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Detection of CO_2 leaks from Carbon Capture and Storage (CCS) sites with combined atmospheric CO_2 and O_2 measurements

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Detection of CO_2 leaks from Carbon Capture and Storage (CCS) sites with combined atmospheric CO_2 and O_2 measurements

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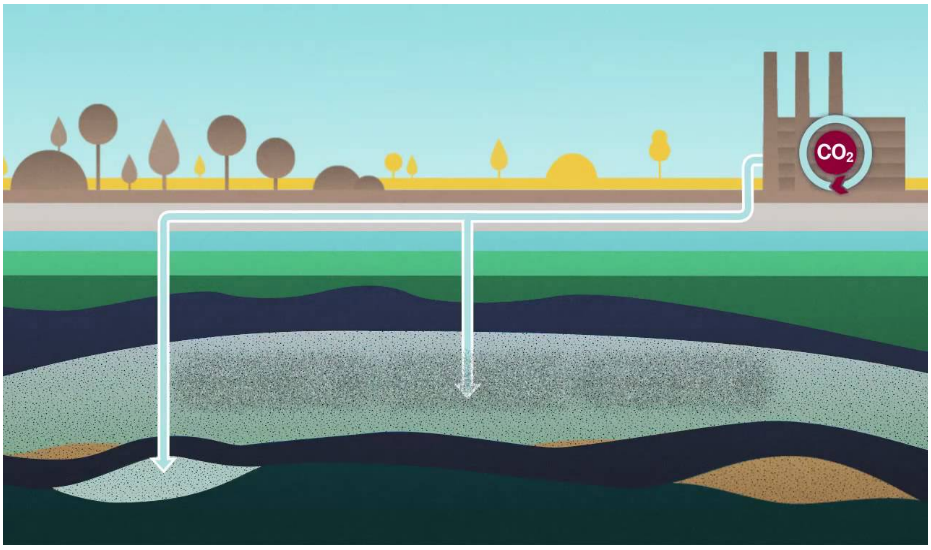
Carbon Capture and Storage (CCS)

CO_2 is captured from (power) plants and stored underground in depleted oil and gas fields or deep saline aquifers.



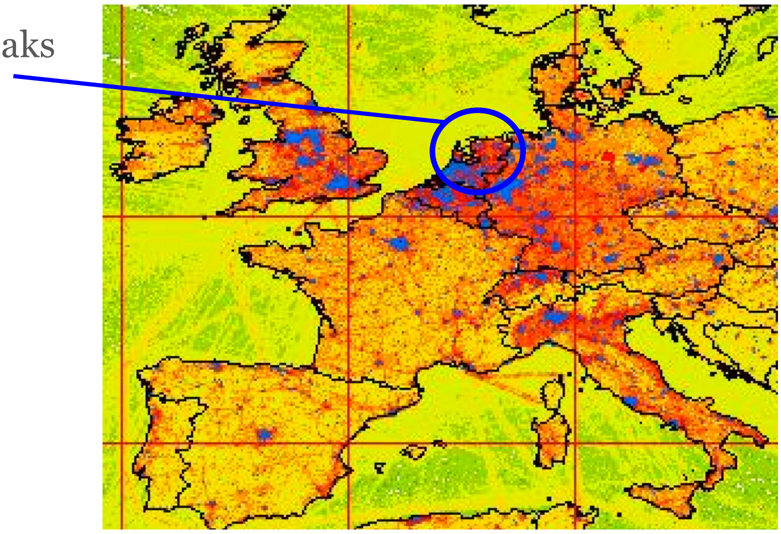
Important concern is the possibility of leakage of stored CO_2 to the atmosphere

Figure source: ZEP (Zero Emissions Platform)

Situation in the Netherlands

Partially empty gas fields present, ideal storage for CO_2
Densely populated region, multitude of (fossil) CO_2 sources present

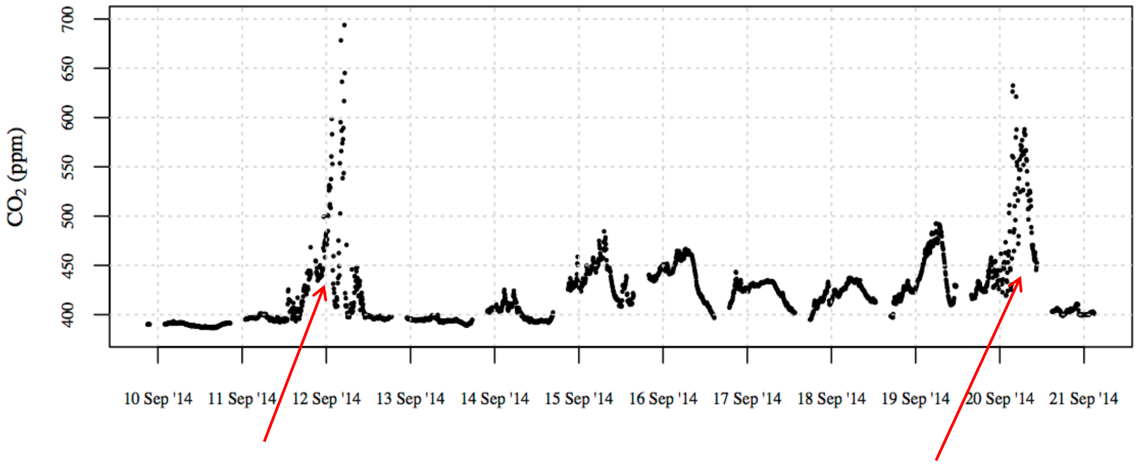
complicated detection of possible leaks



Edgar CO_2 emissions (2010)

Detecting CCS leaks in the atmosphere is difficult

- Rapid mixing of emitted CO_2 with the surroundings
- High natural variability of the atmospheric CO_2 concentration



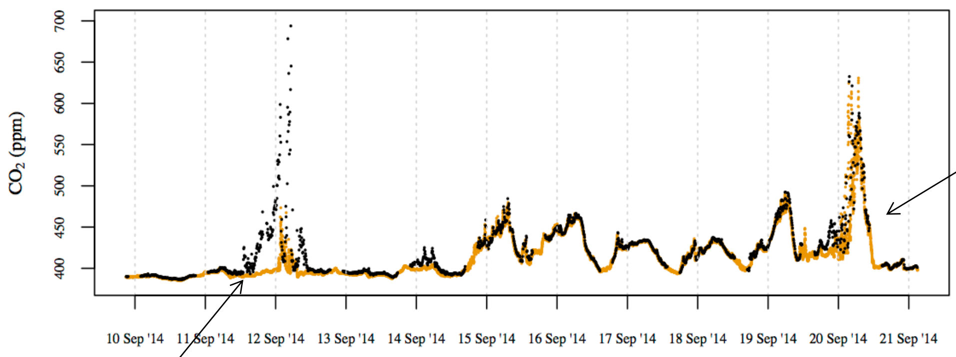
Is there a difference between these two nighttime events?

Possibilities for CO_2 leak detection: Use of tracers

- Add a tracer (e.g. SF_6, CH_4, perfluorocarbon)
  - Additional costs
  - Gases are strong greenhouse gases themselves
  - Migration of the tracers through the underground is not exactly the same as the migration of CO_2

- Use of natural tracers ($^{14}CO_2$, $^{13}CO_2$)
  - $^{14}CO_2$ measurements are very expensive and only possible by flask measurements
  - $^{13}CO_2$ only works when:
    - significant difference between the $\delta^{13}C$ of the biosphere and the source of CO_2
    - sufficient CO_2 perturbation caused by the leak

Measuring CO_2 at multiple locations



Both locations measure the same: natural variability

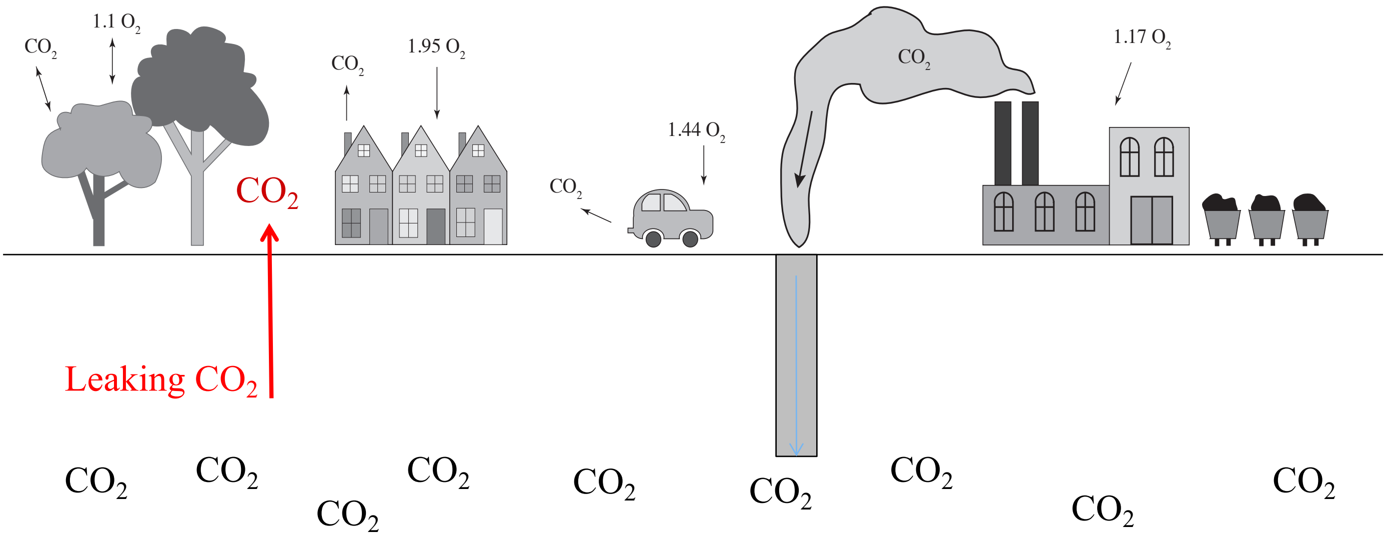
Two locations measure different signal.
Yellow = background. Black = leak detection.

Main drawback: not possible to discriminate between a random (biospheric or fossil fuel combustion) point source of CO_2 and a leak of CO_2.

This method was also applied on pipeline monitoring and published in: Van Leeuwen, C., Hensen, A. Meijer, H.A.J. (2013) Leak detection of CO_2 pipelines pipelines with simple atmospheric CO_2 sensors for carbon capture and storage. Int. j. greenhouse gas control 19, 420-431

Combined O_2 and CO_2 measurements

Most processes show an inverse relationship between O_2 and CO_2, but CO_2 leaks have no counterpart in O_2



O_2 and CO_2 together form the ideal leak detector

Disadvantage: precise and accurate O_2 measurements are complicated

O_2 for leak detection: design criteria

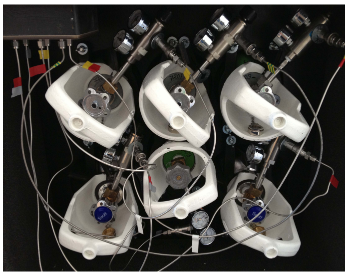
- precision down to the ppm level
- long term calibration is less of an issue
- sturdy design, needs to be “mobile”
- fully automated, remote control
- should be able to run for about a month between services (air dryer and reference gas cylinder should last that long)

Design of a transportable O_2 – CO_2 instrument

Our system would fit in any small building or van.

the equipment in three “flight cases” (or road cases)

the small air inlet mast (6 m)

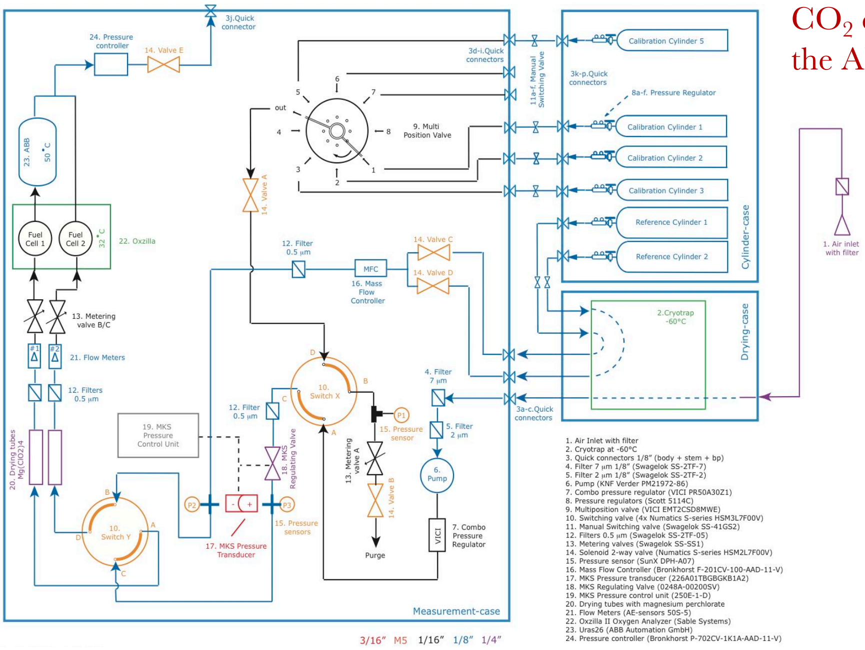


the reference and calibration cylinders with protection cap

-60° C drying system, with $Mg(ClO_4)_2$ trap follow-up

The CO_2 / O_2 /(and $\delta^{13}C$) device: under the hood

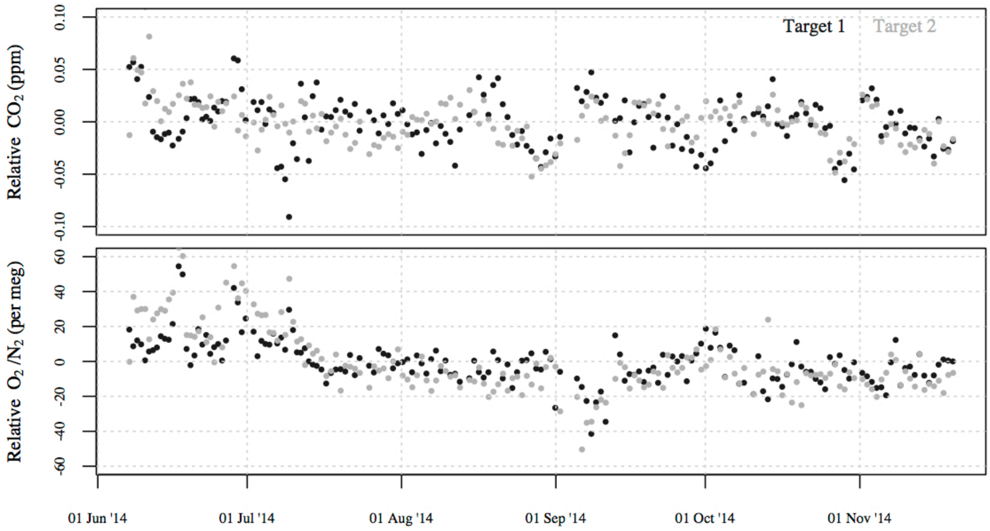
CO_2 concentration (and $\delta^{13}C$) using the ABB NDIR device (URAS 26)



1. Air Inlet with filter
2. Cryotrap at -60°C
3. Quick connectors 1/8″ (body + stem + bp)
4. Filter 7 µm 1/8″ (Swagelok SS-2TF-7)
5. Filter 2 µm 1/8″ (Swagelok SS-2TF-2)
6. Pump (KNF Verder PM21972-86)
7. Combo pressure regulator (VICI PR50A30Z1)
8. Pressure regulators (Scott 5114C)
9. Multiposition valve (VICI EMT2CSD8MWE)
10. Switching valve (4x Numatics S-series HSM3L7F00V)
11. Manual Switching valve (Swagelok SS-41GS2)
12. Filters 0.5 µm (Swagelok SS-2TF-05)
13. Metering valves (Swagelok SS-SS1)
14. Solenoid 2-way valve (Numatics S-series HSM2L7F00V)
15. Pressure sensor (SunX DPH-A07)
16. Mass Flow Controller (Bronkhorst F-201CV-100-AAD-11-V)
17. MKS Pressure transducer (226A01TBGBGKB1A2)
18. MKS Regulating Valve (0248A-00200SV)
19. MKS Pressure control unit (250E-1-D)
20. Drying tubes with magnesium perchlorate
21. Flow Meters (AE-sensors 50S-5)
22. Oxzilla II Oxygen Analyzer (Sable Systems)
23. Uras26 (ABB Automation GmbH)
24. Pressure controller (Bronkhorst P-702CV-1K1A-AAD-11-V)

Differential oxygen: Oxzilla

Quality of the measurements



	CO_2 (ppm)		O_2 / N_2 (per meg)	
	Target 1	Target 2	Target 1	Target 2
Average stdev within a target run (n = 48)	0.011	0.010	12	15
Stdev of all target runs (n = 48)	0.021	0.018	8	8
Stdev of pairs, averaged (n = 47)	0.011	0.009	5	6

Demonstrations in the field, at our station Lutjewad

CO_2 release experiments: 3-5 g/s

station Lutjewad

testing the wind

the small mast

CO_2 cylinder pack

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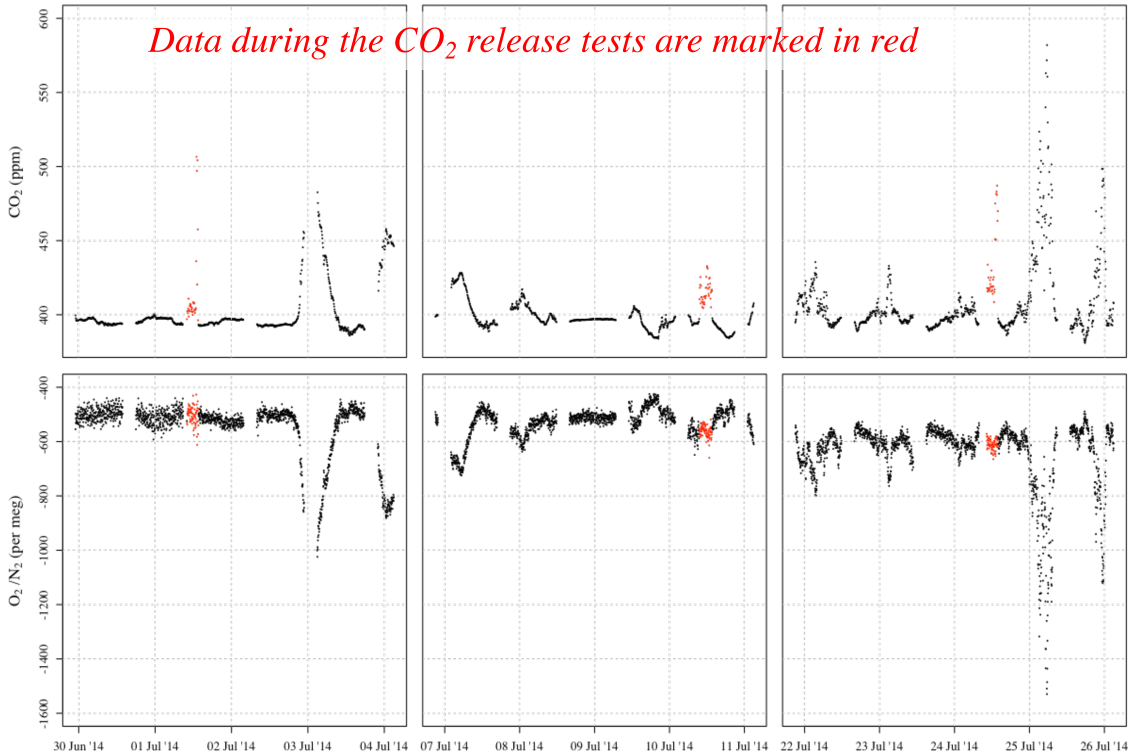
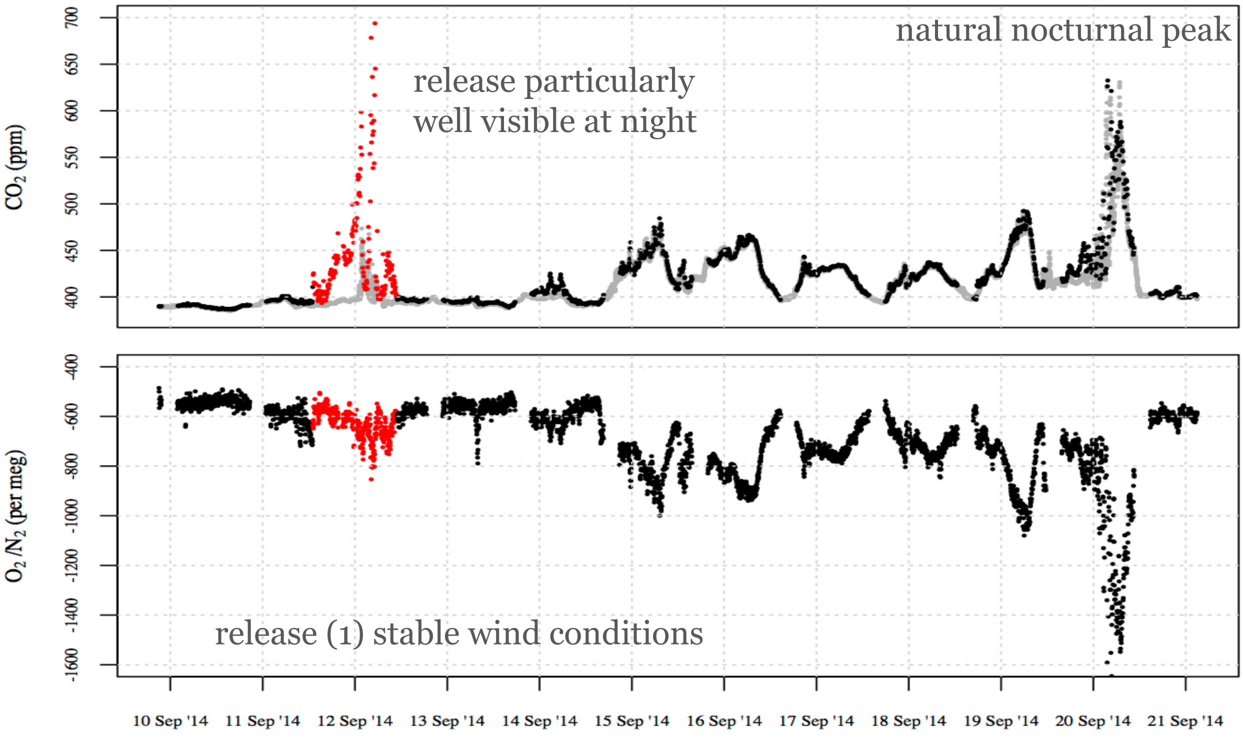
short term day-time CO_2 release experiments



Data during the CO_2 release tests are marked in red

24-hour CO_2 release experiments

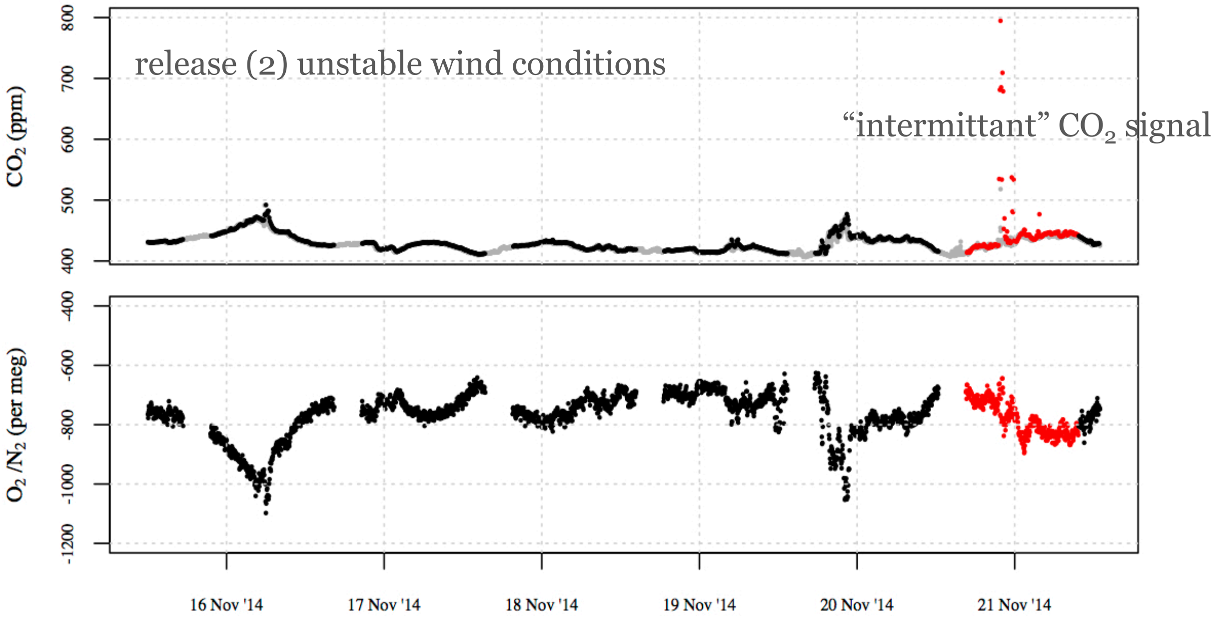


natural nocturnal peak

release particularly
well visible at night

release (1) stable wind conditions

24-hour CO_2 release experiments

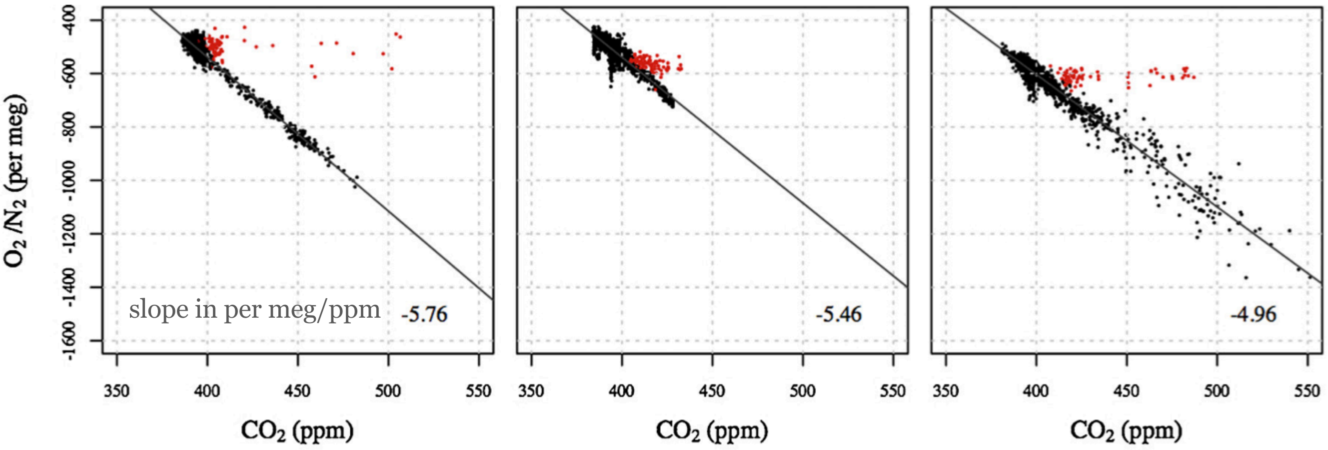


release (2) unstable wind conditions

“intermittant” CO_2 signal

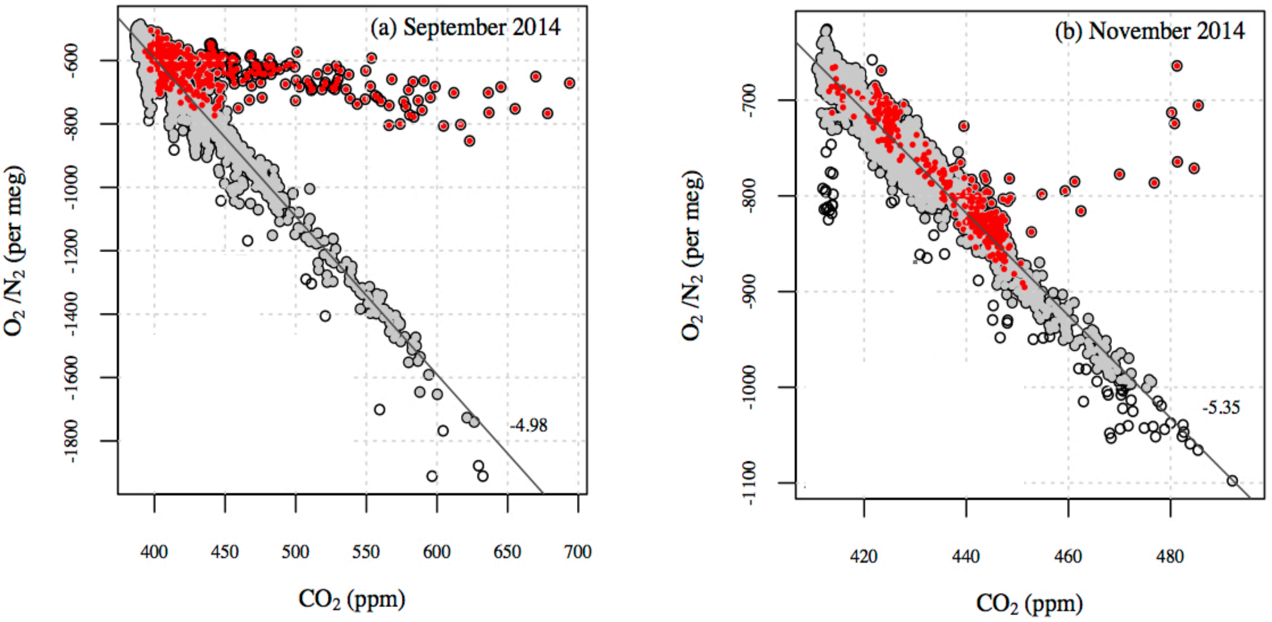
CO_2 release tests: analysis

the three daytime releases: O_2/N_2 plotted against CO_2



CO_2 release tests: analysis

the two 24-hour releases: O_2/N_2 plotted against CO_2

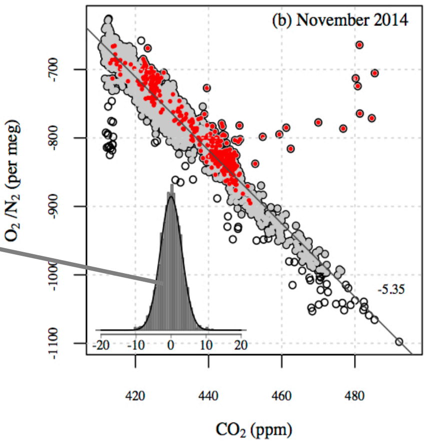


leak detection qualitatively very clear. Quantitative analysis?

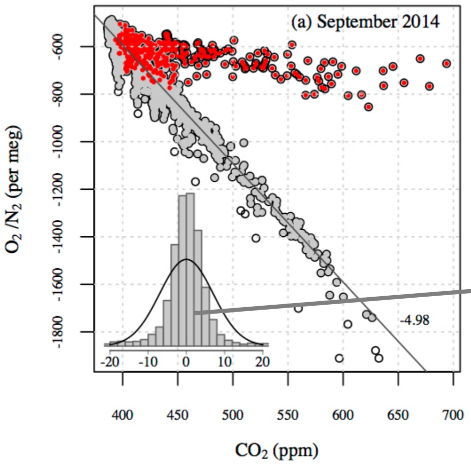
Strategies for analysis

I Compare time intervals (e.g. hours) with the general relationship

- determine, for a longer period, the O_2-CO_2 slope for all measurements (apply outlier filtering)
- calculate the standard deviation of the (horizontal) scattering around this slope (in pppm)



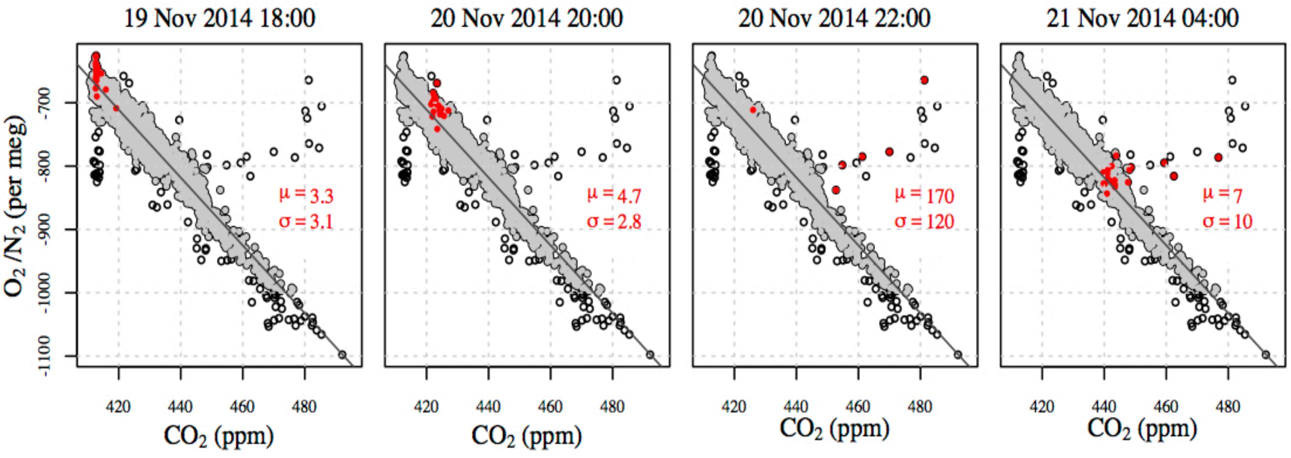
$\mu_{general}=0$, $\sigma_{general}=3$



$\mu_{general}=0$, $\sigma_{general}=7$

Strategies for analysis

- now calculate the average value and scatter around the slope for every individual hour of the whole period



- Creterion for detection of a leak: $(\mu_{hour} + \sigma_{hour}) \geq (\mu_{general} + \alpha \times \sigma_{general})$

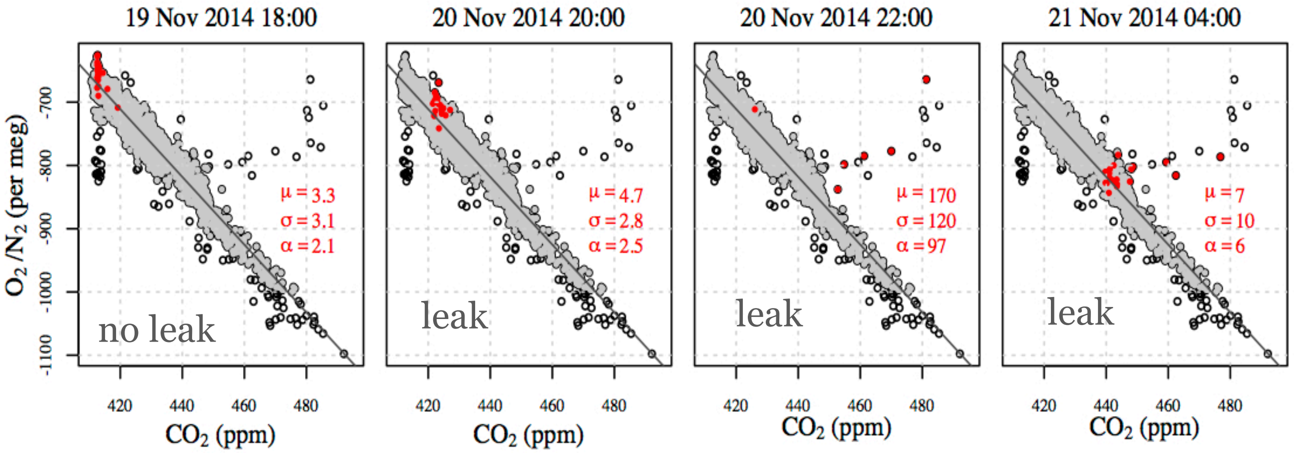
the 16% highest points of the hour

the 2.2% (α=2) highest points of the total
0.1% (α=3)

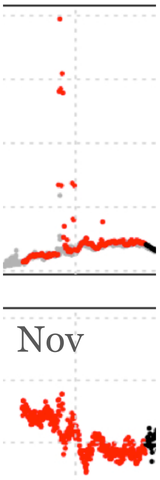
(in fact a modified X^2 test)

Strategies for analysis

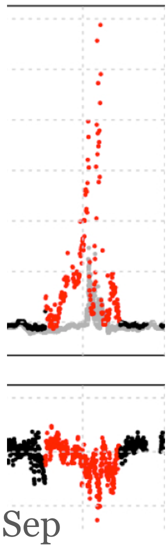
- we can reformulate $(\mu_{hour} + \sigma_{hour}) \geq (\mu_{general} + \alpha \times \sigma_{general})$ into: $\alpha = \frac{(\mu_{hour}+\sigma_{hour})}{\sigma_{general}}$
- and then attribute an α value to each individual hour



Strategies for analysis



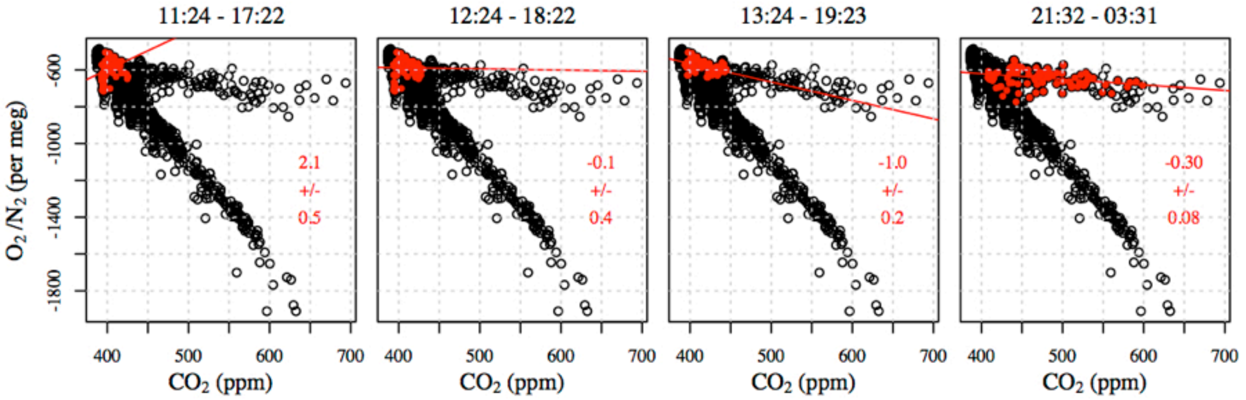
- we determined α=2 to be a good choice
- night time event in September: all 20 leak hours identified, no false positives
- night time event in November: 6 leak hours identified, of which one was false positive
- day time events: leak hours identified, two more false positives
- Additional inspection of wind direction discriminates between false positives and real leaks



With this strategy, persistent leaks can be identified automatically
detection level ≈ 6 ppm (α=2 times observed varibility of 3 ppm)

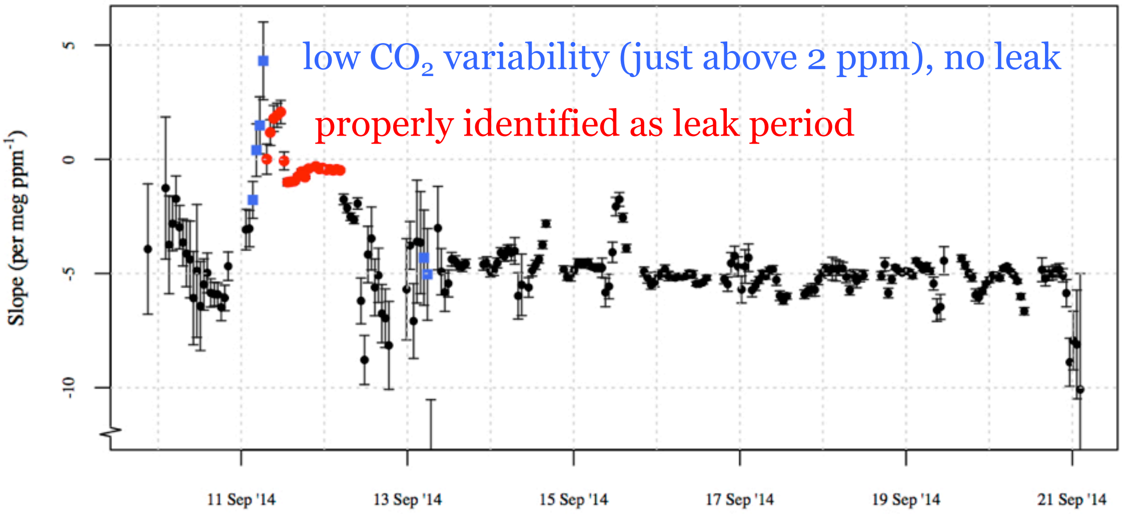
Two strategies for analysis

II) Calculate the slope of time intervals (e.g. 6 hours) throughout time (without outlier filtering)



- Most of the time the slope will be around -5 per meg / ppm
- In case the slope is significantly higher (with a small error) a leak is identified

Two strategies for analysis



low CO_2 variability (just above 2 ppm), no leak

properly identified as leak period

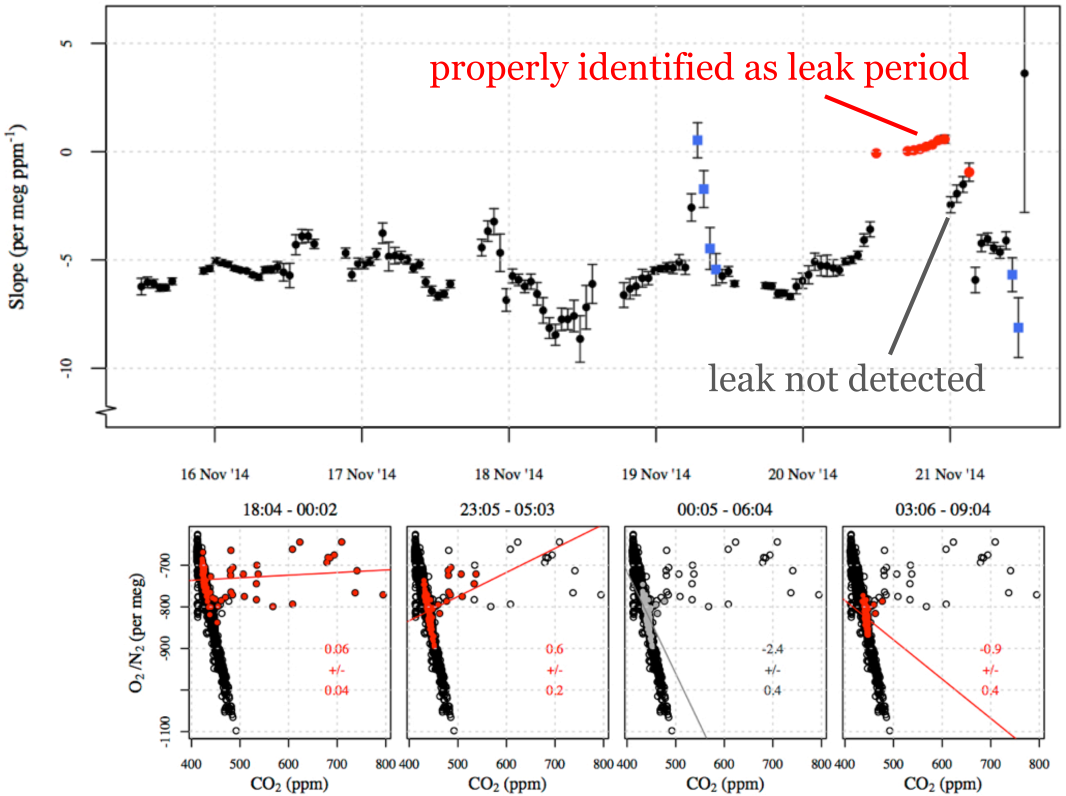
Three categories:

(1) slope fit error < 0.7 per meg/ppm, and slope > -1.5 per meg/ppm: leak

(2) slope fit error > 0.7 per meg/ppm and variability of CO_2>2 ppm: inconclusive

(3) all others: no leaks

Two strategies for analysis


properly identified as leak period

leak not detected

Conclusions

- Combined O_2 and CO_2 measurements are a strong tool in detecting CO_2 leaks from a CCS site and the only tool to discriminate between a leak and another CO_2 source
- Our transportable system can be moved easily from one site to another
- The two analysis methods demonstrated are easy to automate, and together have a high potential for leak detection
- Their set points have been optimised for our system during our release tests; for a system with different precision these set points might need to be adapted
- The precision for O_2 can still be improved. The detection limit might be lowered then from ≈ 6 ppm to ≈ 3 ppm in these surroundings (with both many biogenic and anthropogenic sources of CO_2)

- The best strategy for leak monitoring is:
- Deploy a large number of cheap CO_2-only sensors *(van Leeuwen et al., 2013. Ijggc. 19:420–431)*

  (or alternatively one integrated large pathlength CO_2 sensor)
- When there is leak suspicion: bring in the CO_2-O_2 system

Acknowledgements

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Alwin Stegeman for the slope idea

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