

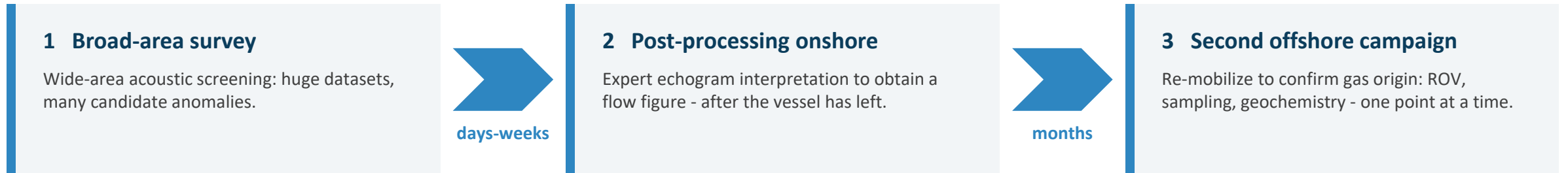
Real-Time Characterization of Subsea Gas Discharges

Using Intelligent Acoustic Vision for Advanced CCS Monitoring

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How characterization is done today



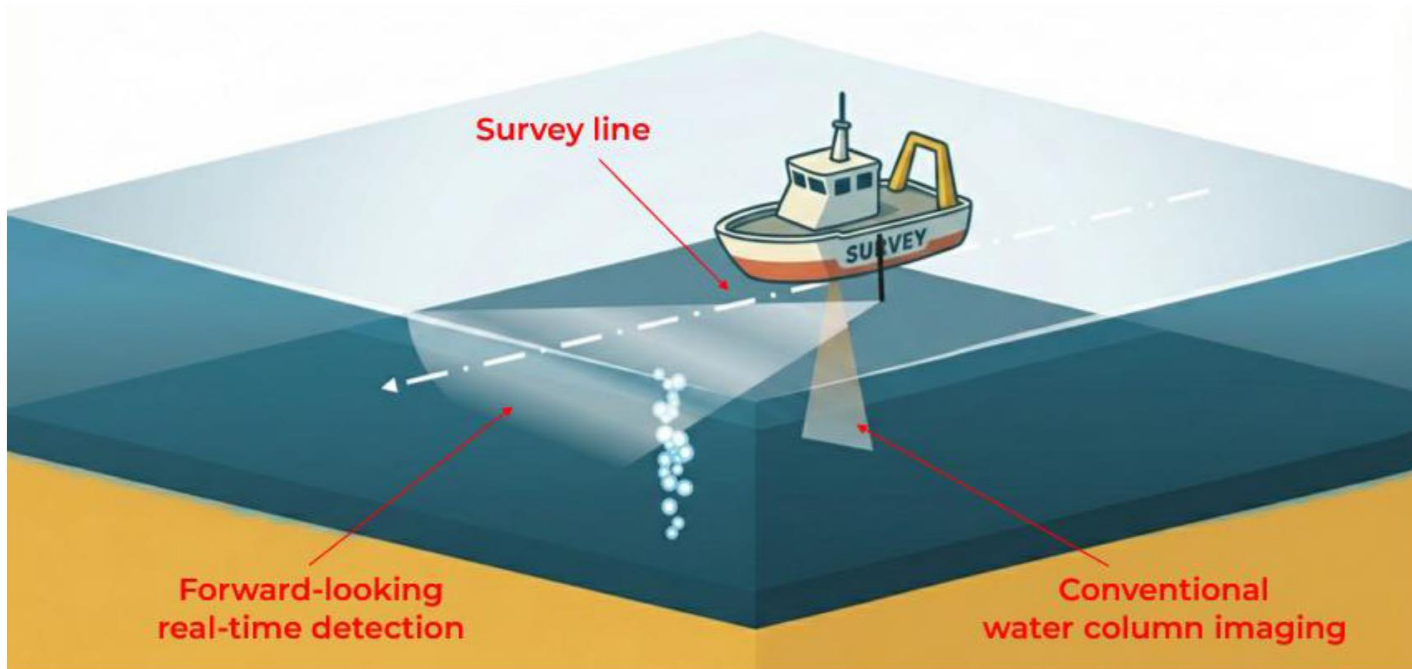
Repeated mobilizations - vessel time spent on anomalies that may be irrelevant.

- In shallow water, **biogenic methane seeps** are common and look very similar to a real CO2 leak - many anomalies are **false alarms**.
- Current detection strategy answers **where** and **when** - never **how much** gas, nor **which** gas.

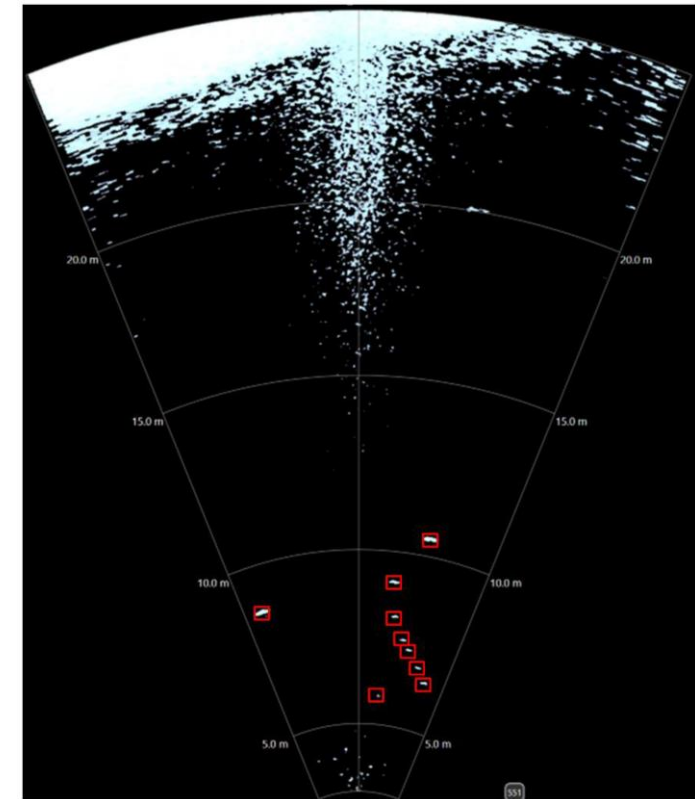
THE NEED: characterize the anomaly **in real time, while the platform is still on station** - turn a detection into a decision.

Prior work: real-time acoustic detection

- **OTC 2026:** a **forward-looking sonar** images the water column **near-horizontally** and detects gas discharges in real time.
- **Stops before quantification** - where & when, not how much / which gas. *That is our gap.*



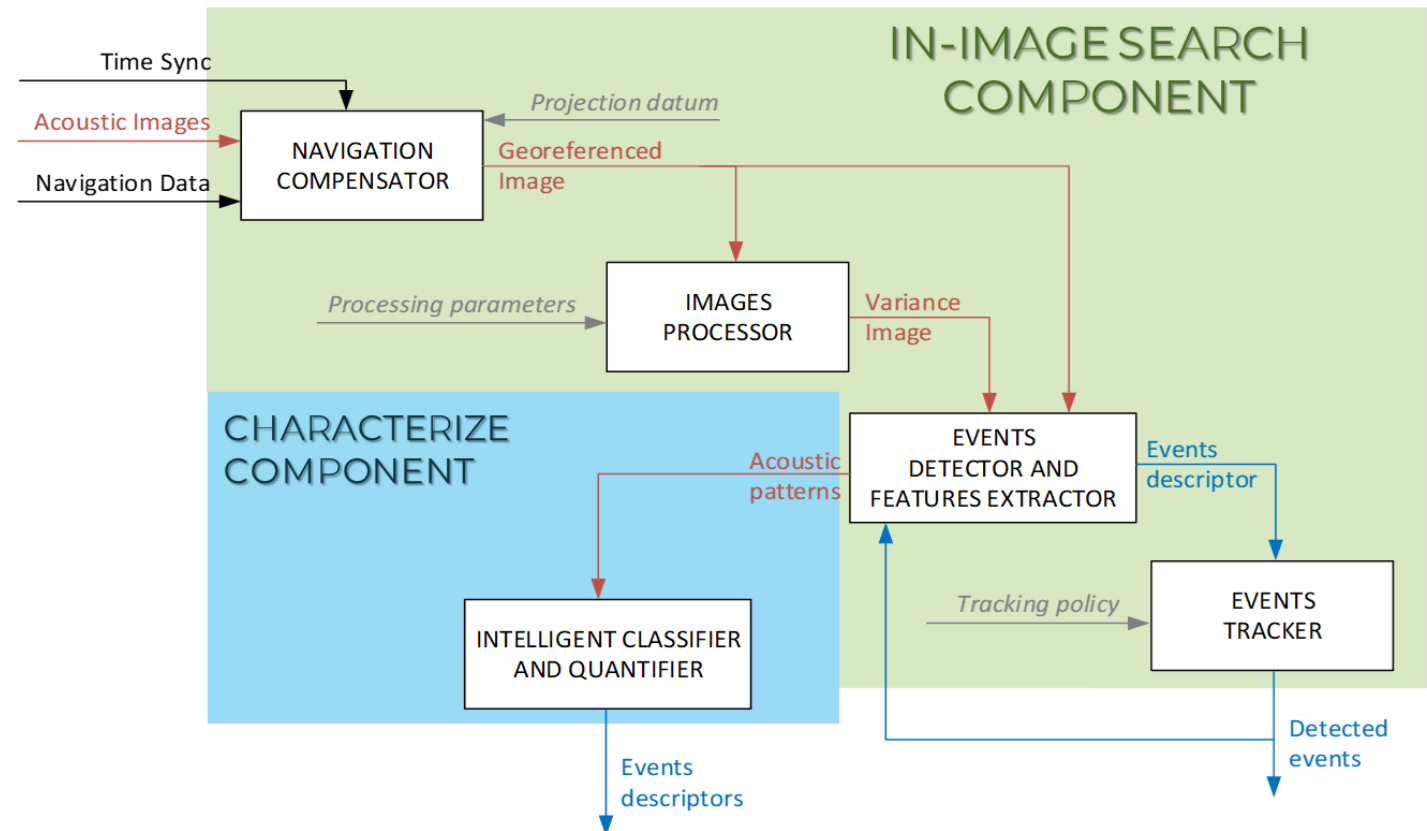
Forward-looking real-time detection vs conventional imaging (adapted from OTC-37003-MS)



Real sonar frame; detected plumes in red (OTC-37003-MS)

From detection to characterization

- We pick up exactly where detection stops - same sonar, same acoustic data.
 - **How much?** -> emission flow rate (regression)
 - **Which gas?** -> gas type (classification)
- Operational purpose for CCS: tell a genuine **CO2 leak** apart from **natural seepage** (biogenic methane).
- **Efficient** (embedded GPU) · **Coherent** (same event) · **Modular** (retrainable).



AIP: In-Image Search (green) -> Characterize Component (blue)

Experimental setup

- **Laboratory test tank**, controlled gas release, TRL-4.
- Regulated **gas panel** (CO2 bottles / air compressor) -> flow rate = **ground truth**.
- **Teledyne BlueView 1350** multibeam forward-looking sonar (1350 kHz).
- **Factorial design**: 2 gases (air, CO2) x 2 distances (1 / 2 m) x 3 nozzles (S / M / M+mesh)
- CTD, sound-velocity - synchronized context.



Mass Flow meter



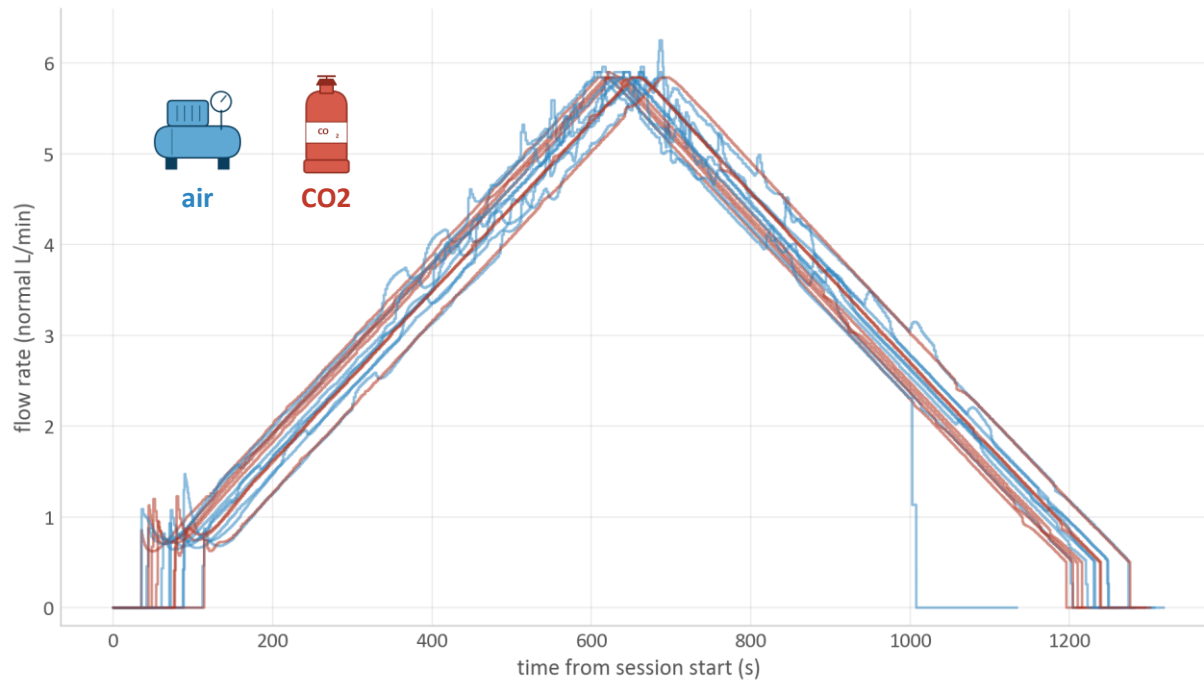
Nozzles



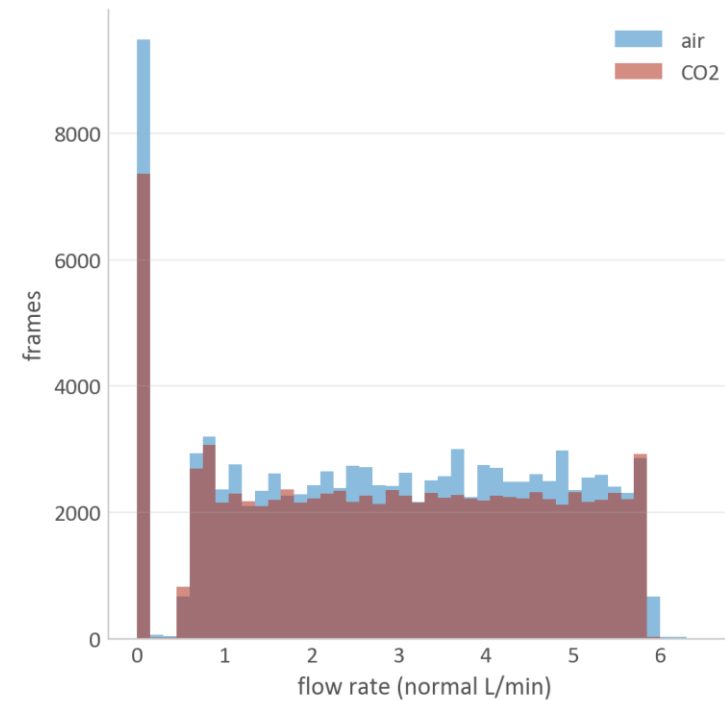
Tank setup

Dataset

- Flow swept by a **rising-and-falling ramp**, 0 - 6.25 normal L/min.
- test13 / test14 = out-of-distribution**: acquired at ~1.5 m, between the 1 m and 2 m training clusters.

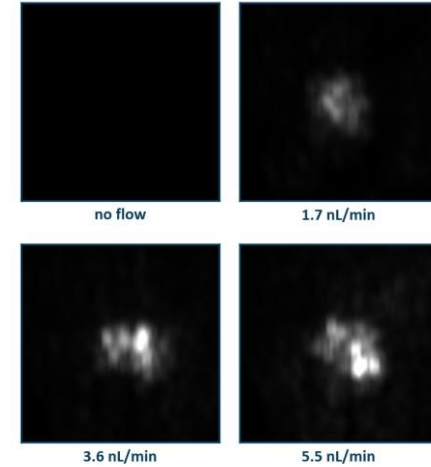


Flow ramp per acquisition session (blue = air, red = CO2)



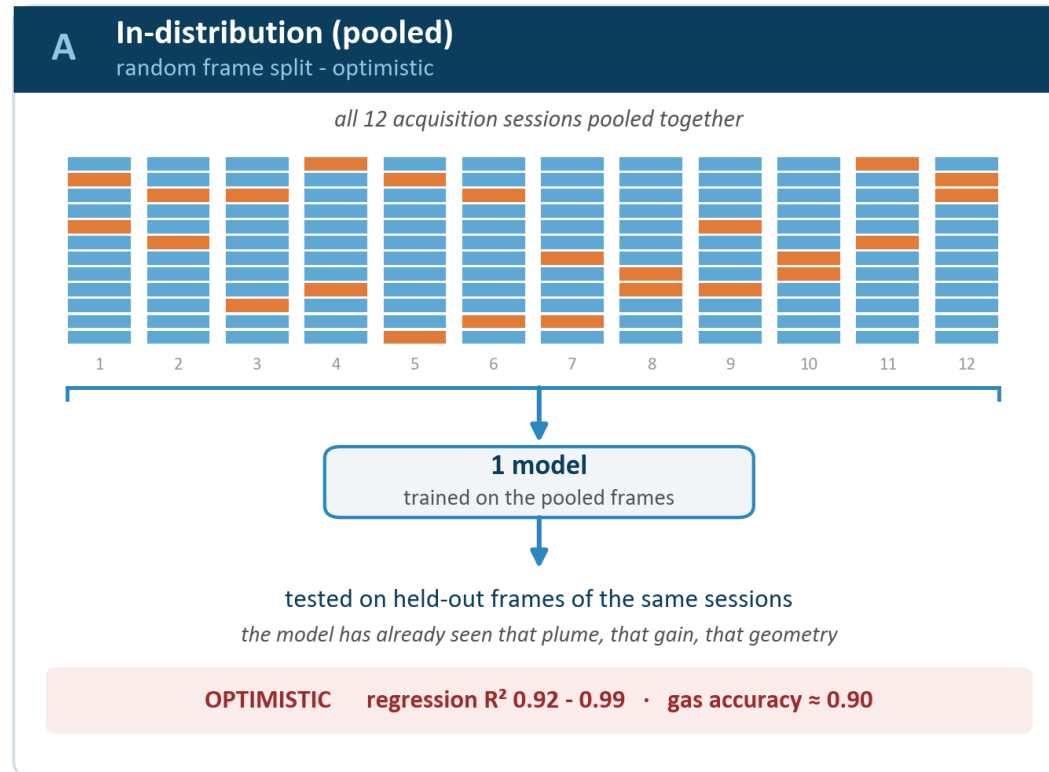
Flow-rate distribution across the campaign

What the network sees
64 x 64 crops, one acquisition

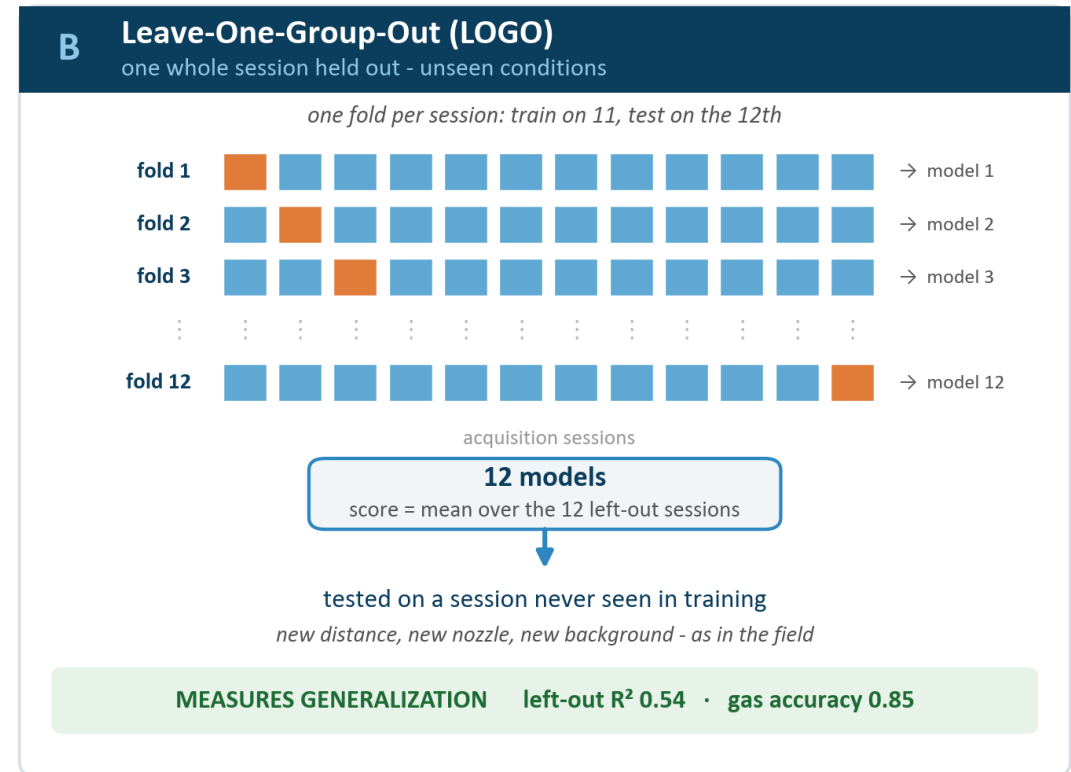


Models & evaluation protocol

- **Regression:** CNN-2D (1 frame), CNN-LSTM, **Conv3D** (5-frame volume). · **Classification:** CNN-lite.
- Two protocols - we read **every** result through the **left-out** lens, because that is the number that predicts field behaviour.



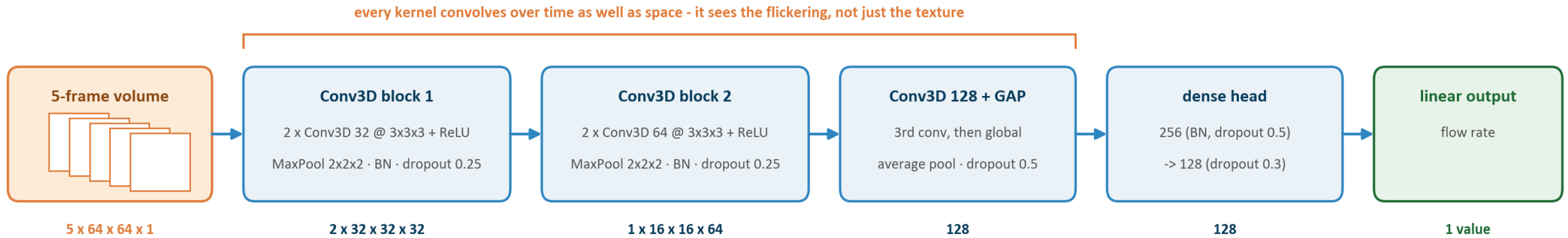
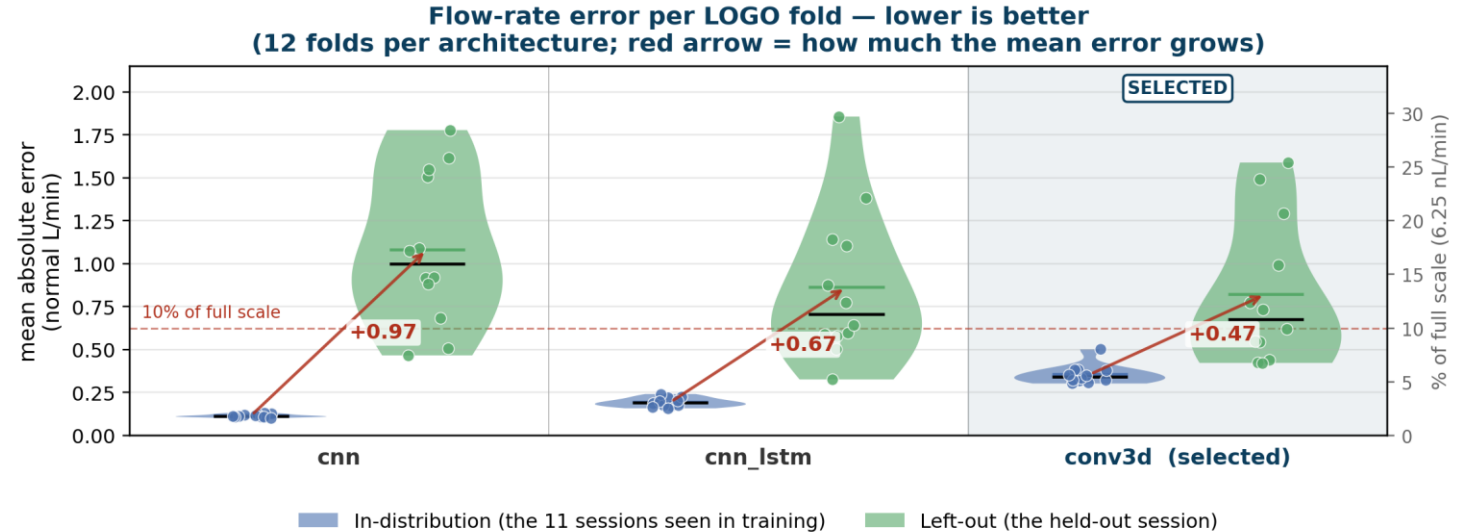
■ used for training



■ held out for testing

Flow-rate regression - the model that fits best generalizes worst

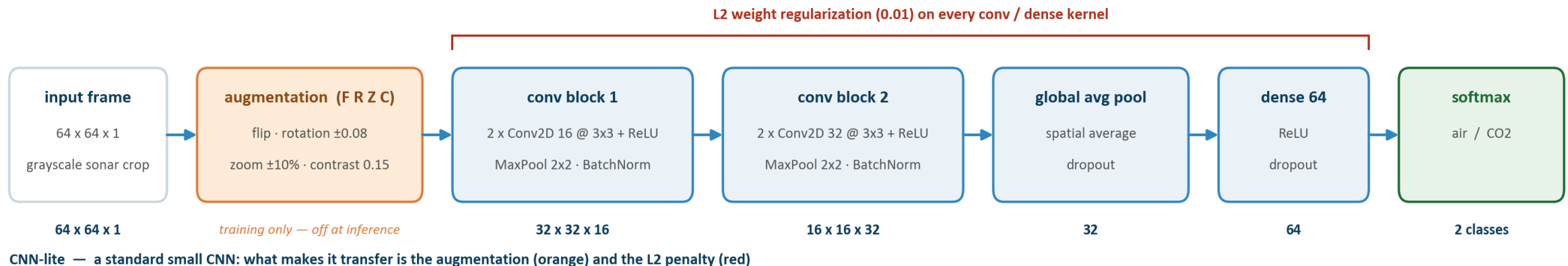
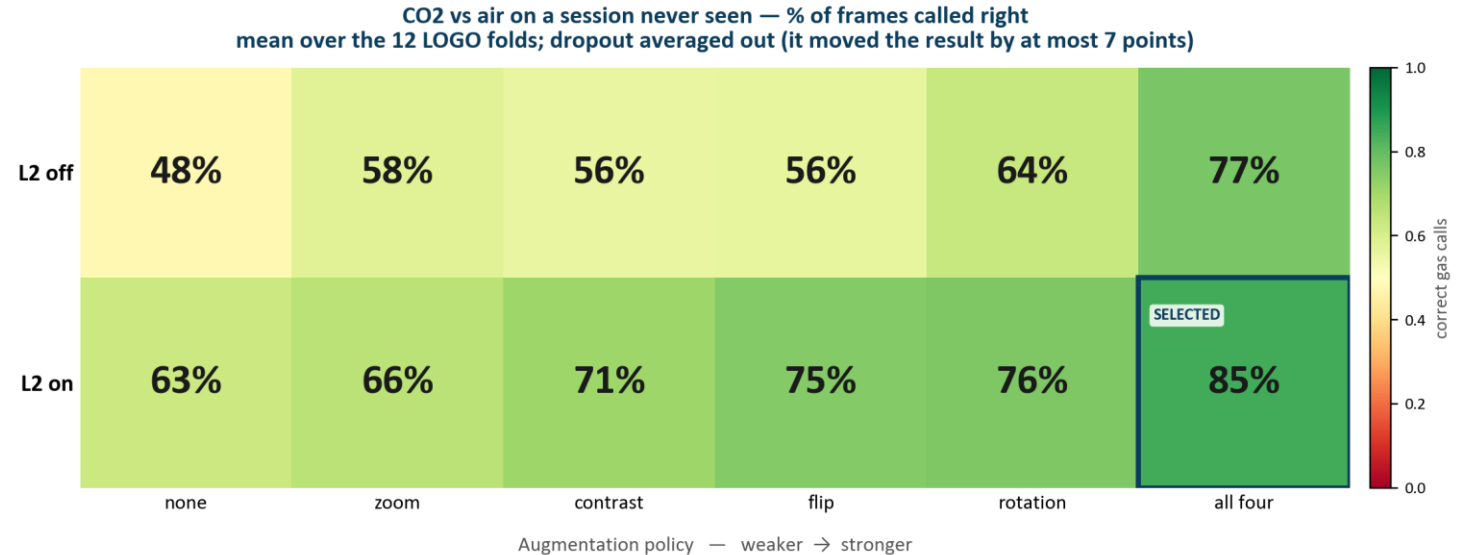
- **In-distribution:** all three excellent.
- **On a session never seen:** error 5-10x higher - the best fit degrades the most.
- **Conv3D selected:** 0.82 nL/min, ~13% of full scale - the gap shrinks with temporal context.



Conv3D — selected for deployment: the architecture that transfers best to a session it has never seen

Gas classification - regularization is decisive

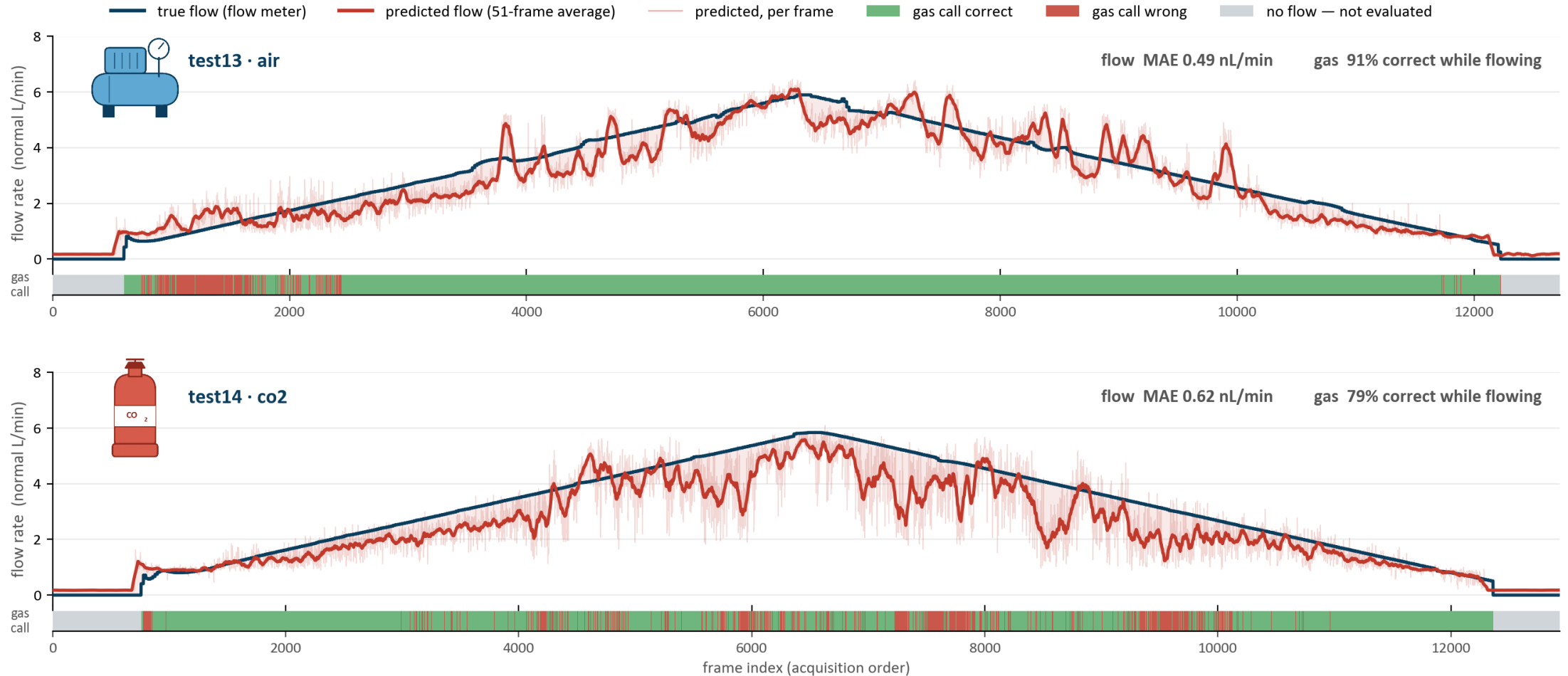
- CO2 vs air from the **same frames** - a small CNN on each detected crop.
- Trained naively: **48% on a session never seen** - a coin flip. It memorizes the **session**, not the gas.
- Augmentation + L2** - not the architecture - takes it to **85%**.



Joint characterization using out-of-training data

Joint characterization on two sessions never seen in training

Conv3D flow rate (span-calibrated) + CNN-lite gas call, frame by frame — novel ~1.5 m stand-off distance



Limitations & outlook

- **Limitations:** controlled lab tank, single sonar; CO₂ vs **air as a proxy**; flow calibration still configuration-specific.
- **Outlook:**
 - Broader acquisitions - close the coverage gaps the LOGO folds exposed, and **push beyond 0 - 6.25 nL/min**
 - Multi-task (flow + gas) and memory-based models
 - **At-sea campaign before end of 2026 -> CO₂-vs-CH₄** under real marine conditions

Conclusions

What we found

- Flow rate **and** gas type in real time, from the **detector's own frames**.
- On sessions never seen: **0.8 nL/min** flow error, **85%** of gas calls right.
- What still fails is a **coverage gap**, not model capacity.

What it changes

- A detection becomes a **decision**: how much, and which gas.
- **Fewer false alarms** - CO2 leakage vs natural seepage.
- Same event, same window: **no second campaign**.



Thank you

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Backup - full numbers

Regression LOGO (mean, 12 folds)	In-dist MAE	Left-out MAE	In-dist R2	Left-out R2
CNN-2D	0.11 nL/min	1.08 nL/min	0.99	0.19
CNN-LSTM	0.19 nL/min	0.86 nL/min	0.98	0.47
Conv3D (selected)	0.36 nL/min	0.82 nL/min	0.93	0.56

Classification (left-out)	In-dist acc	Left-out acc	Std
No aug / no L2	~0.98	0.48	~0.30
Full aug (FRZC), no L2	~0.93	0.77	~0.16
Full aug + L2 (selected)	~0.90	0.85	0.13

- Aug ranking $N < Z < C < F < R < \text{FRZC}$. · Simulation (Conv3D, test13 / test14): R2 **0.76 / 0.55** uncalibrated, **0.88 / 0.75** span-calibrated (single scalar gain); gas 91% / 79% on flowing frames (83% / 81% with zero-flow frames included).