sidescan sonar, acoustic transducer (for communication), compass

Characteristic Scales



Pairing Plumes with AUVs for Plume Tracking

Plume Type	AUV Type
Hydrothermal Vent	Actively-propelled
Oil spill	Actively-propelled
HAB	Gliders, Actively-propelled

Gliders are best for:

- long-duration missions, tracking features advected primarily by ocean currents (plumes w/o jet sources), swimming ~20 km in a day (24 hrs at 0.25 m/s) over weeks or months

Actively-propelled AUVs are best for:

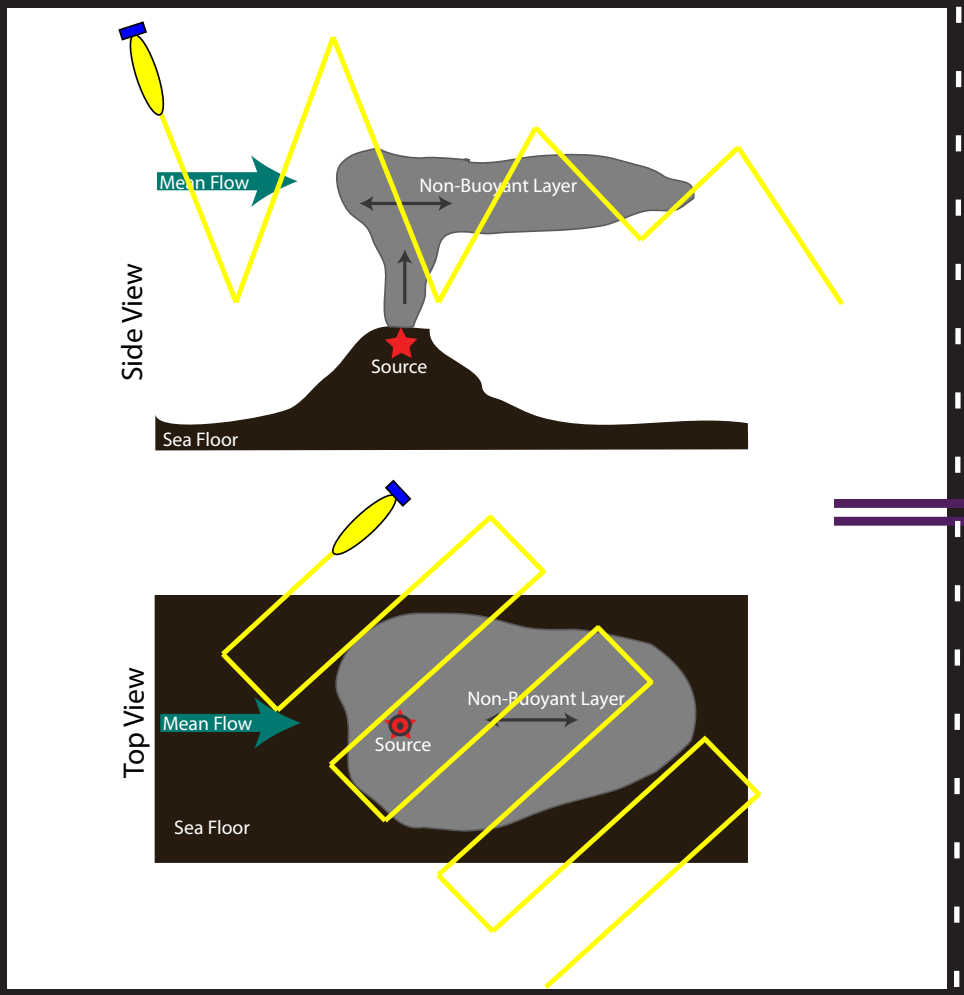
- shorter-duration missions, deep and time-dependent missions, tracking highly time-variant features, swimming against currents, more agility and control in range of motion, swimming >120 km in a day (24 hrs at 1.5 m/s) over a few days (though many can only operate 12 hrs or less between recharging)

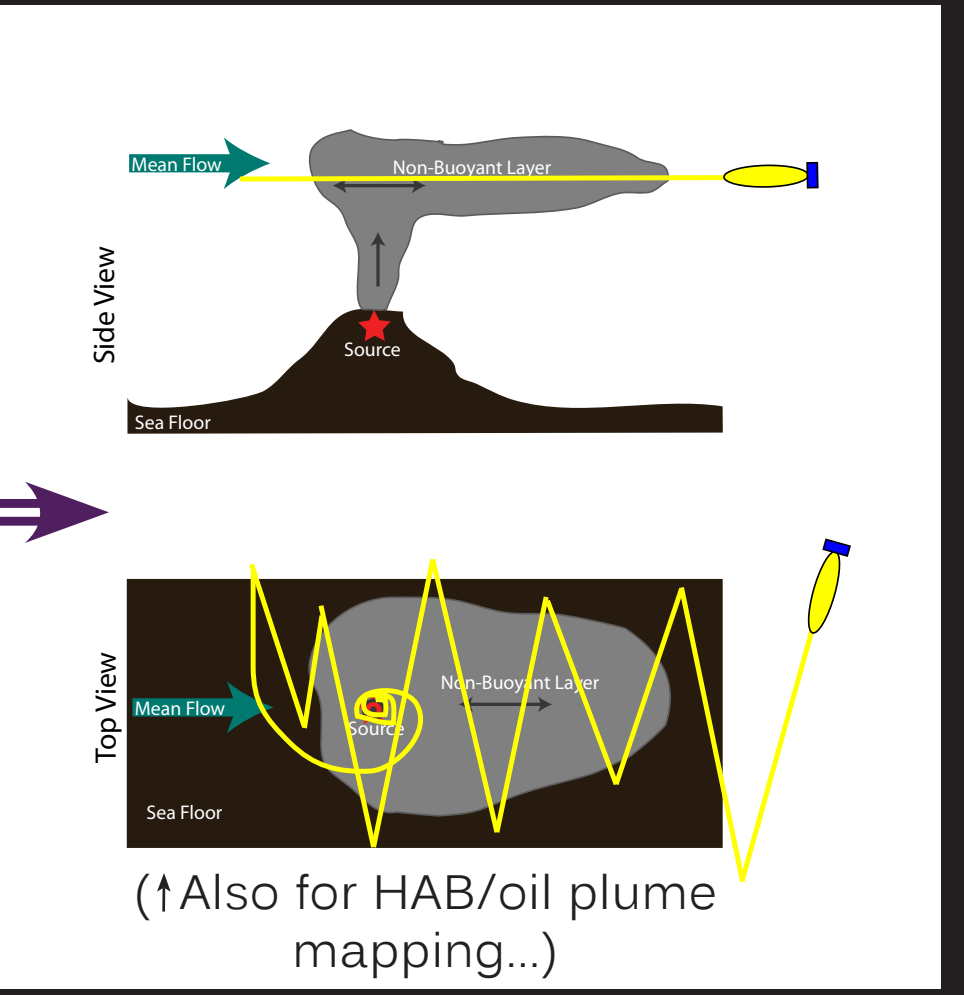
Adaptive Plume Tracking - 1

Non-Buoyant Layer Discovery

Source Localization

- Hydrothermal Vent Plume -





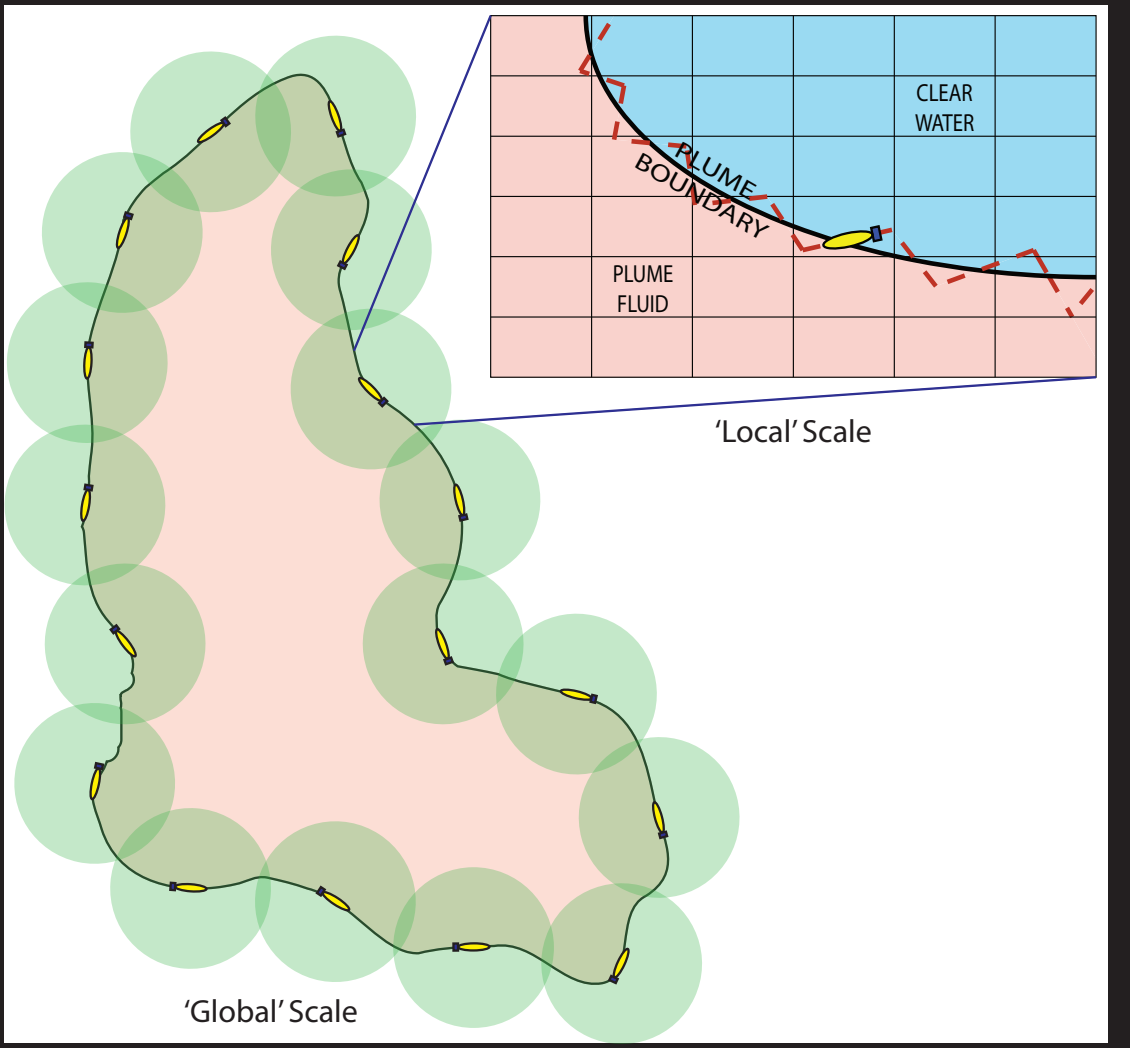
(↑Also for HAB/oil plume mapping...)

- Plume Tracking with AUVs - S. Petillo & H. Schmidt -

Adaptive Plume Tracking - 2

Boundary Tracking

- HAB or Oil Plume -



- Plume Tracking with AUVs - S. Petillo & H. Schmidt -

Conclusions

- Proposed using fully autonomous and environmentally adaptive AUVs for discovering and tracking underwater plumes
- Summarized the physical features and characteristic spatiotemporal scales of HV plumes, oil spill plumes, and HABs
- Generalized the abilities and scales of coverage of gliders vs. actively propelled AUVs.
- Presented some concepts for optimal plume tracking with AUVs
- Looking Forward: Classify different types of plumes based on their features & dynamics, and select one to focus on for tracking with AUVs

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