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Recreational Sailing Fleets as a Coastal Observing System

A citizen-science architecture and metrological methodology

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About me

Last century

Geophysicist

Then

Software engineer

Now

Product manager

Also

Sailor

Side hustle

Citizen scientist

Founder of Stichting Project SeaSense, a Dutch non-profit for sailing-based ocean observation.



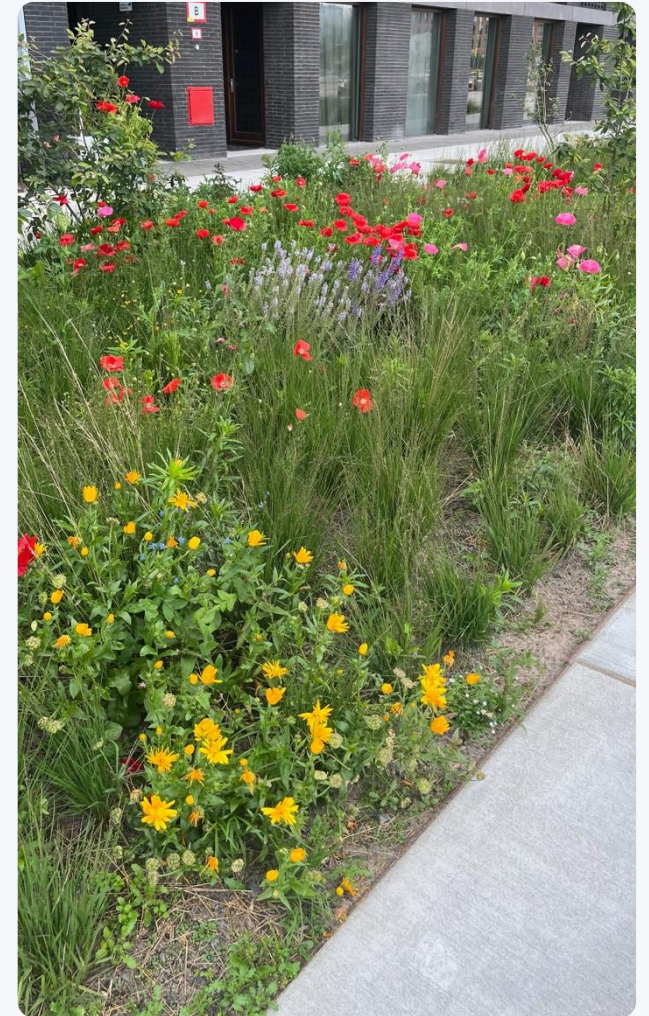
2021 United Nations Decade
2030 of Ocean Science
for Sustainable Development

It started with my plants

I watered my plants with Amsterdam canal water.

Salt from the North Sea intrudes into the canals. Too much salt kills plants.

So: a cheap AliExpress conductivity sensor and a dashboard, to see when the water was safe to use.



Sail with purpose

1. Put sensors on my sailboat.
2. Then on more sailboats.
3. Create a global network of observatories.

A modern yacht already carries

- a masthead anemometer
- an echo sounder
- a hull water-temperature sensor
- a network bus connecting them

Almost none of the data is recorded.

Or shared with scientists.

Random instruments, random boats, random places

Random instruments

Consumer grade, uncalibrated, unknown make and model. No traceable uncertainty.

Random boats

Unknown mounting height and siting. Heeling, moving platforms. Crew switches power off.

Random places

The owner decides where and when. Fair-weather routes, rarely near a reference station.

A boat reads about **1 hPa** higher than a station 25 km away.
Instrument error, or a real difference in the weather?

Can we create a platform to capture this data?
How much usable signal can be recovered?

Prototypes, 2025



Trial 1. Sensor buoy towed behind a paddleboard through Amsterdam.



First data. The first run in Amsterdam.

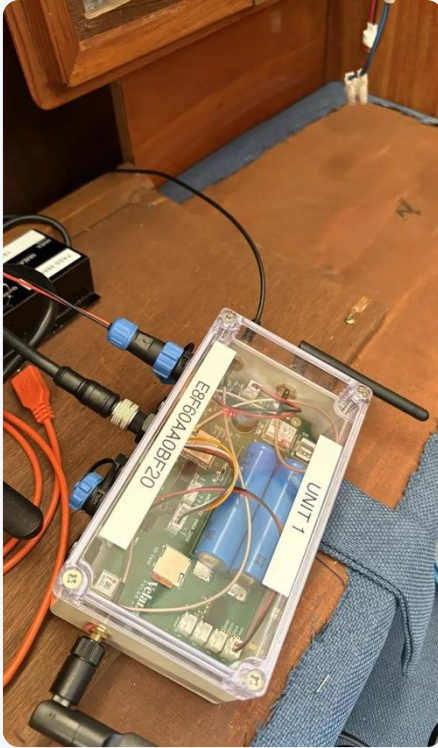


Trial 2. From a sailboat, past reference station Markermeer Midden.

Lessons

- Towing a buoy is not optimal, so add a pump & water circuit and make a FerryBox
- Start with using existing sensors on the boat, only then add more sensors.

Two tiers, 2026



Tier 1 · in development



Tier 2 · sailed

Tier 1 · under €200

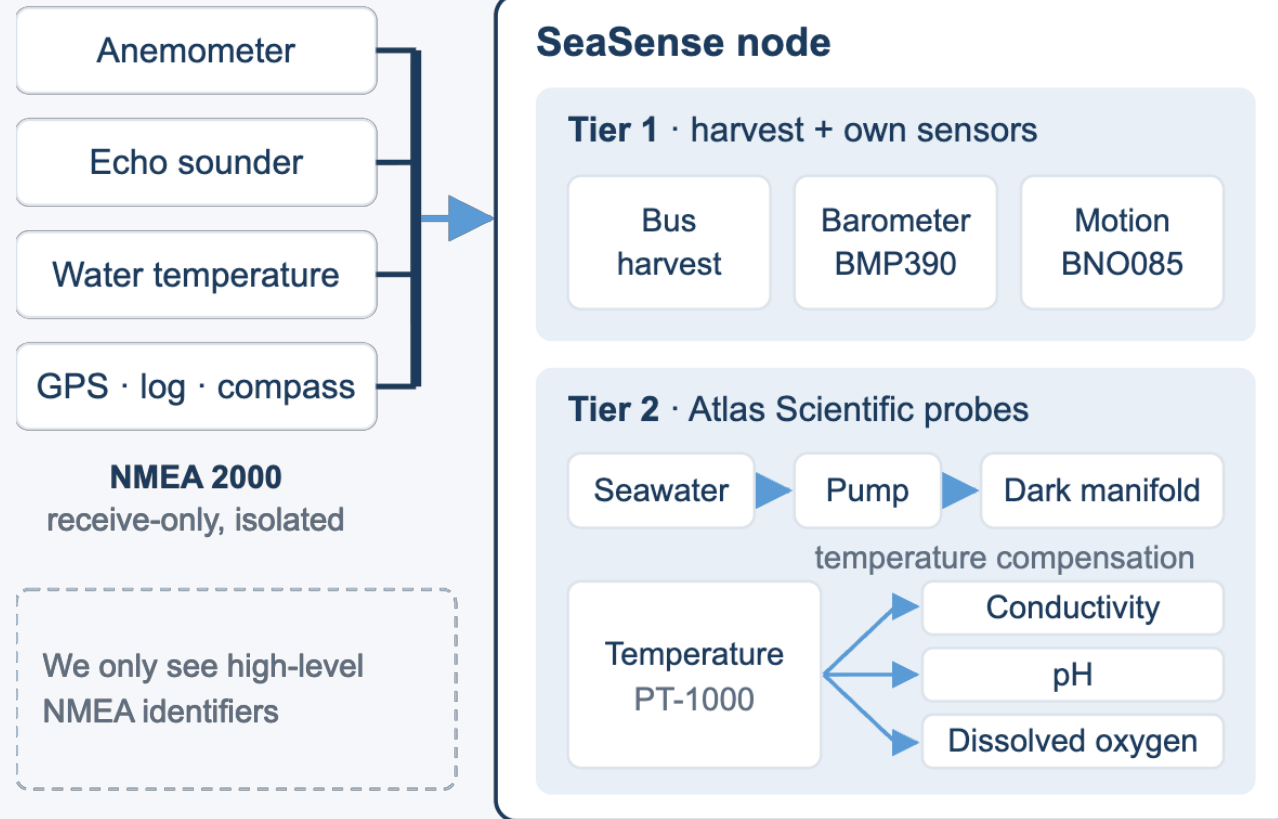
Harvests the boat's marine-bus instruments. Adds pressure and motion sensors. Adds battery for prolonged measurement and LTE modem to send data back to our platform over NB-IoT

Tier 2 · from €1,000 plus plumbing

Tier 1 plus flow-through water quality: pump, dark manifold, PT-1000, conductivity, pH, dissolved oxygen. Needs plumbing.

How the platform works

ON BOARD



ASHORE

uplink
buffered

Data platform

one ingest API for all partners
time-series store

provenance on every sample:
instrument identity, vessel,
installation metadata

Planned

reference validation
repeat routes
export to aggregators

The Tier 2 unit

Function	Part	Specification and pre-departure adjustment
Controller	Hat Labs SH-ESP32	ESP32, CAN built in, 8–32 V
Bus	NMEA 2000	galvanically isolated, receive-only
Pressure	Bosch BMP390	± 0.50 hPa absolute, 0.02 Pa noise, factory calibrated only, sea level
Motion	BNO085, 9-DOF	pitch and roll, 100 Hz, zeroed level on board
Temperature	Atlas EZO-RTD, PT-1000 in thermowell	circuit ± 0.1 °C; Class A probe ± 0.18 °C; factory calibrated
Conductivity	Atlas EZO-EC, K 10 probe	$\pm 2\%$, 2-point calibration at 12,880 and 150,000 $\mu\text{S}/\text{cm}$; fresh water below that is extrapolated
pH	Atlas EZO-pH, lab-grade probe	± 0.02 , 3-point calibration with pH 4, 7 and 10 buffers
Dissolved oxygen	Atlas EZO-DO, lab-grade galvanic probe	± 0.05 mg/L, 1-point calibration in air only; zero never set
Flow	Seaflo pump, dark manifold	flush, then read, every 15.5 min
Power	From boat's instrument panel	2.5 W node, pump ~ 2 A while running

Adjusted, not calibrated: nothing was compared against a traceable reference, and no adjustment record was kept except one DO timestamp (23 June). Atlas advises repeating the adjustment for DO monthly, pH yearly (monthly for high accuracy), conductivity at least yearly.

The method: reduce noise, anchor the signal

Mechanism	What it does
Instrument identity	N2K product info: maker, model, firmware, ideally serial every sample
Repeat routes	Same ground twice separates vessel error from environment, for specific parameters
Co-location	Passes near reference stations
Per-vessel profiles	Static bias, seasonal drift, quality grade per instrument per vessel
Density	Many boats agree or disagree at crossings

The method we are working towards.

Then: a boat



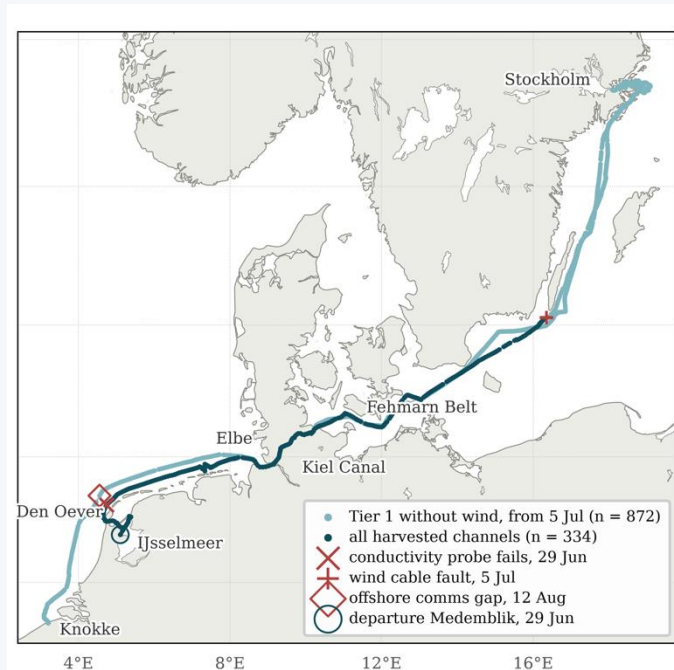
The boat with the first Project SeaSense unit.

Sponsor **Contest Yachts** found a launching customer for a new 63CS.

The owner chose route and schedule. **We went where the boat went.**

It sailed on the **maiden voyage** to Sweden and back.

Seven weeks at sea, no access



Where: Medemblik, Den Oever, German Bight, Kiel Canal, open Baltic, Stockholm archipelago, back to Knokke.

1,080 **15.5 min** **29 Jun–16 Aug**
observations cadence under way

The maiden voyage: what worked, what did not

Worked

- Seven weeks autonomous
- Data backfilled on reconnect
- All channels kept reporting, except for wind
- Our first proper data set

Oops

- Boat: panel off in harbour, no data
- Boat: wind cable failed, day 6
- Ours: probes calibration adjustments, almost no record kept
- Ours: no anti-fouling
- Ours: conductivity and DO probes degraded

Method

Tested

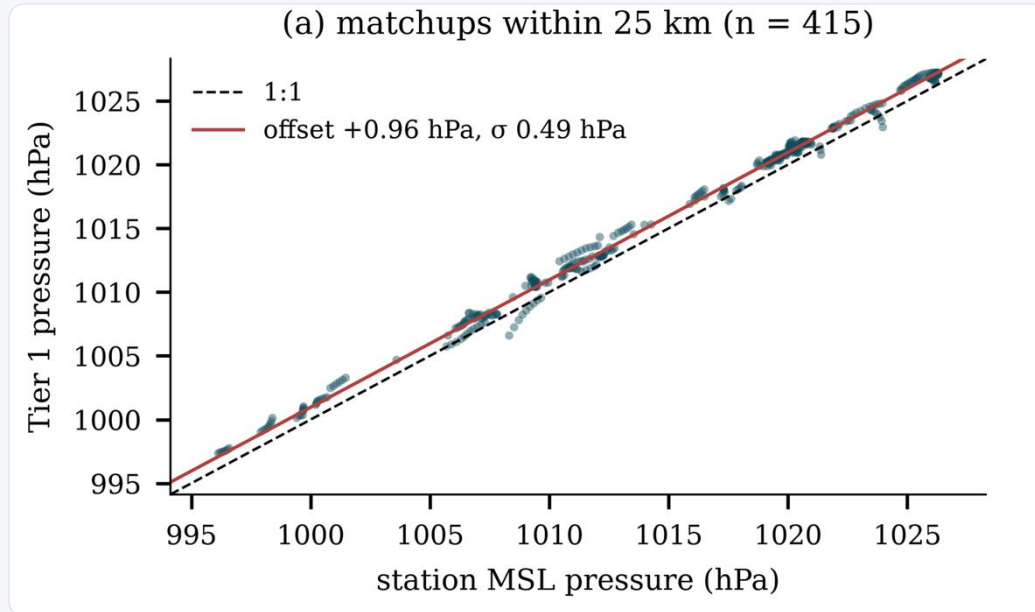
- Repeat routes
- Chance co-location
- One-boat barometric pressure profile

Not yet

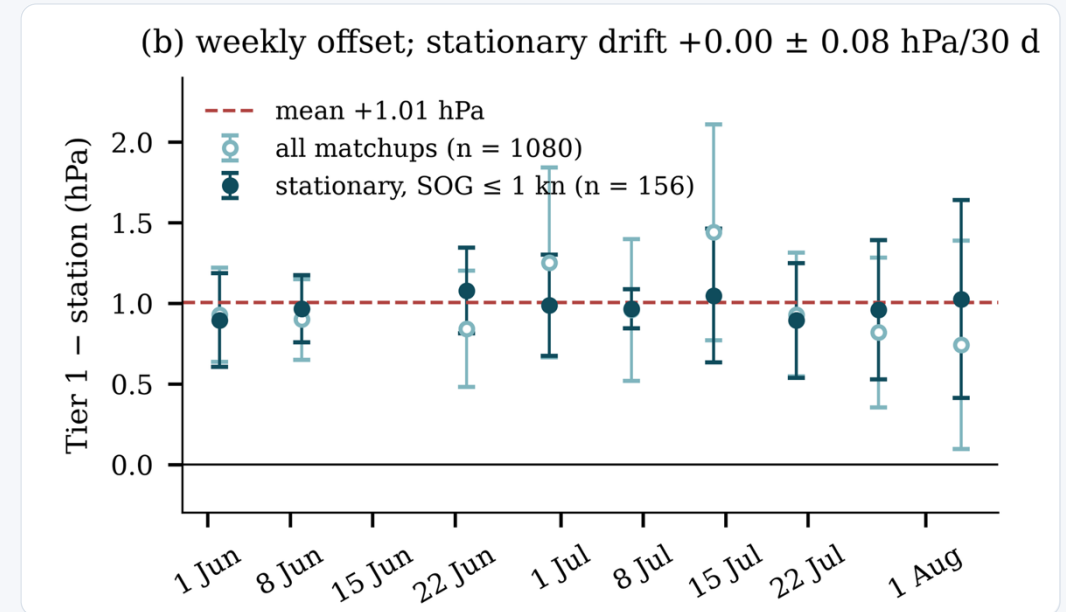
- Density
- Planned station passes
- Multi-season profiles
- Full instrument identity

The unit ran quite well the whole voyage. Need more boats and planned station passes to complete the method.

Pressure: fixed offset



+0.96 hPa offset against the nearest KNMI, DWD or SMHI station within 25 km (19 stations). σ 0.49 hPa, n = 415.
Hypothesis: solder stress (documented ± 0.8 hPa)



No measurable drift, June to August. June's offset applied blind:
RMSE **1.10** $\rightarrow$ **0.53 hPa**.

One fixed offset, no measurable drift. High added value.

Depth: usable in shallow water

Against itself (small sample of repeat passes)

0.45 m

median disagreement between repeat passes, 0–10 m

22 of 135 pairs, from 11 locations (16 in the Stockholm archipelago);
both under way, ≥ 24 h apart, within 500 m

Against a survey model

+0.37 m

median residual below 5 m against the EMODnet terrain model

n = 48, 45 in the IJsselmeer over 7 days; mean -0.13 , SD 1.24 m. Also
consistent with an unconfigured transducer offset.

Deeper water is limited by an interpolated reference and leisure sounders at their range limit.

Repeat passes show limited disagreement, also against model. High added value in shallow water.

Water temperature: mean agrees, with large scatter

Against a model, mean

+0.04 °C

PT-1000 minus Open-Meteo Marine
SST

CMEMS-derived model, hourly, 0.25° grid ·
726 marine matchups

Against a model, single readings

1.67 °C

RMSE: a point on a boat against a
model grid cell

almost all scatter, not bias

Against the boat's own sensor

0.36 °C cooler

PT-1000 against the boat's own water-
temperature sensor

mean (median 0.40) · SD 0.52 °C · n = 884

The mean agrees. Single readings can differ by more than a degree. We cannot yet say how much of that is the sensor.

Model grid cell too coarse. Needs a better reference. Medium added value.

Wind

r 0.86

wind speed vs ECMWF ERA5
reanalysis

r 0.74 vs 139 coastal stations

+9%

speed reads high vs ERA5

mast height (27 m assumed) explains under
1%

-11°

direction offset, vessel minus reference
large scatter in light air

Wind follows the references, with offsets we cannot explain yet. A short record: the boat's wind cable failed on day 6 at sea .

Masthead sensor sits in air bent by sails and rolling rig. Low added value.

Water quality: sensitive, not durable yet

Conductivity, matched the typical IJsselmeer value in fresh water. Resolved the Den Oever front, 1.5 to 46.3 mS/cm in 124 minutes. Failed 3.5 hours later, first day at sea; cause unknown, air lock suspected.

pH resolved the Elbe plume on two crossings 42 days apart, profile correlation 0.84. The level moved 0.2. Effective n below 14, no reference, so unvalidated.

Dissolved oxygen read 68% of air saturation where higher is expected. Two setup errors: zero point never set, and salinity compensation fed by the dead conductivity probe. Not reported.

Limited still by endurance and setup, not sensitivity.

Wrap-up

What we built

- A node that reads the boat's own instruments
- Additionally measures pressure, motion and water quality parameters
- Can run unattended throughout the season
- A platform that ingests data and can update node firmware over-the-air
- Provenance fields on every sample; specific n2k instrument identity still to do

What we learned

- **Pressure:** high added value, after one offset
- **Depth:** high added value, in shallow water
- **Water temperature:** medium
- **Wind:** low
- **Water quality:** sensitive, not durable yet in current setup

Added value is our post-trial judgement: how stable the error is, and what stations and weather models do not already cover.

Data platform works end to end from probe sensing to data ingest.

Data quality of several parameters is already of value, plus insights on how to improve the others.

Next: from one boat to many, starting with Tier 1

Blue Lung

50 boats, the Netherlands, 2027

Sailing traffic on inland lakes. Tests cross-vessel consistency and density.

Round the world

Long-distance cruisers with an audience

Open ocean, very limited reference stations.

Med charter fleets

Same waters, every week

Repeat passes and per-vessel profiles at scale.

Scale up Tier 1 deployments onto the platform. Optimise Tier 2 probe quality before scale. Further improve data quality & traceability.

How can many boats together improve data quality?

How do we get recreational boats to pass limited reference stations?

How to improve probe quality on tight budget?

Which other parameters can we include?



**2021
2030** United Nations Decade
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Thank you, get in touch

Campaigns

Host or join a measurement campaign

Parameters

What should we measure, at which accuracy

Sensors

Test, calibrate or suggest alternative low cost

Data

Use, analyse or cross-check the fleet data

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Sponsors: Contest Yachts · Naiad Foundation · Aknastic · PredictWind, and volunteers



projectseasense.org/zoran

Corrections to the paper

Paper says	Correct value
§IV-A: barometer ± 1 hPa (ICP-10111); offset inside spec	BMP390 sailed, ± 0.50 hPa; offset attributed to solder drift ($\leq \pm 0.8$ hPa)
§IV-C: PT-1000 is the only traceably calibrated probe	Factory adjustment only; never compared to a reference
Fig. 1: 2026 deployment around a measuring station	The deliberate station pass was Trial 2 (2025)
Fig. 2: validation and EMODnet/IHO export	Target architecture; neither is on the platform
Fig. 5: ± 0.96 hPa	+0.96 hPa
§VI: all validation uses the 1,080 set	Pressure 1,080 (10 Aug); others 915 (8 Aug); repeat depth to 16 Aug
§VI: other channels over 99% after wind fault	$\geq 98.8\%$ (STW 98.8%, depth 99.2%)
§VI: 0.45 m from 135 repeat pairs	22 of 135 pairs, 0–10 m
§VI: no depth scale error; conductivity supplied the correction	Slope 0.972–0.997 excludes 1 (1.6%); salinity was climatological
SST +0.09 °C, n = 757, satellite	+0.04 °C, n = 726; Open-Meteo Marine model
Two onboard probes / compensation channel	PT-1000 vs the boat's own NMEA 2000 sensor
69-day analysis window	67.6 days
§V/§VI: 15.5 m, 124 m	15.5 min, 124 min