‘SmartAUVs for detection and qua
of greenhouse gas seepage in the

Ivar-Kristian Waarum
NGI and UiO Institute of Informatics
ikw@ngi.no

SmartAUVs duration and collaborators

NRC call:	Artificial intelligence, robotics and autonomy
Duration:	2022-2026
Budget:	~16 MNOK
History:	ACT4storage -> SmartAUVs

NGI

FFI Forsvarets forskningsinstitutt

PML Plymouth Marine Laboratory

Havforskningsinstituttet

UiO University of Oslo

Universitas Bergensis

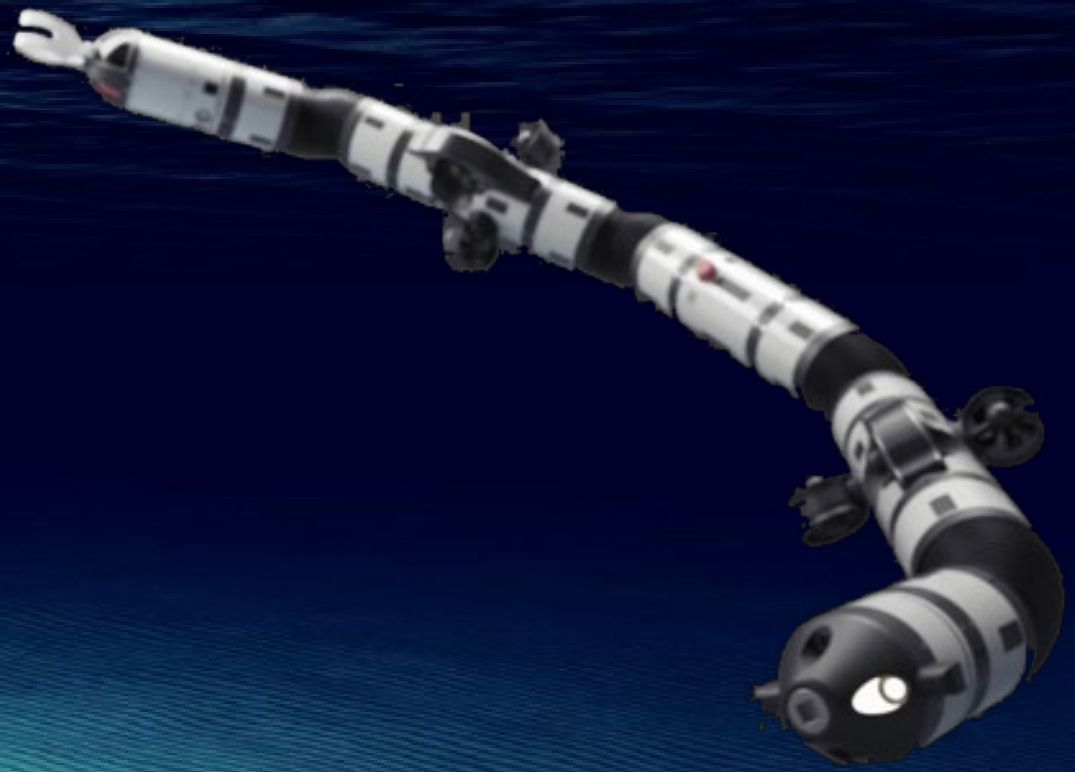
TotalEnergies

equinor

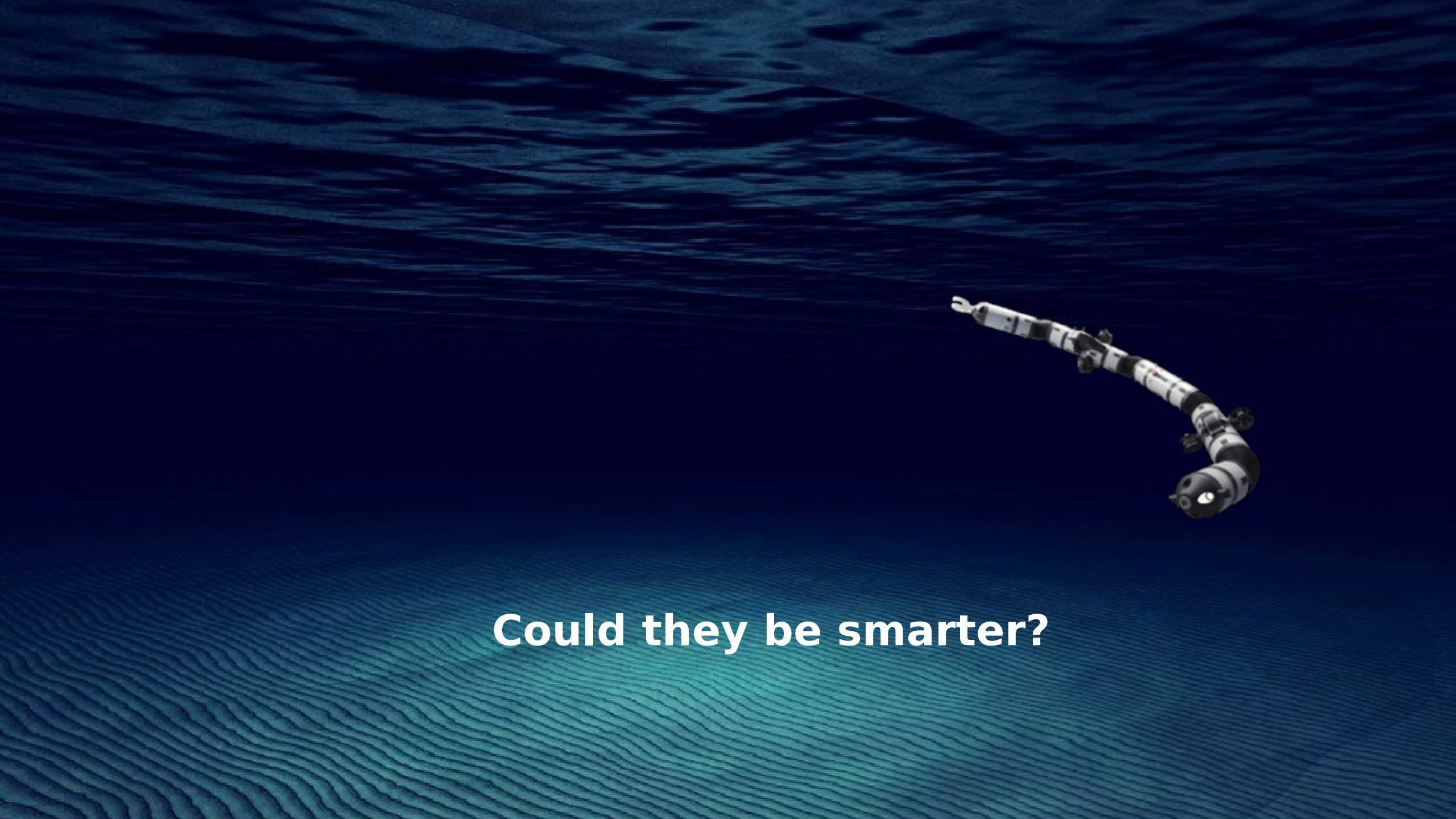
Eelume Subsea Intervention

Kongsberg

AUVs are mobile sensor platforms that can ca
payload for environmental monitoring



- Synthetic aperture sonar
- Echo sounder
- pCO2
- pCH4
- pH
- pO2
- Current meter



Could they be smarter?

SmartAUVs work packages

WP1: Understanding marine emission scenarios

WP2: Modelling and simulations

WP3: Intelligent algorithms for automated gas seep detection

PhD #1

WP4: Adaptive path planning for autonomous operations

PhD #2

WP5: Field trials - demonstrating enhanced AUV autonomy

Eelume

HUGIN

SmartAUVs work packages

WP1: Understanding marine emission scenarios

WP2: Modelling and simulations

WP3: Intelligent algorithms for automated gas seep detection

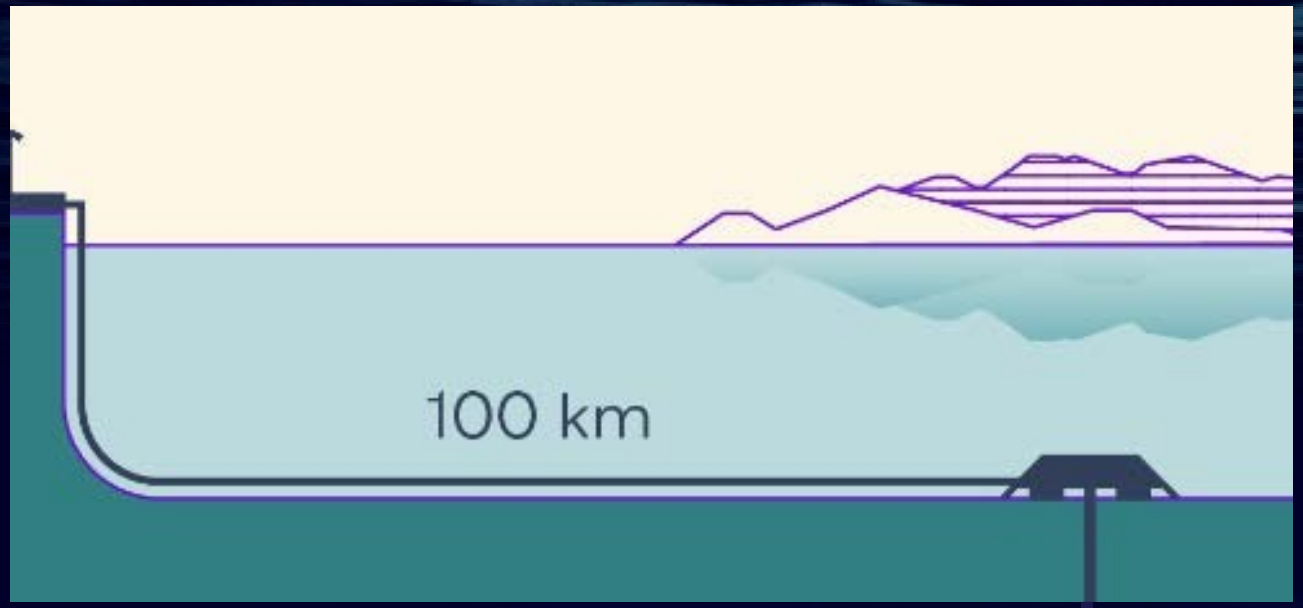
WP4: Adaptive path planning for autonomous operations

WP5: Field trials - demonstrating enhanced AUV autonomy

Eelume

HUGIN

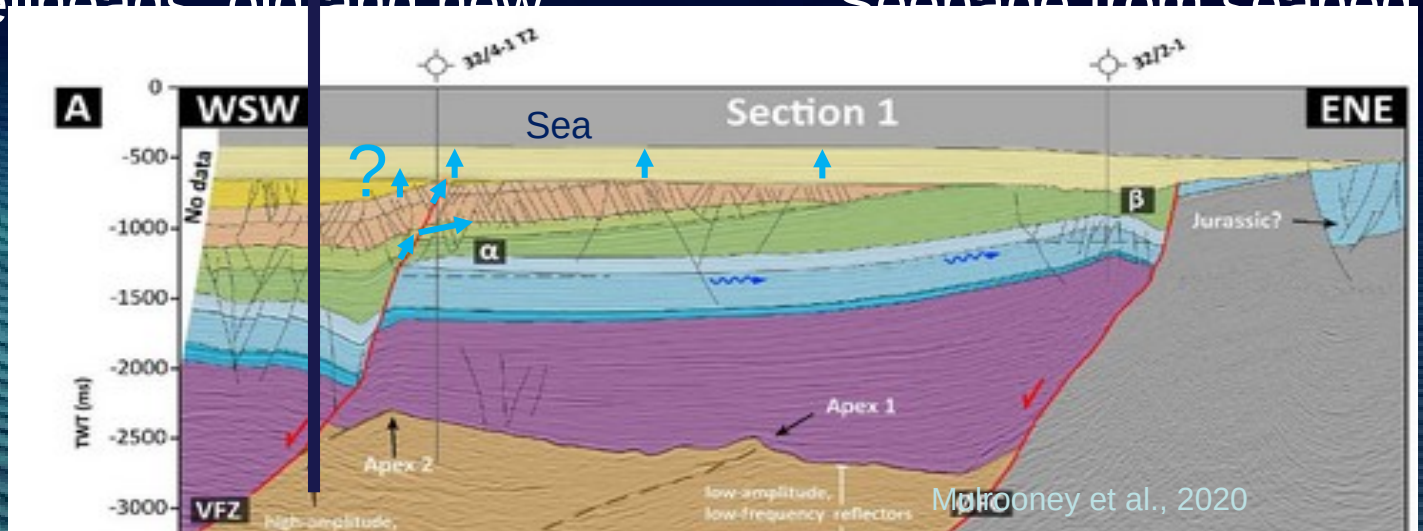
Leakage sources are different



Pipelines

Wellheads, old and new

Seepage from seabed



Mcrooney et al., 2020

Overview of emission scenarios – from re

Leakage scenario	Simulating scenario	Physical location/environment	Emission type	Priority
1a – Pipeline, CO2, Low rate	Leakage from a pipeline in a coastal region	Oslo fjord, ~70 m water depth. Sandy, relatively flat seabed	CO2, low leak rate (1 l/min)	1
1b- Pipeline, CO2, medium rate	Leakage from a pipeline in a coastal region	Oslo fjord, ~70 m water depth	CO2, medium leak rate (10 l/min)	1
1c- Pipeline, CO2, "high" rate	Leakage from a pipeline in a coastal region	Oslo fjord, ~70 m water depth	CO2, medium leak rate (50 l/min)	2
1d- Pipeline, CH4, low rate	Leakage from a pipeline in a coastal region	Oslo fjord, ~70 m water depth	CH4, low leak rate (1 l/min)	1
1e-Pipeline, CH4, medium rate	Leakage from a pipeline in a coastal region	Oslo fjord, ~70 m water depth	CH4 medium leak rate (10 l/min)	1
1f-Pipeline, CH4, "high" rate	Leakage from a pipeline in a coastal region	Oslo fjord, ~70 m water depth	CH4 medium leak rate (50 l/min)	2
2a – Well, CO2, Low rate	Leakage from an offshore well	North Sea (Smeaheia), 300 m water depth, sandy, flat seabed	CO2, low leak rate (1 l/min)	2
2b- Well, CO2, medium rate	Leakage from an offshore well	North Sea (Smeaheia), 300 m water depth, sandy, flat seabed	CO2, medium leak rate (50 l/min)	2
2c- Well, CH4, low rate	Leakage from an offshore well	North Sea (Smeaheia), 300 m water depth, sandy, flat seabed	CH4, low leak rate (1 l/min)	2
2d-Well, CH4, medium rate	Leakage from an offshore well	North Sea (Smeaheia), 300 m water depth, sandy, flat seabed	CH4 medium leak rate (50 l/min)	1
3 - Natural CH4 seepage	Distributed CH4 seepage from multiple point sources	North Sea	CH4, many small releases (10 points, 0.1 l/min each)	3
1e – Pipeline in clay	Leakage from a pipeline in a coastal region	Oslo fjord but clay seabed, so smaller bubble size	CH4, medium leak (10l/min)	4
2e - Well, CO2, very high leak rate	Leakage from an offshore well	North Sea (Smeaheia), 300 m water depth, sandy seabed	CO2, 100 l/min	5
2f - Well, CH4, very high leak rate	Leakage from an offshore well	North Sea (Smeaheia), 300 m water depth, sandy, flat seabed	CH4, 100 l/min	5

1. Pipeline leakage, coastal environment

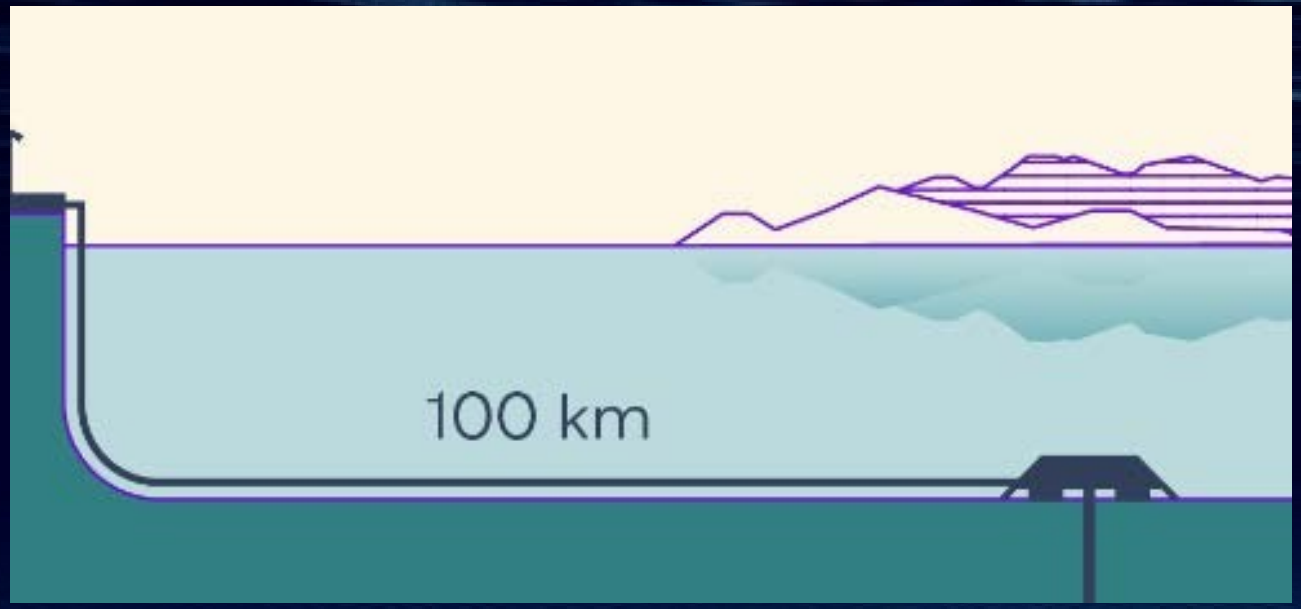
2. Leakage along well, North Sea

Natural CH4 seepage

Pipeline leakage, clay seabed

Leakage along a well at higher leak rates

Following a pipeline helps the AUV to navigate, but not to detect leakage or act intelligently



Pipelines

Wellheads, old and new

O&G operator’s vision

The characteristics of gas seepage is heavily the marine environment

uniform and stratified crossflow“

The characteristics of gas seepage is heavily the marine environment

Strong current

From SOCOLOFSKY et al “Multi-phase plumes in uniform and stratified crossflow“

The characteristics of gas seepage is heavily the marine environment

Currents **Buoyancy** **Stratification**

Acoustic sensors for bubbles, chemical sensors for dis

From SOCOLOFSKY et al "Multi-phase plumes in uniform and stratified crossflow"

SmartAUVs work packages

WP1: Understanding marine emission scenarios

WP2: Modelling and simulations

WP3: Intelligent algorithms for automated gas seep detection

WP4: Adaptive path planning for autonomous operations

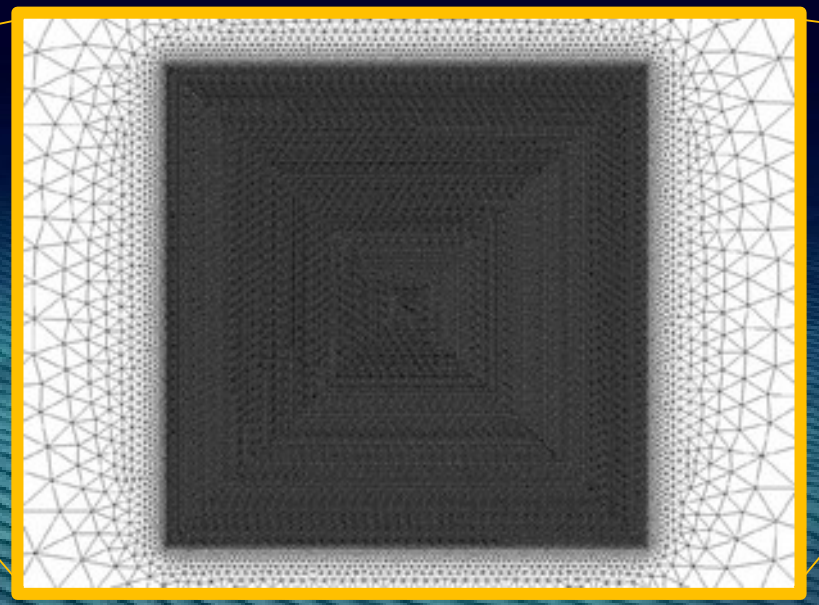
WP5: Field trials - demonstrating enhanced AUV autonomy

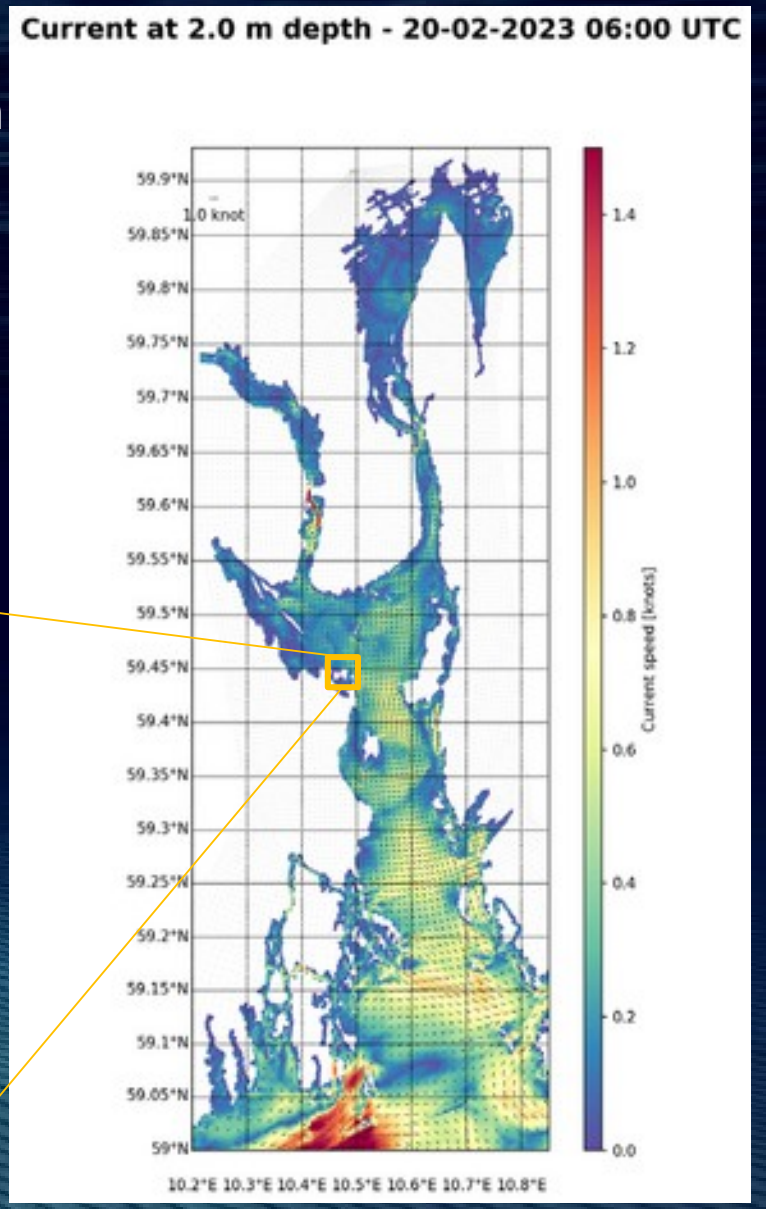
Eelume

HUGIN

High resolution simulation framework

- Developed a 250 x 250 m meter scale grid that can be applied to both
- For local conditions, we will apply forcing data from larger models:
  - Currents
  - Temperature
  - Salinity





Slide from M. Dewar/P

The PLUME modelling system

- Aims
  - Develop a numerical model to show the plume dynamics of a CO_2 or CH_4 release

- Gas bubble plume physics
  - Initial bubble sizes
  - Bubble rise velocities
  - Gas dissolution
  - Bubble rise heights

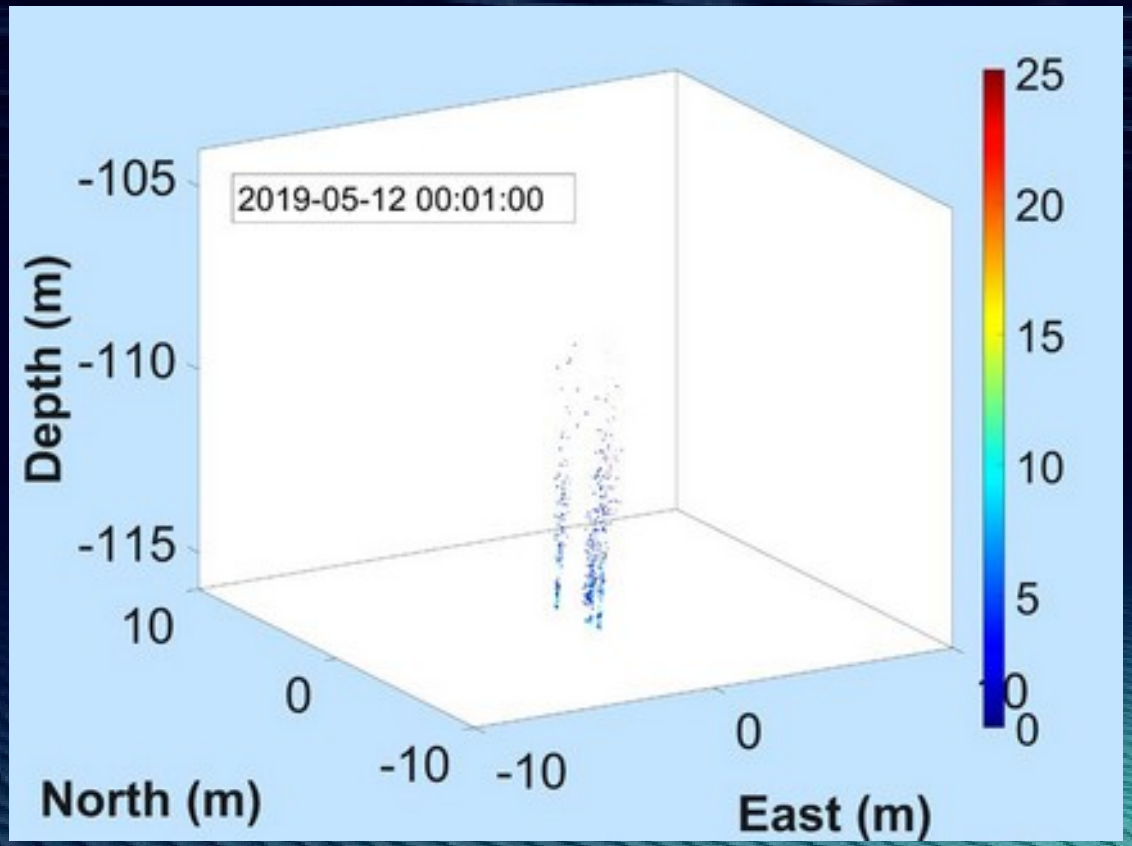
- Localised and coastal chemistry
  - Changes in seawater density and currents
  - Distribution of the dissolved solution plume
  - Increases in pCO_2*
  - Reductions in pH*
  - Increase in pO_2*

*reactions limited to only CO_2

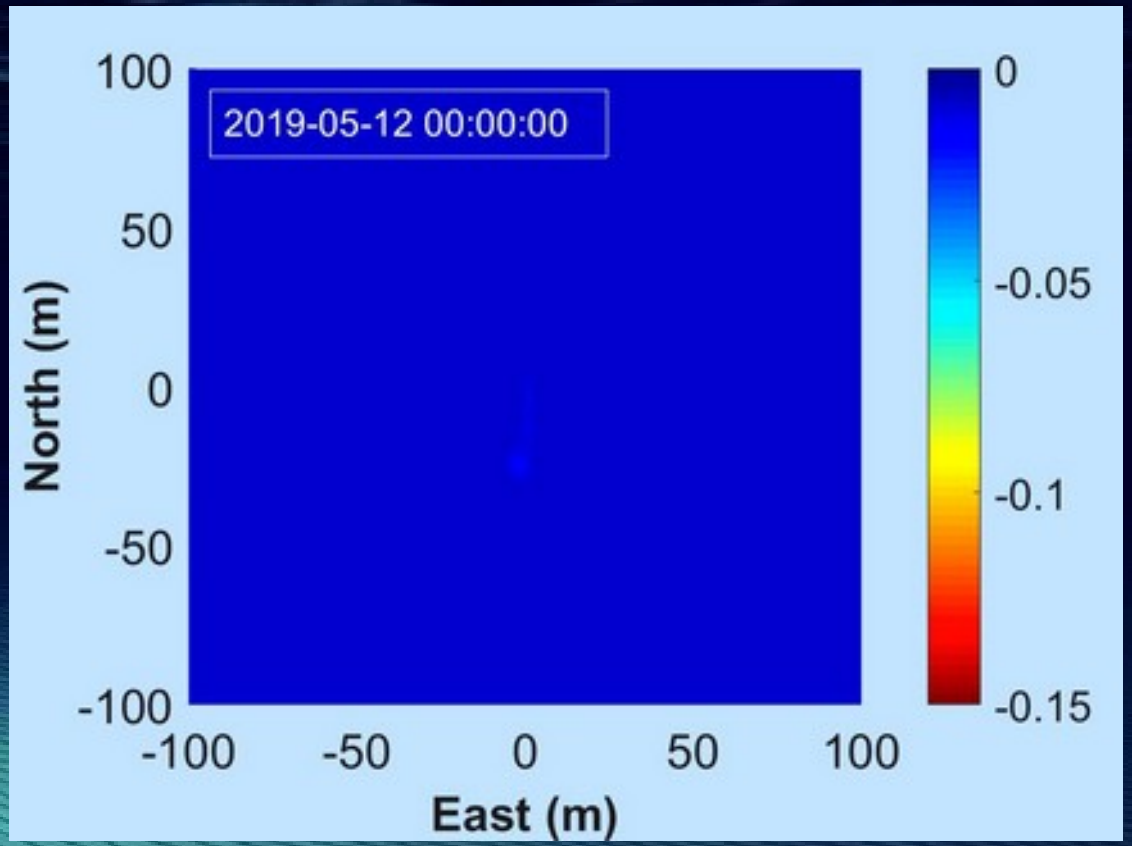
Slide from M. Dewar/PI

PLUME simulation

Bubble Plume



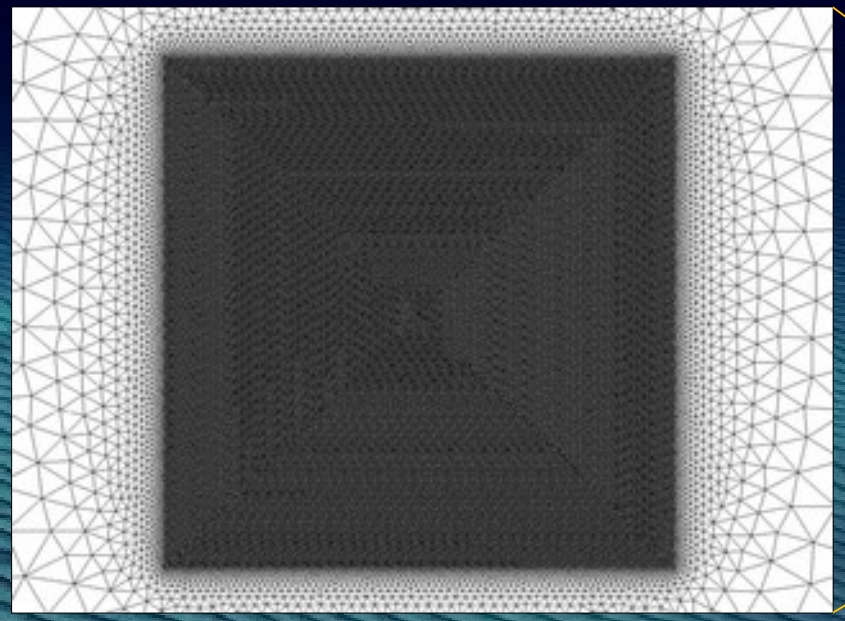
ΔpH Plume

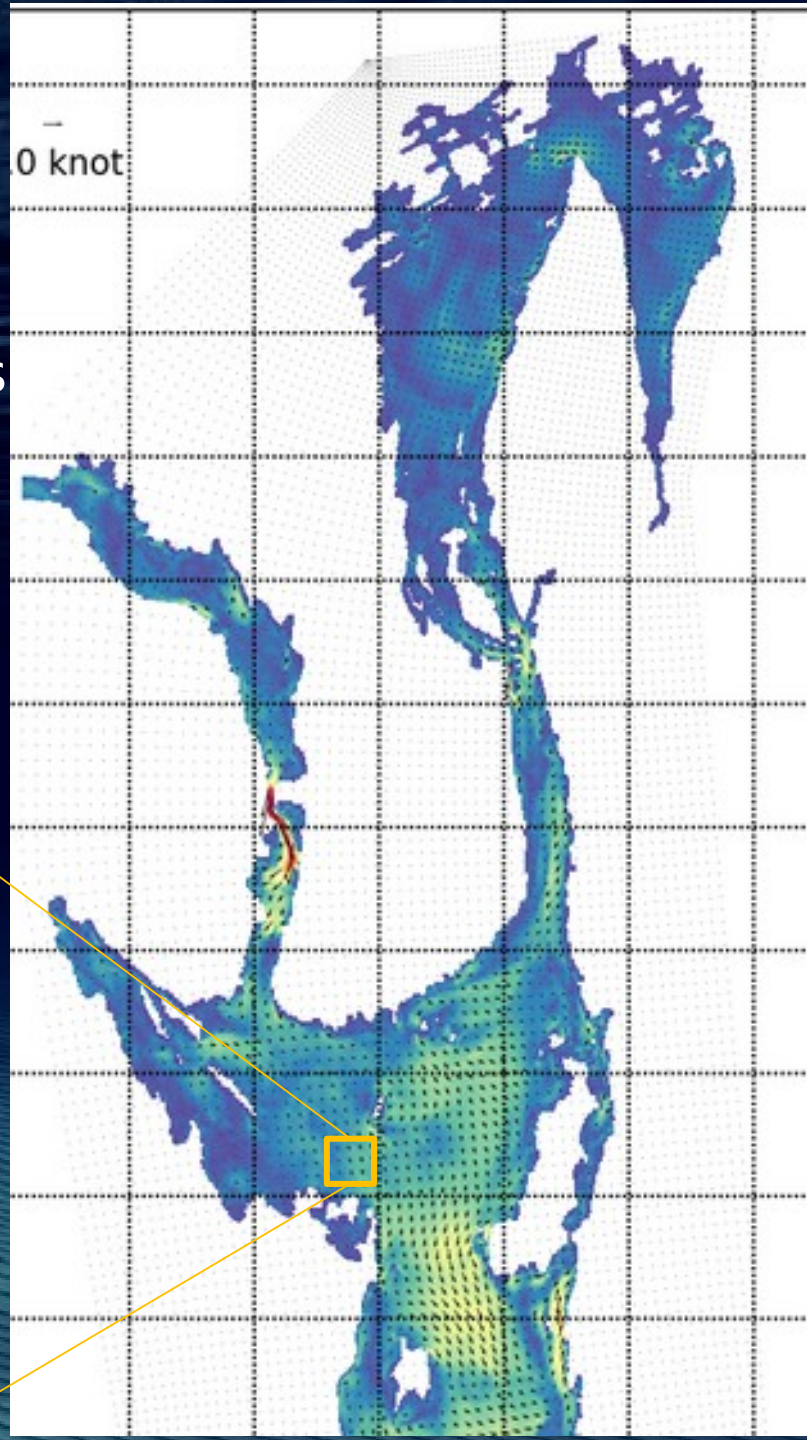


Slide from M. Dewar/Pl

Simulations – ‘Digital ocean’

- Up to ten different leakage scenarios
- Leakage scenarios simulated over 2 tidal cycles (~12 hours
- Leakage data stored at second intervals at every point in a one meter resolution
  - Dissolved gas concentration
  - Bubble parameters
- Oceanographic data stored at ~10 minute intervals
  - Currents
  - Salinity
  - Temperature
  - Density





SmartAUVs work packages

WP1: Understanding marine emission scenarios

WP2: Modelling and simulations

WP3: Intelligent algorithms for automated gas seep detection

WP4: Adaptive path planning for autonomous operations

WP5: Field trials - demonstrating enhanced AUV autonomy

Eelume

HUGIN

SmartAUVs work packages

WP1: Understanding marine emission scenarios

WP2: Modelling and simulations

WP3: Intelligent algorithms for automated gas seep detection

WP4: Adaptive path planning for autonomous operations

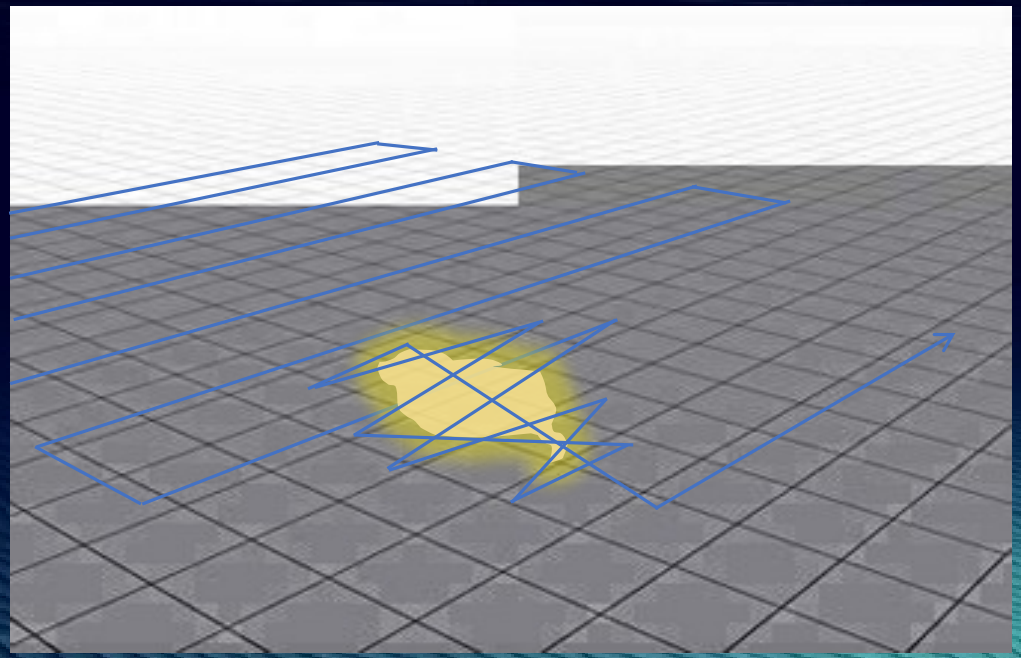
WP5: Field trials - demonstrating enhanced AUV autonomy

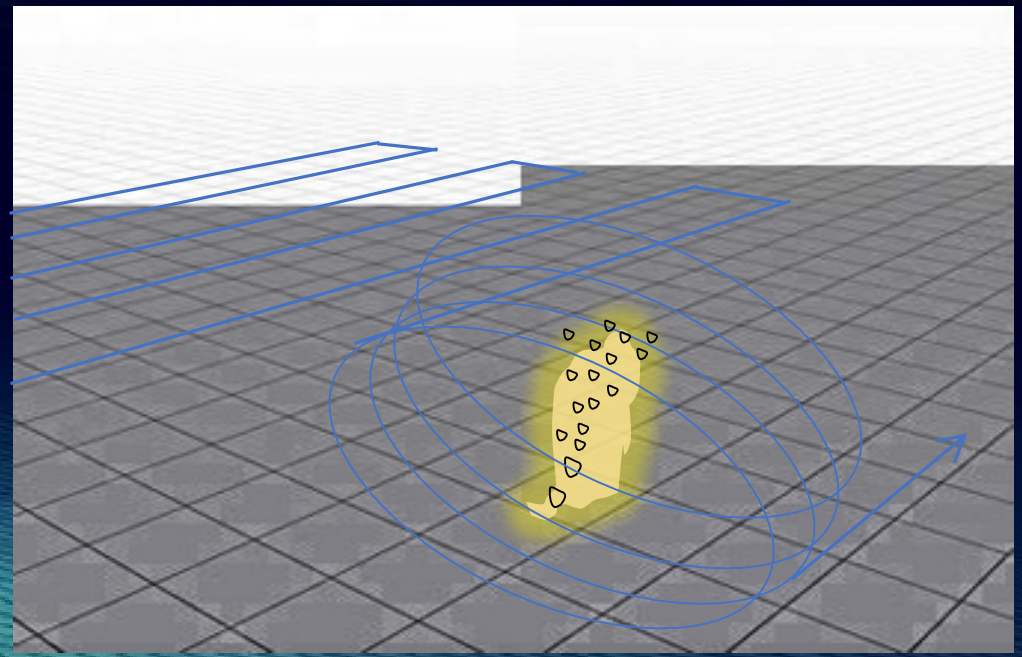
Eelume

HUGIN

The output from an AUV mission should be a m

seepage ***with the highest accuracy where it is most***





Adaptive behavour

A priori information

Realtime information

Risk assessment
- Area of interest
- Hotspots

Feature properties
- Oceanography
- Chemical
- Origin

Preliminary plan
- Go/No go zones
- Pattern

AUV hardware
- Navigational capabilities
- Sensors

Modelling algorithm

Static	**Dynamic**
Risk image Feature properties	Sensor measurements

Path planning algorithm

Static	**Dynamic**
Preliminary plan AUV Hardware	Model Position msr. Previous plan Battery msr.

New waypoints to navigation layer

A priori information

Realtime information

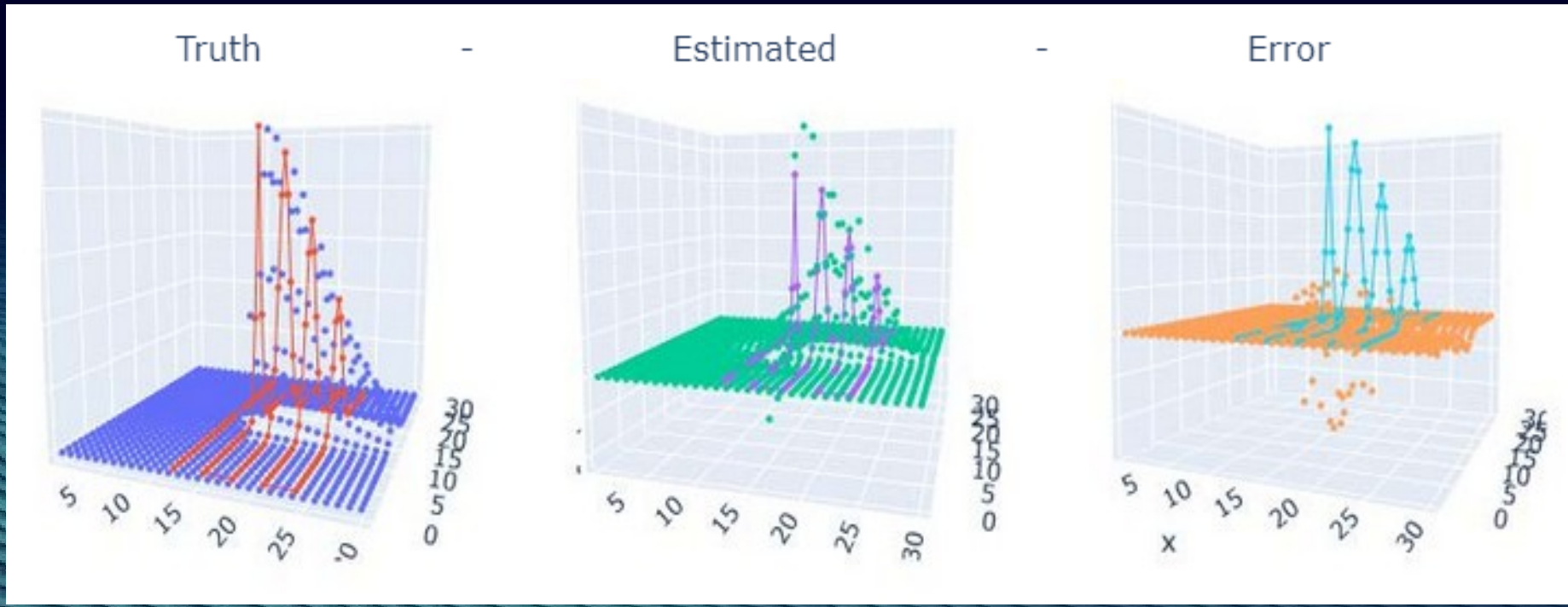
Risk assessment
- Area of interest
- Hotspots

Feature properties
- Oceanography
- Chemical
- Origin

Modelling algorithm

Static
Risk image
Feature properties

Dynamic
Sensor measurements



SmartAUVs work packages

WP1: Understanding marine emission scenarios

WP2: Modelling and simulations

WP3: Intelligent algorithms for automated gas seep detection

WP4: Adaptive path planning for autonomous operations

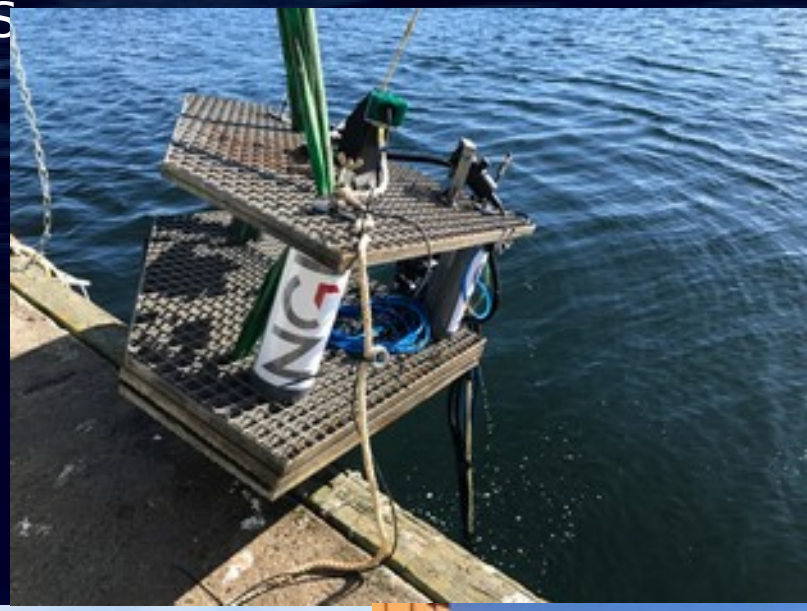
WP5: Field trials - demonstrating enhanced AUV autonomy

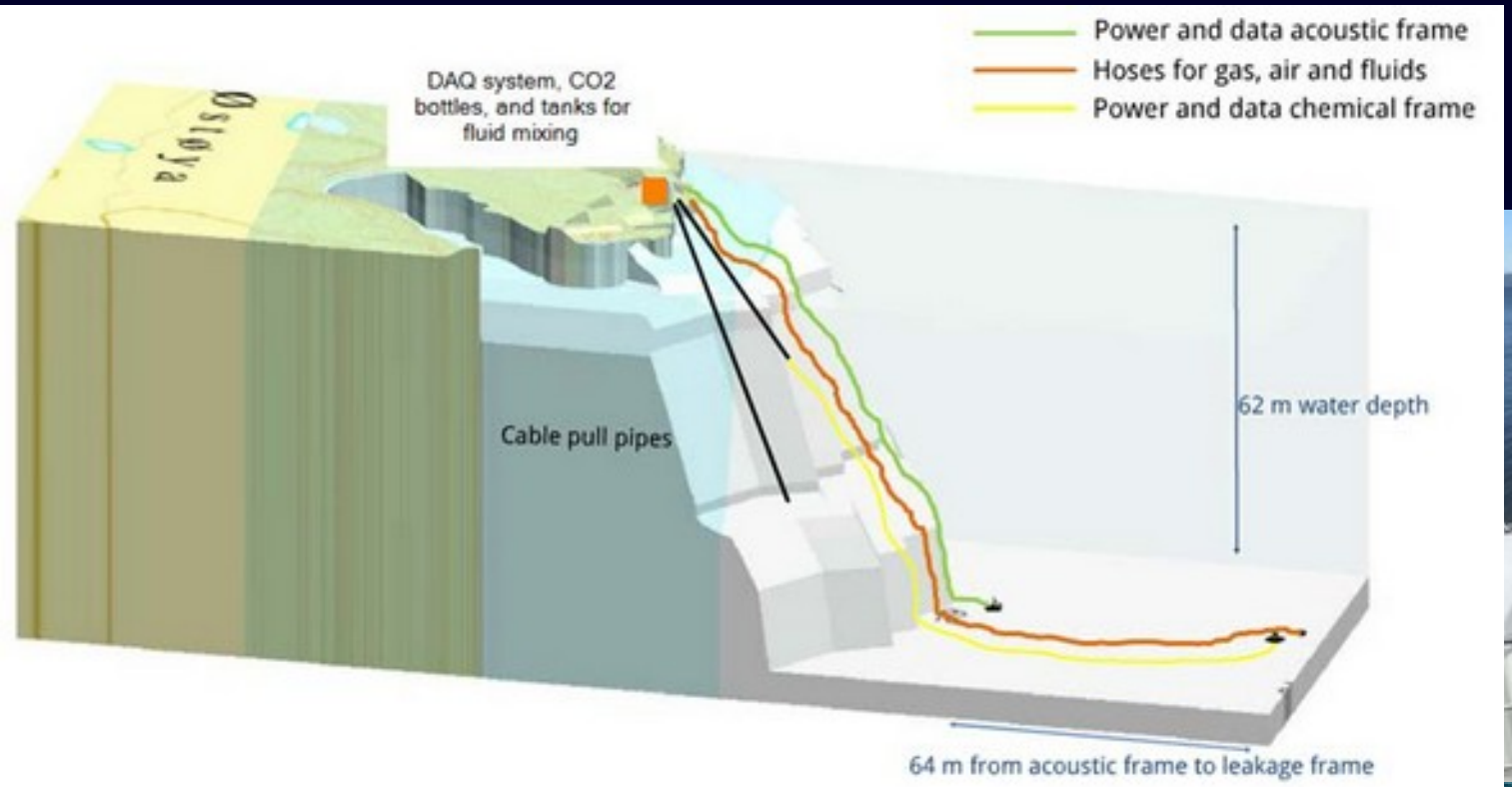
Eelume

HUGIN

Images from ACT4storage

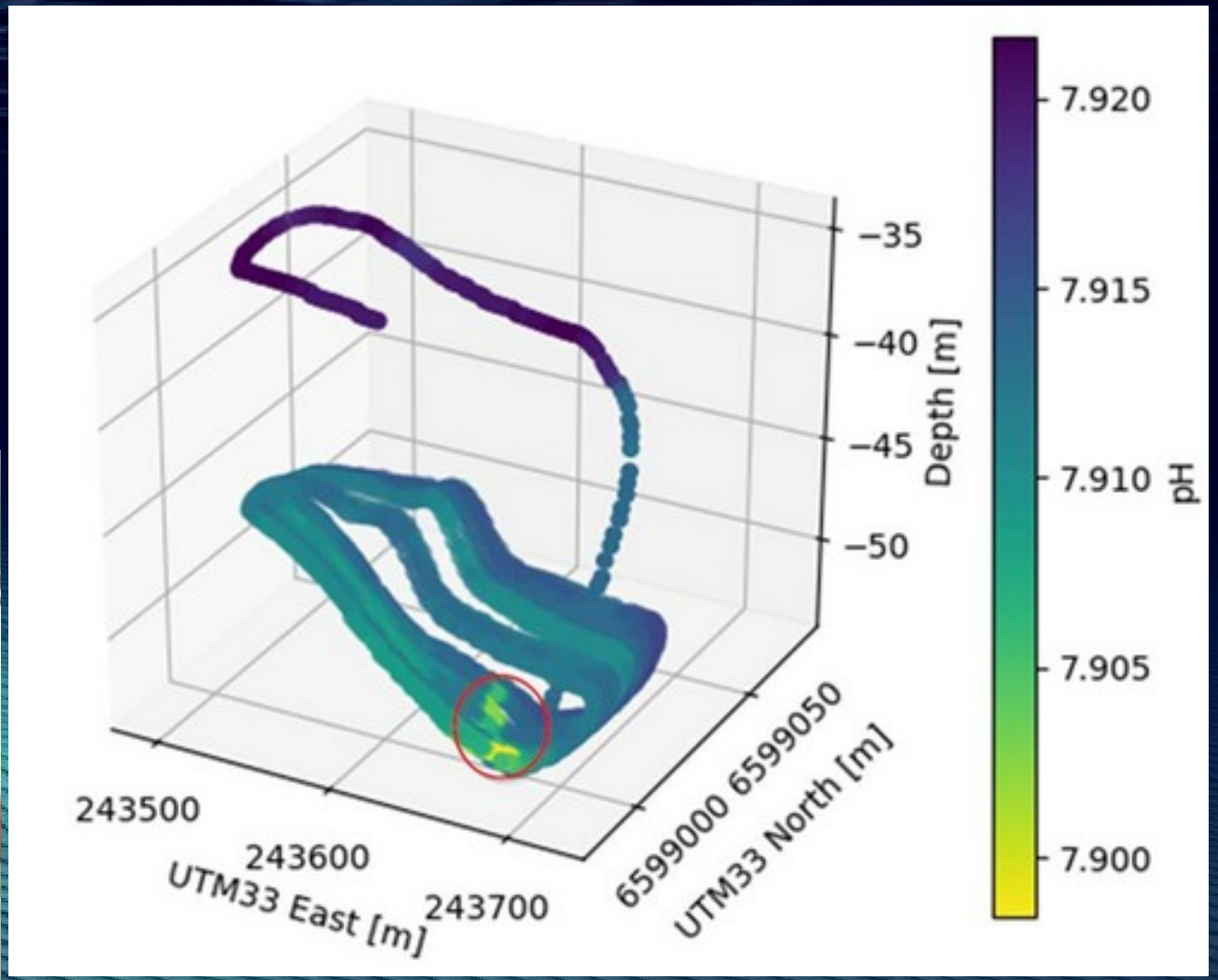
- 60 m water depth, geochemical conditions representative of North S
- Release of dissolved CO_2 only, gas-phase CO_2 only (bubbles), and a combination of both





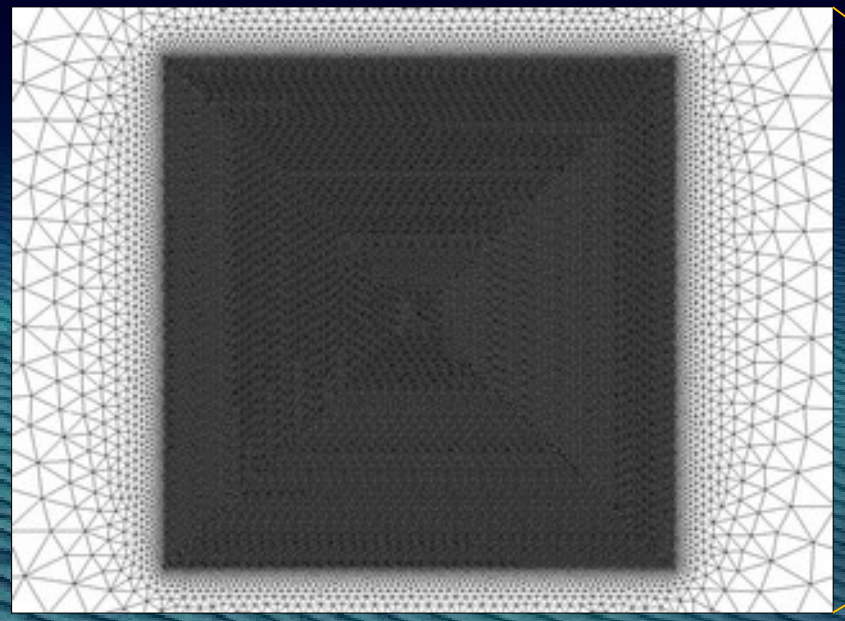
Images from ACT4storage

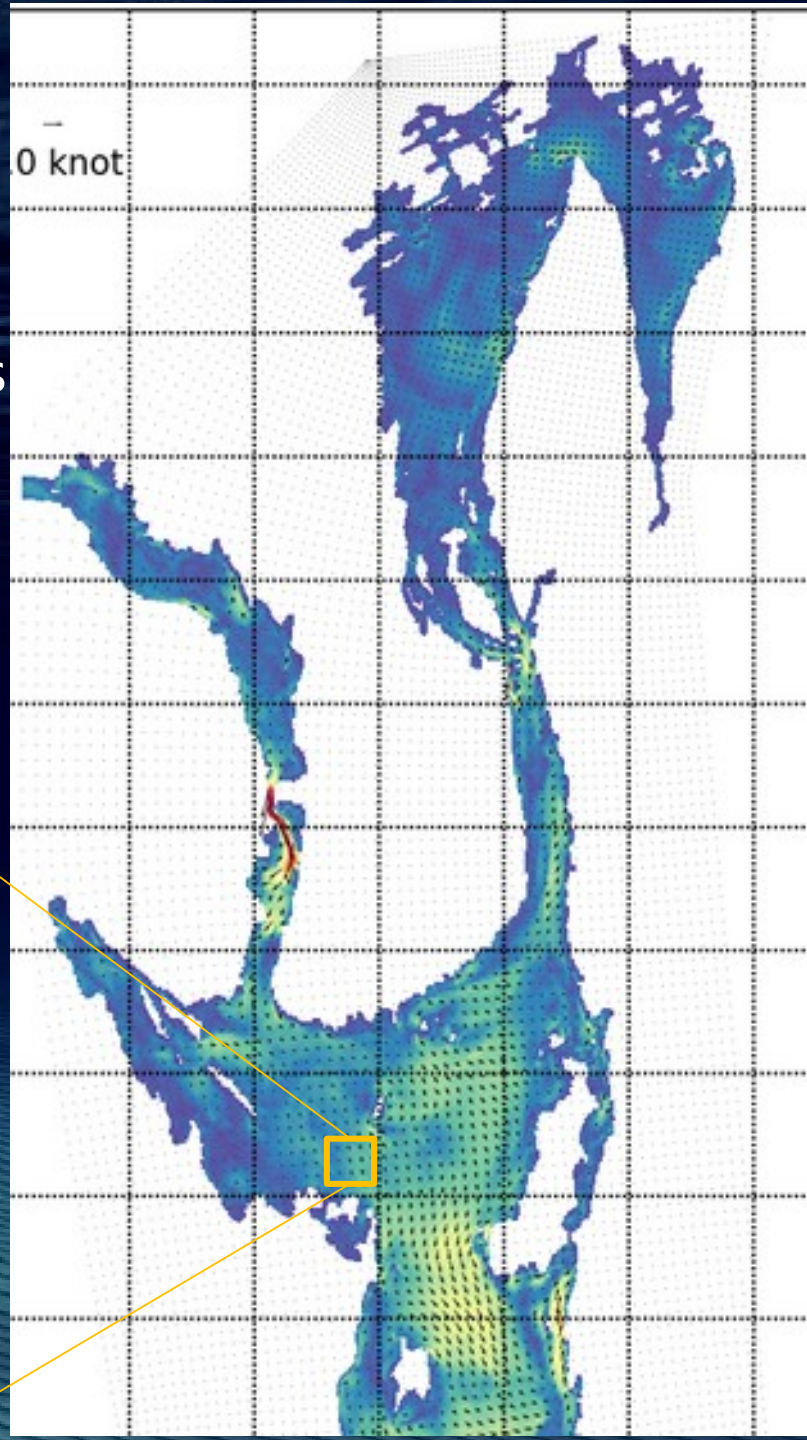
- **SmartAUVs** field trials planned for 2024 and 2025
- Leakage source ~400 meters from shore



‘Digital ocean’ -> ROBIN

- Up to ten different leakage scenarios
- Leakage scenarios simulated over 2 tidal cycles (~12 hours
- Leakage data stored at second intervals at every point in a one meter resolution
  - Dissolved gas concentration
  - Bubble parameters
- Oceanographic data stored at ~10 minute intervals
  - Currents
  - Salinity
  - Temperature
  - Density

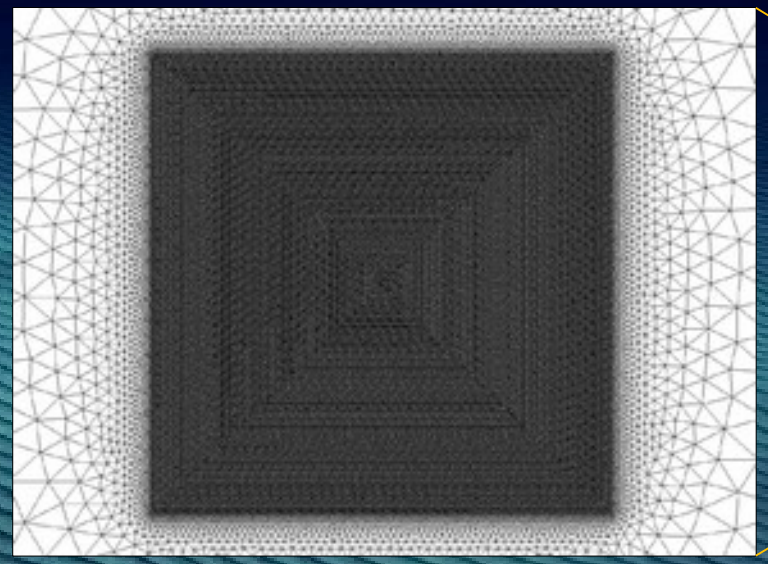


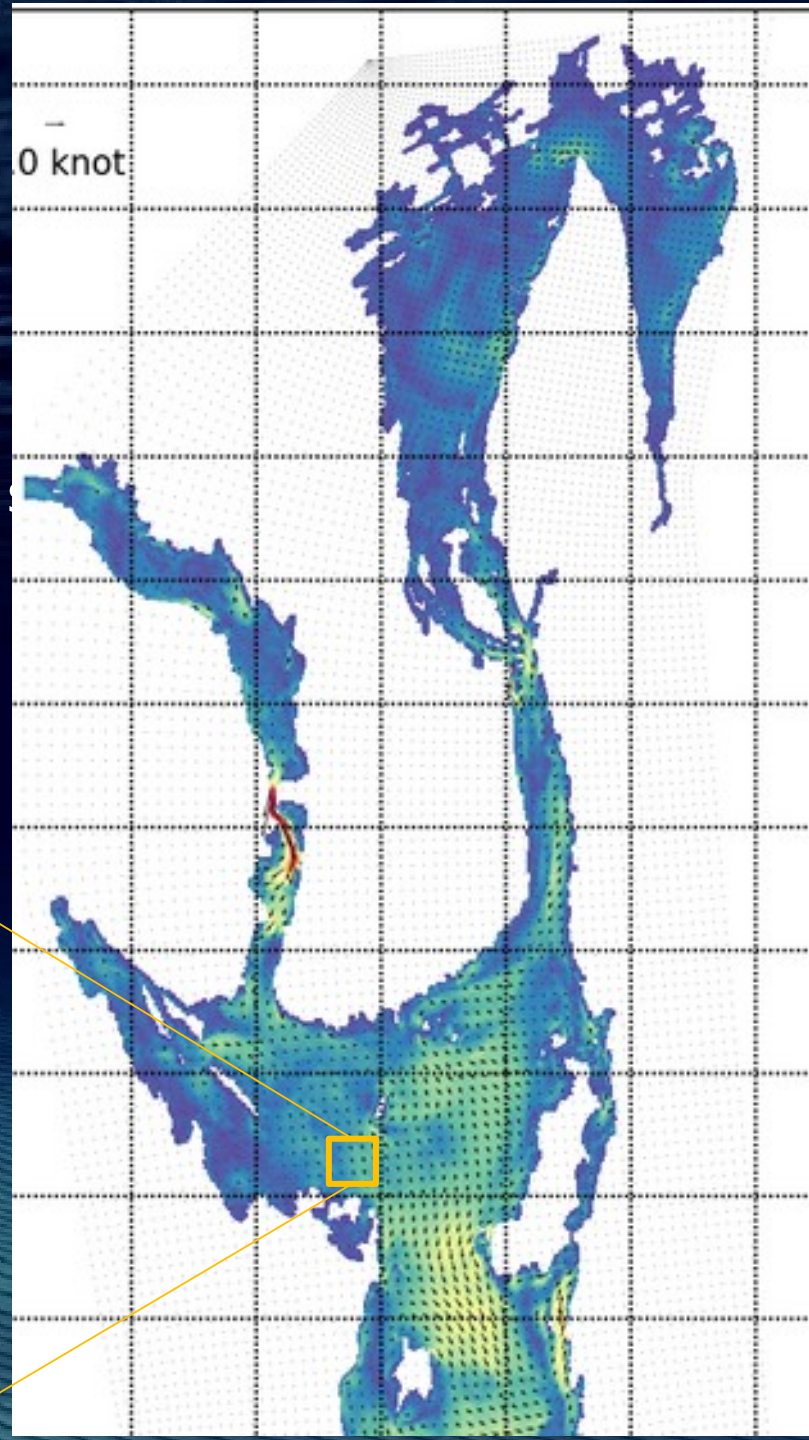


‘Digital ocean’ -> ROBIN

- Use a leakage scenario as training or testing
- Hunt for artificial leakage in a realistic environment
  - or map salinity/temperature
- Read parameters from the simulation (stored as netCDF or
  - E.g. parameter c at position x,y,z at time t
  - Use directly as artificial sensor input, or add sensor noise/range etc.
- Let agent compute next position to sample at
- Pair with robot model if you want kinetics as well
- Add no-go zones or areas of interest

- Path planning
- Mapping
- Decision making
- more?





12 RESPONSIBLE CONSUMPTION AND PRODUCTION

13 CLIMATE ACTION

14 LIFE BELOW WATER

15 LIFE ON LAND

16 PEACE, JUSTICE AND STRONG INSTITUTIONS