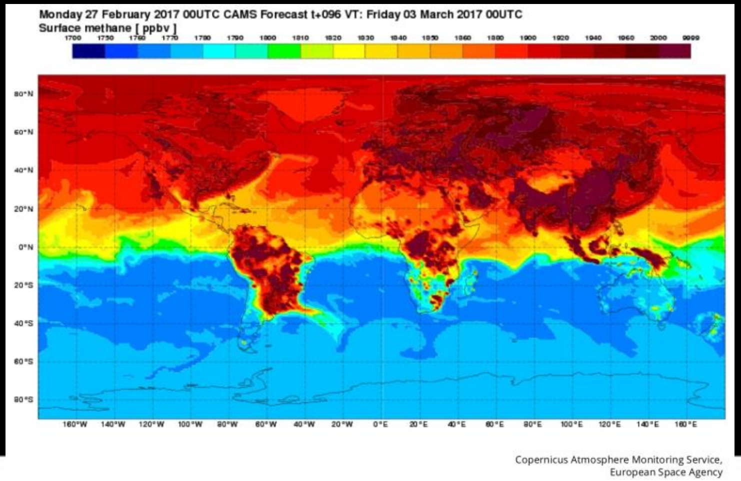
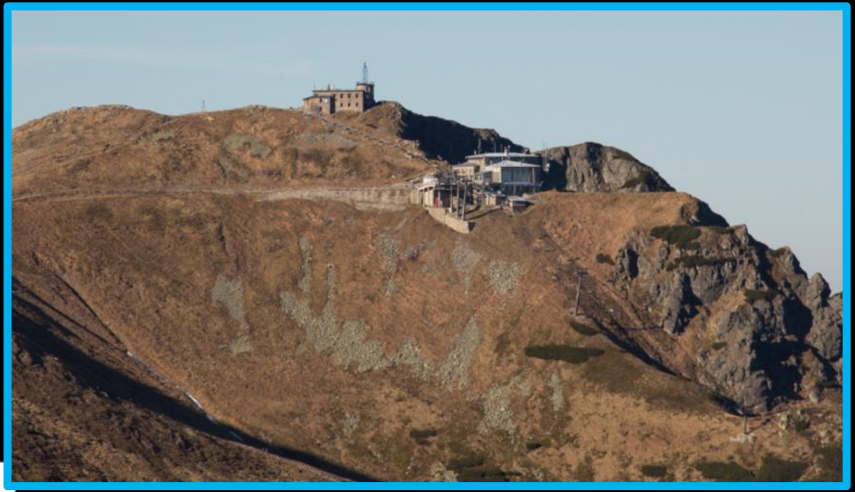
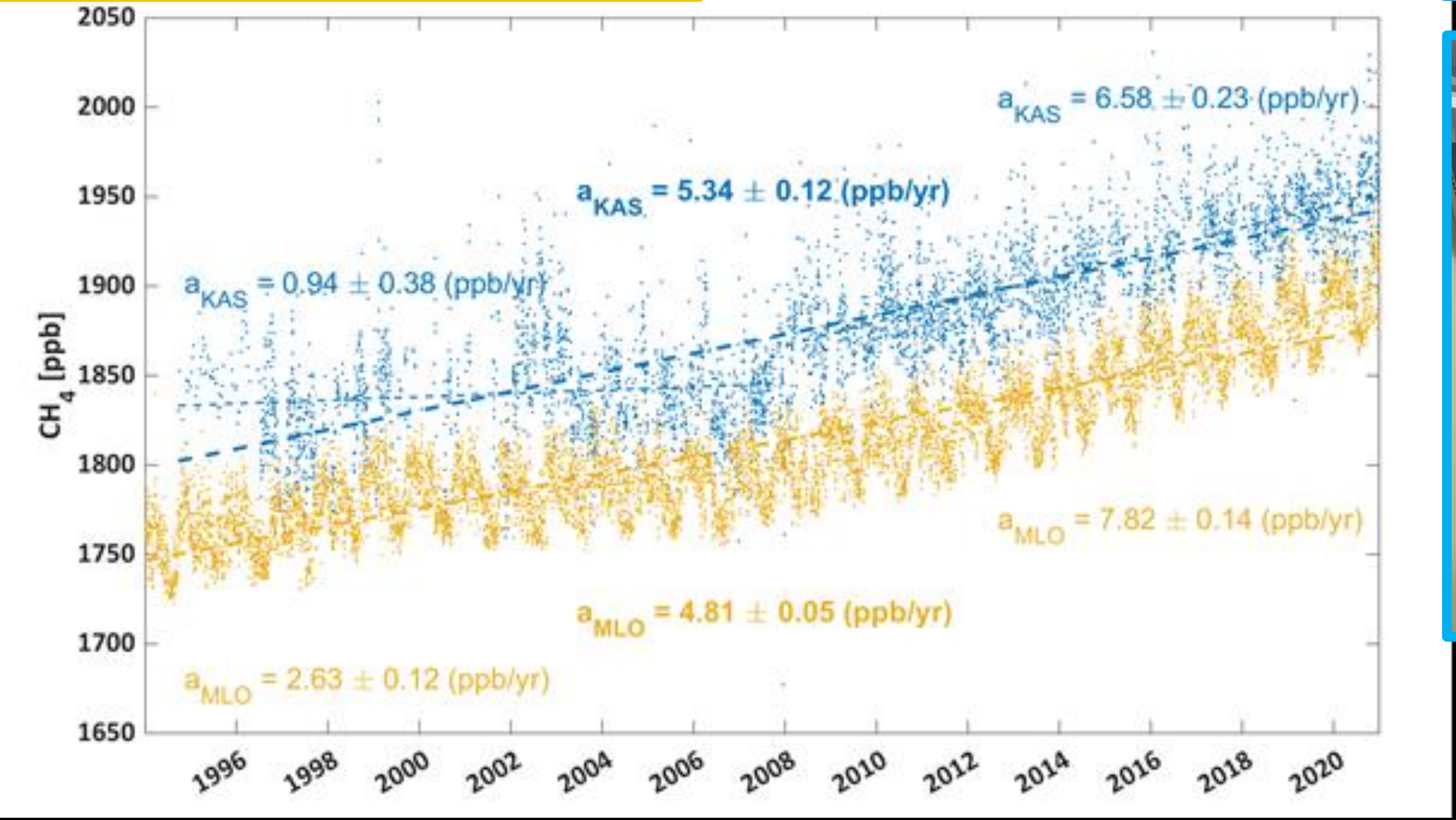
IGF UW, 11.10.2024

Estimation of methane emissions using mobile ground-based and airborne analysers

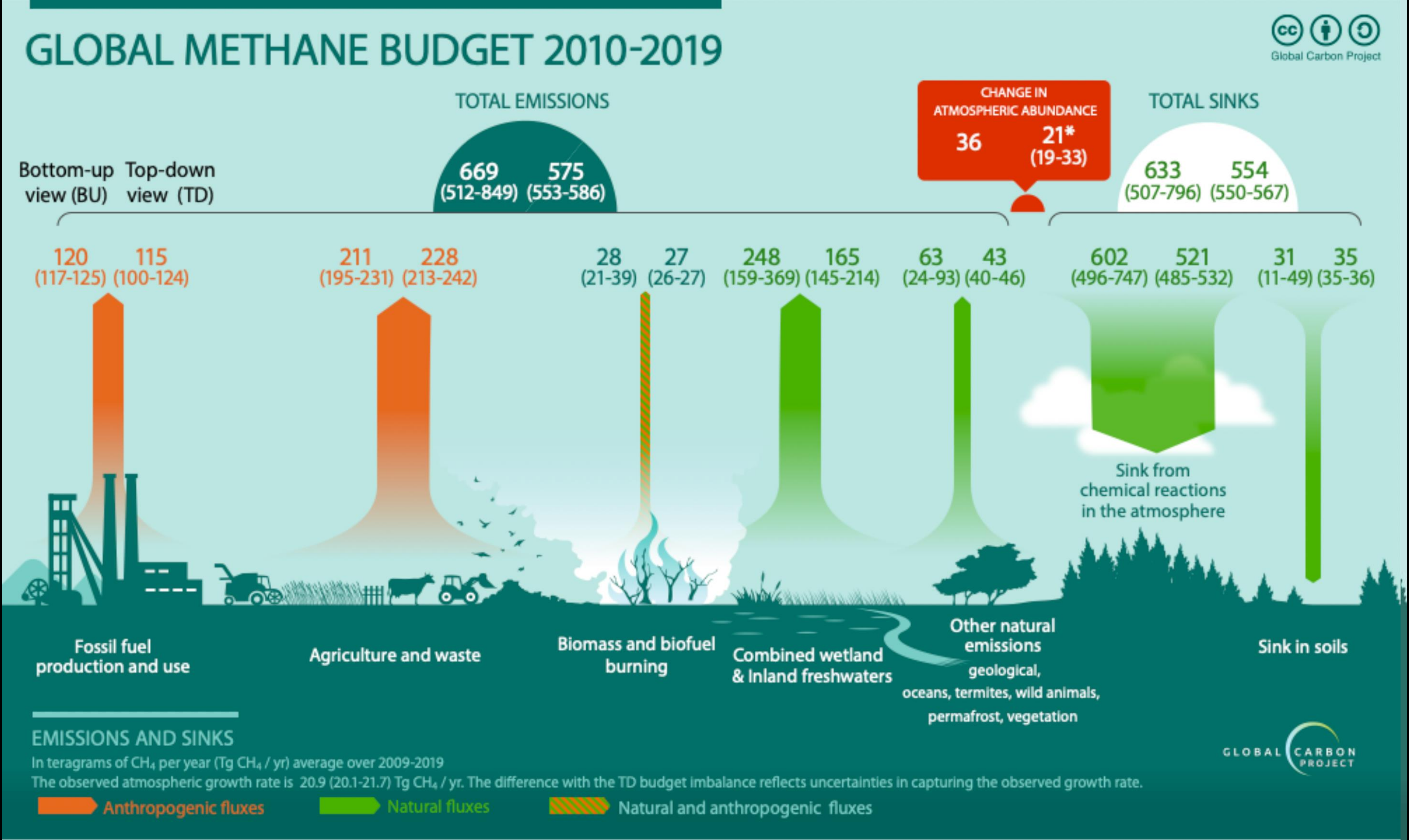
Jarek Necki
and Environmental Physics Group
AGH

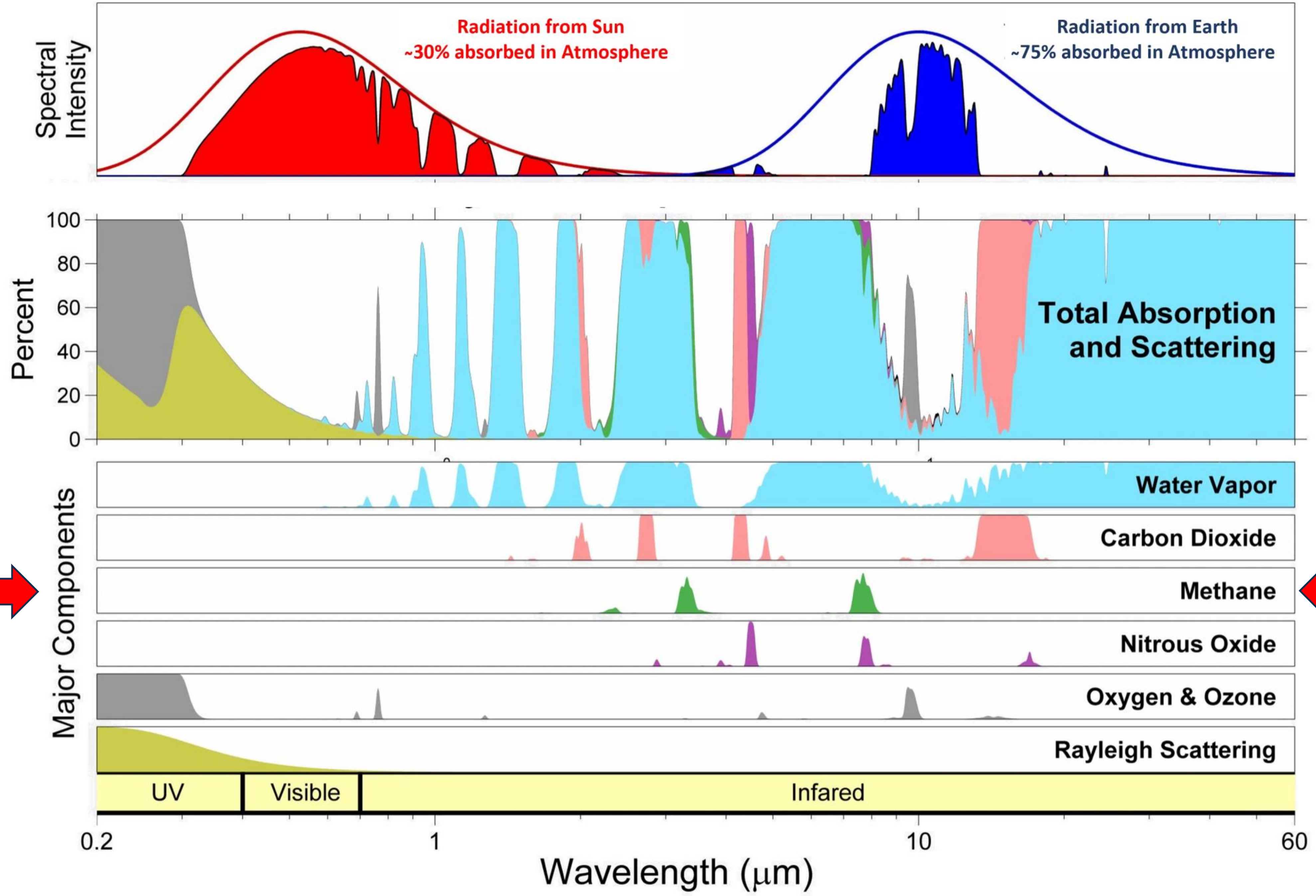

Monday 27 February 2017 00UTC CAMS Forecast t+096 VT: Friday 03 March 2017 00UTC
Surface methane [ppbv]
Copernicus Atmosphere Monitoring Service,
European Space Agency




CH_4 [ppb]
2050
2000
1950
1900
1850
1800
1750
1700
1650
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
a_{KAS} = 6.58 ± 0.23 (ppb/yr)
a_{KAS} = 5.34 ± 0.12 (ppb/yr)
a_{KAS} = 0.94 ± 0.38 (ppb/yr)
a_{MLO} = 7.82 ± 0.14 (ppb/yr)
a_{MLO} = 4.81 ± 0.05 (ppb/yr)
a_{MLO} = 2.63 ± 0.12 (ppb/yr)

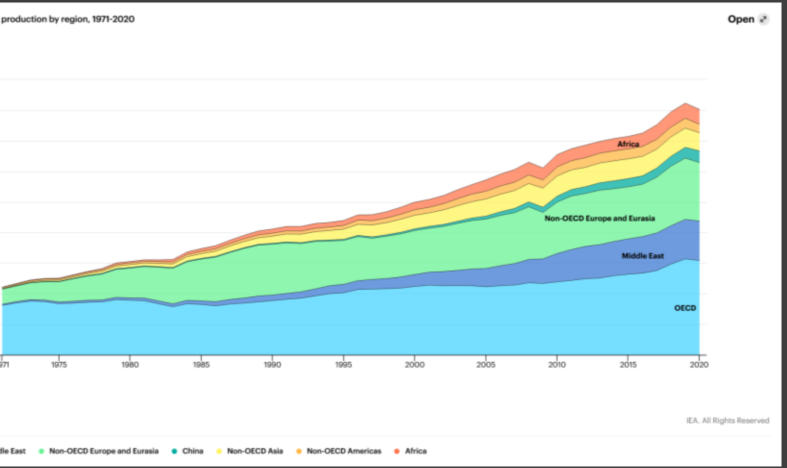

PICARRO
PICARRO

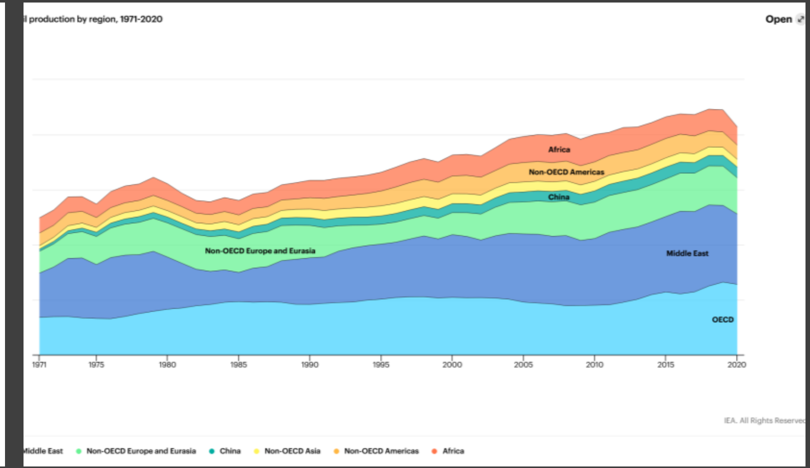

GLOBAL METHANE BUDGET 2010-2019
Global Carbon Project
TOTAL EMISSIONS
CHANGE IN ATMOSPHERIC ABUNDANCE
36
21*
(19-33)
TOTAL SINKS
Bottom-up view (BU)
Top-down view (TD)
669 (512-849)
575 (553-586)
633 (507-796)
554 (550-567)
120 (117-125)
115 (100-124)
211 (195-231)
228 (213-242)
28 (21-39)
27 (26-27)
248 (159-369)
165 (145-214)
63 (24-93)
43 (40-46)
602 (496-747)
521 (485-532)
31 (11-49)
35 (35-36)
Sink from chemical reactions in the atmosphere
Fossil fuel production and use
Agriculture and waste
Biomass and biofuel burning
Combined wetland & Inland freshwaters
Other natural emissions
geological, oceans, termites, wild animals, permafrost, vegetation
Sink in soils
EMISSIONS AND SINKS
In teragrams of CH_4 per year (Tg CH_4 / yr) average over 2009-2019
The observed atmospheric growth rate is 20.9 (20.1-21.7) Tg CH_4 / yr. The difference with the TD budget imbalance reflects uncertainties in capturing the observed growth rate.
Anthropogenic fluxes
Natural fluxes
Natural and anthropogenic fluxes
GLOBAL CARBON PROJECT

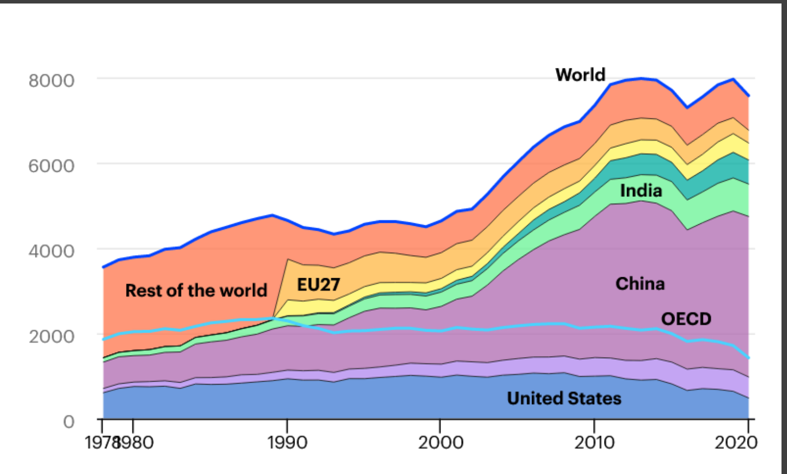

Radiation from Sun
~30% absorbed in Atmosphere
Radiation from Earth
~75% absorbed in Atmosphere
Spectral Intensity
Percent
100
80
60
40
20
0
Total Absorption and Scattering
Major Components
Water Vapor
Carbon Dioxide
Methane
Nitrous Oxide
Oxygen & Ozone
Rayleigh Scattering
UV
Visible
Infared
0.2
1
10
60
Wavelength (μm)

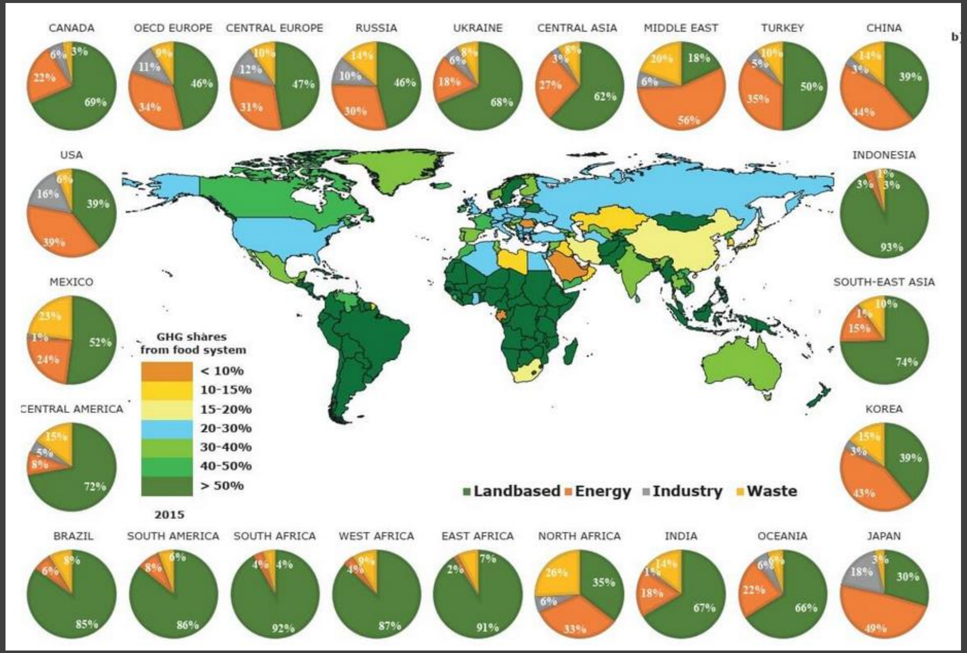
Methane pledge

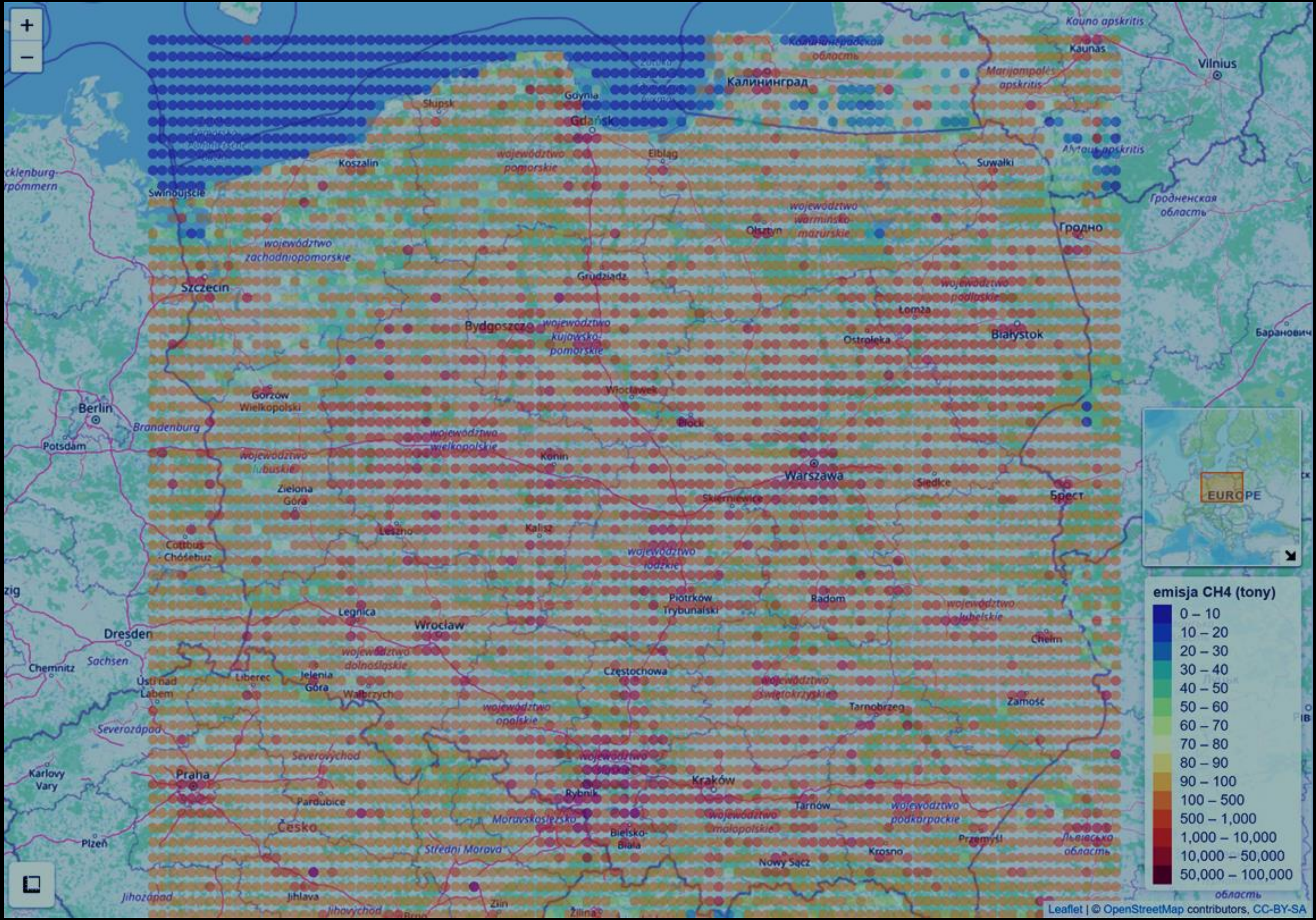
Industrial emissions – 3 main sources: NG, Oil, Coal

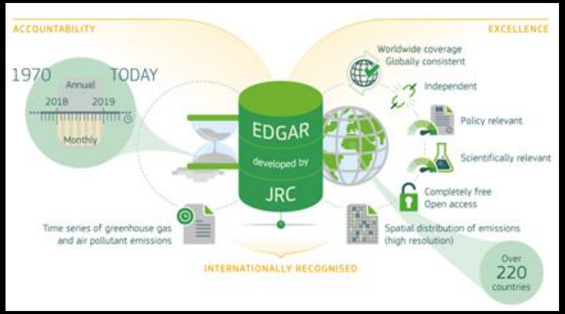






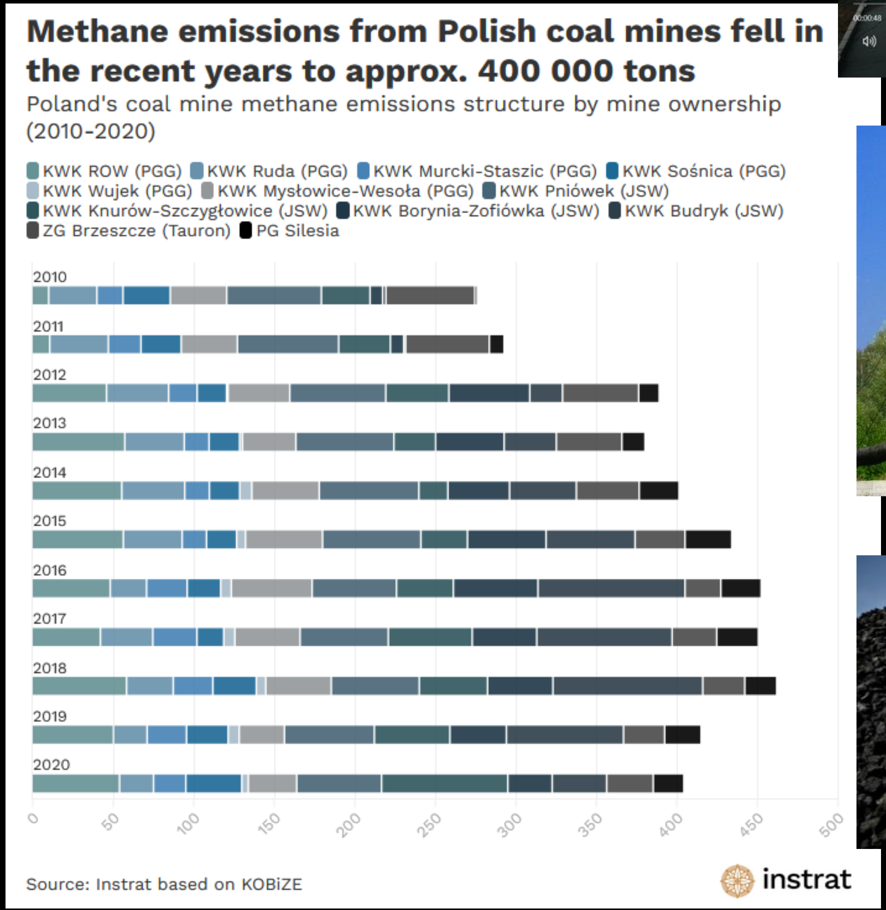


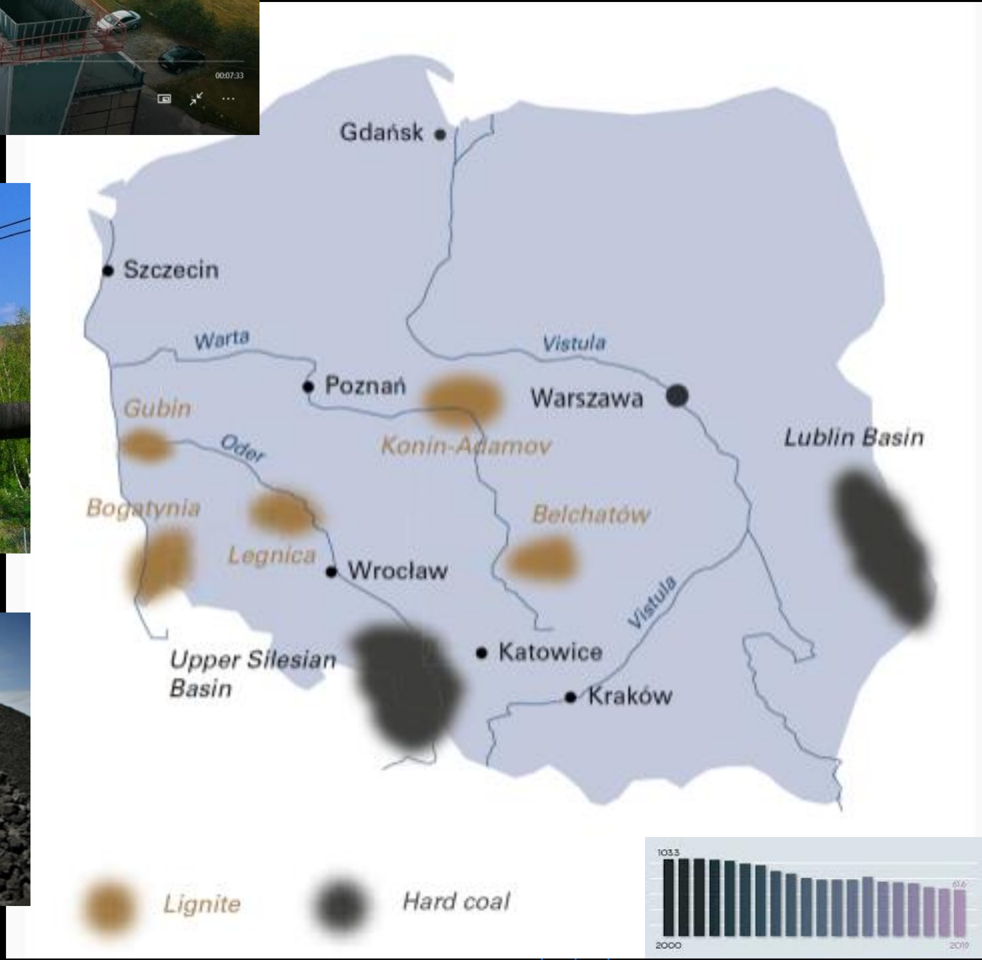

emisja CH4 (tony)
0 – 10
10 – 20
20 – 30
30 – 40
40 – 50
50 – 60
60 – 70
70 – 80
80 – 90
90 – 100
100 – 500
500 – 1,000
1,000 – 10,000
10,000 – 50,000
50,000 – 100,000
EUROPE
Leaflet | © OpenStreetMap contributors, CC-BY-SA


ACCOUNTABILITY
EXCELLENCE
1970
TODAY
Annual
2018
2019
Monthly
EDGAR
developed by
JRC
Worldwide coverage
Globally consistent
Independent
Policy relevant
Scientifically relevant
Completely free
Open access
Time series of greenhouse gas and air pollutant emissions
Spatial distribution of emissions (high resolution)
INTERNATIONALLY RECOGNISED
Over
220
countries

Methane from coal mines

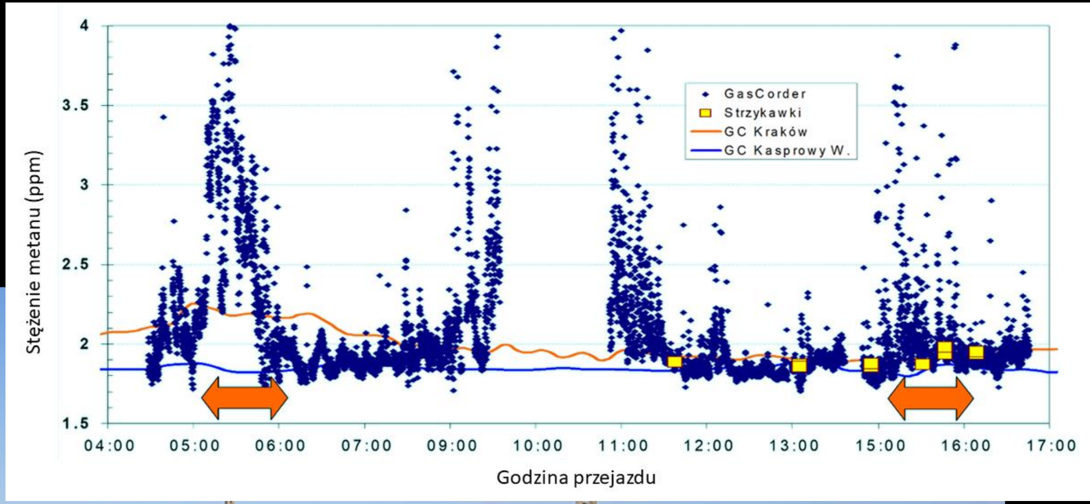
- exhaust shafts
- drainage stations
- closed coal mines
- debris heaps
- coal piles



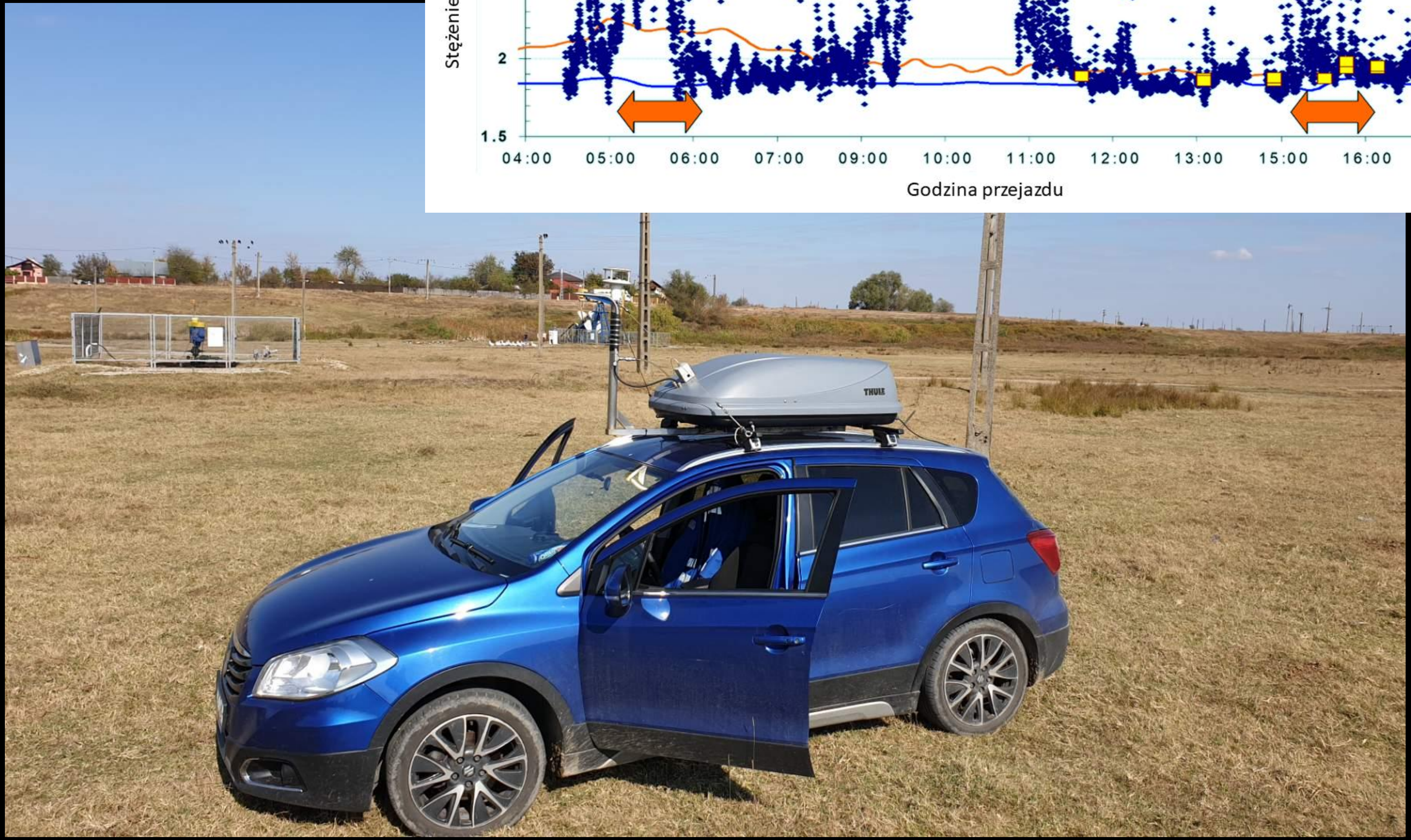


www.agh.edu.pl

1991



Mobilne analysers

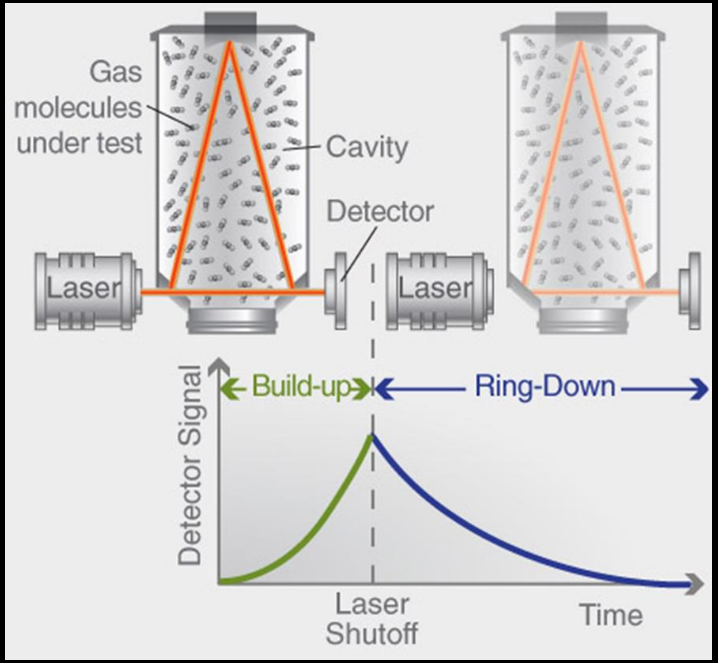


2018

CRDS

OA-ICOS

OF-CEAS


Gas molecules under test
Cavity
Detector
Laser
Laser
Detector Signal
Build-up
Ring-Down
Laser Shutoff
Time

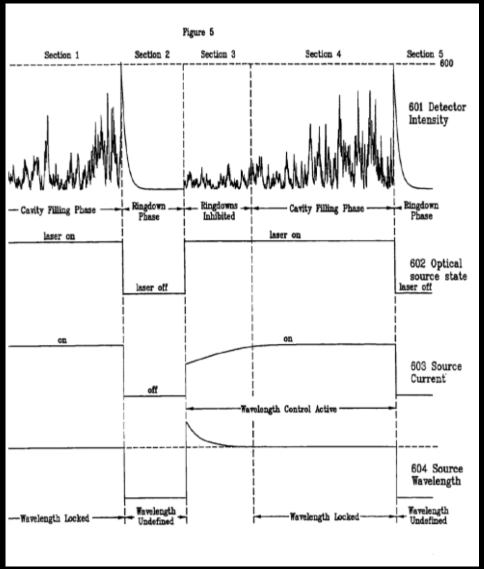
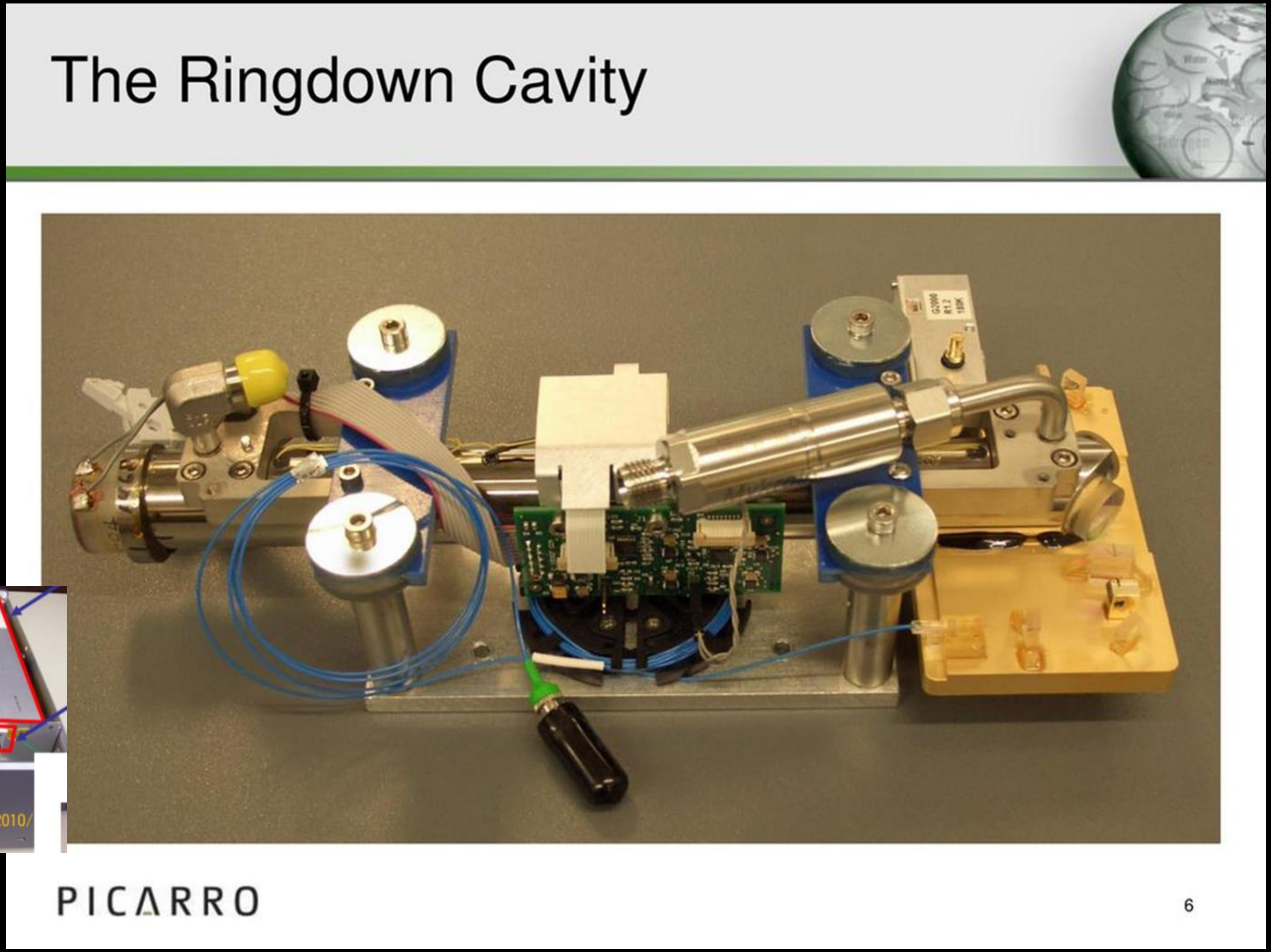
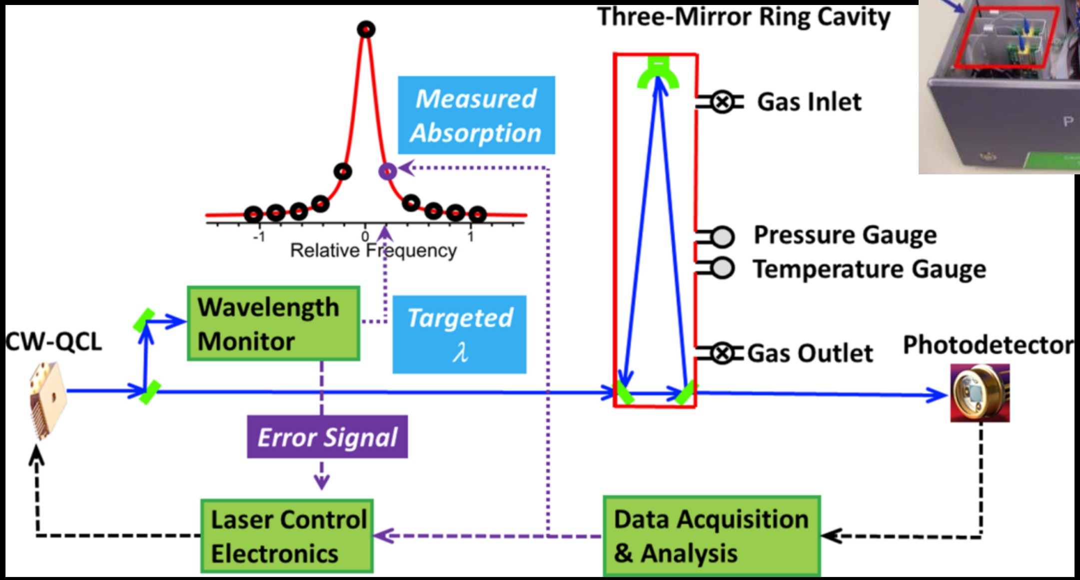
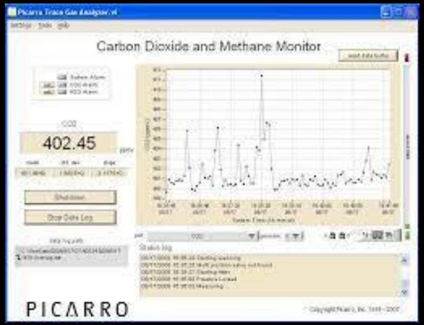


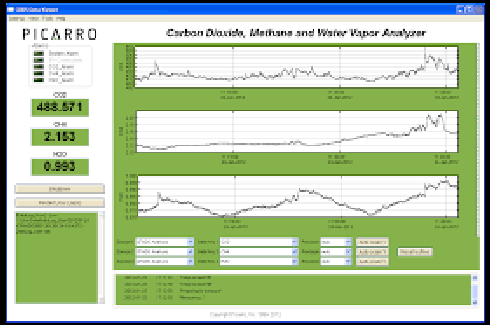
Figure 5
Section 1
Section 2
Section 3
Section 4
Section 5
600
601 Detector Intensity
Cavity Filling Phase
Ringdown Phase
Ringdowns Inhibited
Cavity Filling Phase
Ringdown Phase
laser on
laser off
laser on
602 Optical source state
laser off
on
off
on
603 Source Current
Wavelength Control Active
604 Source Wavelength
Wavelength Locked
Wavelength Undefined
Wavelength Locked
Wavelength Undefined


The Ringdown Cavity
PICARRO
6


PICARRO
2010/


Three-Mirror Ring Cavity
Measured Absorption
Gas Inlet
-1
0
1
Relative Frequency
Pressure Gauge
Temperature Gauge
Wavelength Monitor
Targeted λ
Gas Outlet
Photodetector
CW-QCL
Error Signal
Laser Control Electronics
Data Acquisition & Analysis

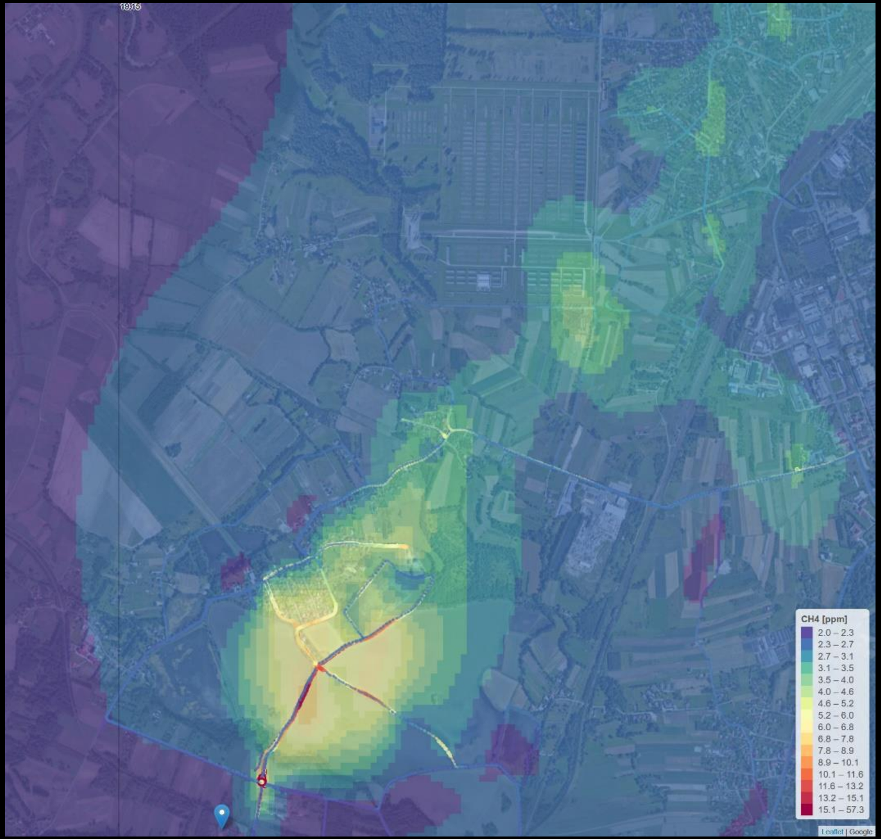

Carbon Dioxide and Methane Monitor
402.45
PICARRO

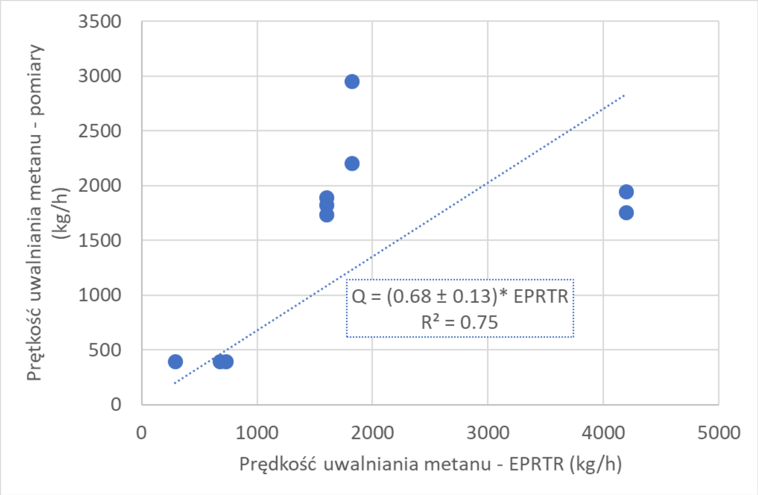

PICARRO
Carbon Dioxide, Methane and Water Vapor Analyzer
488.571
2.153
0.993

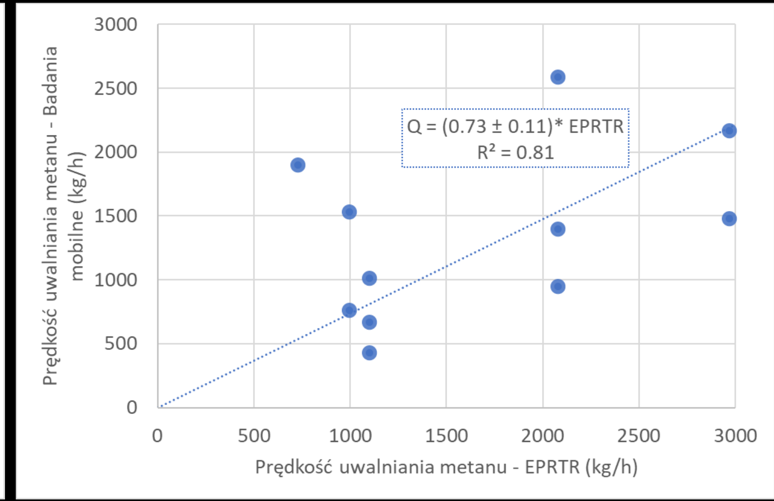
CRDS

Mobile techniques – plume disspersion

500 kt CH_4 per year (250 – 750)







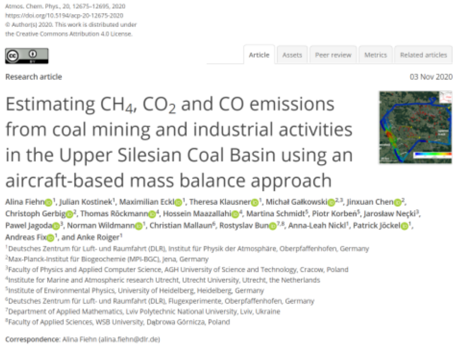
Airplane technique: Mas balance with laser spectrometer (Picarro)


PICARRO
Applications Products Technology Support Company
Continuous Monitoring for Real Time Insights
HOME / PRODUCTS / G2401-M IN-FLIGHT GAS CONCENTRATION ANALYZER

G2401-m In-flight Gas Concentration Analyzer

Measures CO, CO_2, CH_4, and H_2O

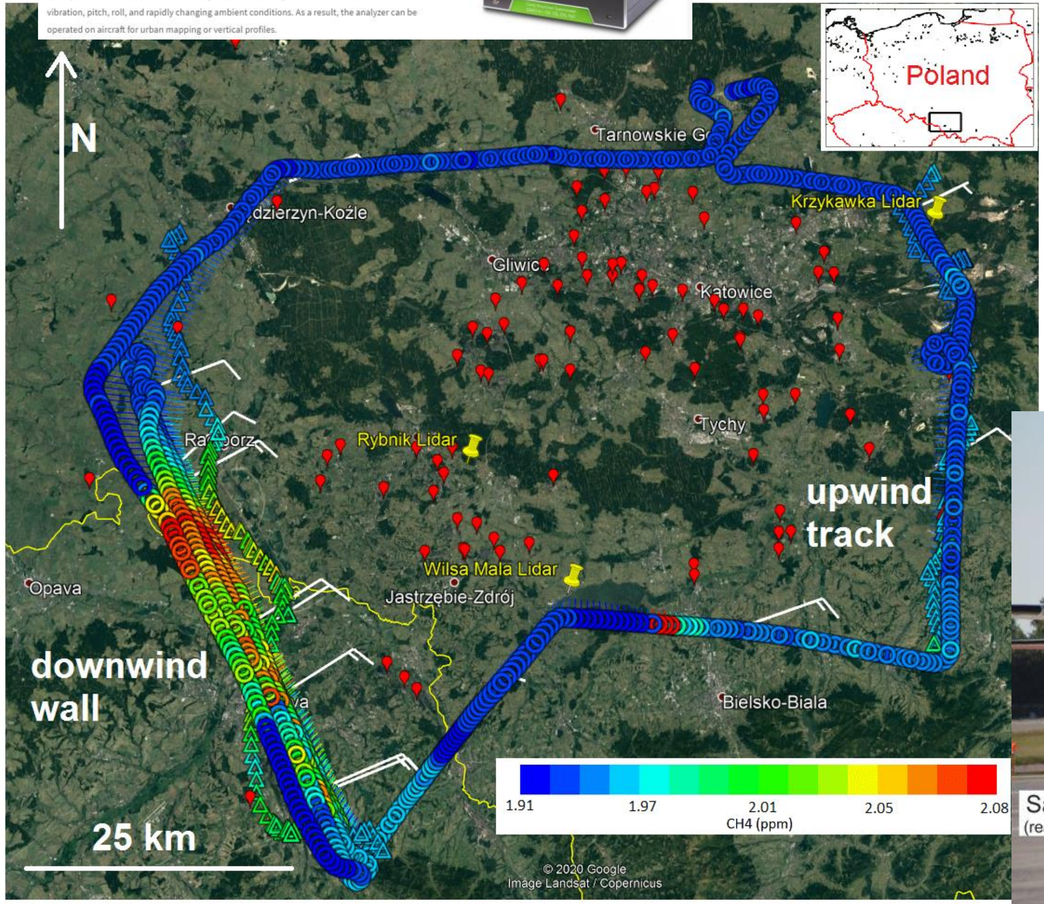
The Picarro G2401-m gas concentration analyzer provides simultaneous, precise measurement of carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4) at parts-per-billion (ppb), and water (H_2O) vapor at parts-per-million (ppm) sensitivity with negligible drift for atmospheric science, air quality, and emissions quantification. Flight-optimized design elements minimize effects of aircraft vibration, pitch, roll, and rapidly changing ambient conditions. As a result, the analyzer can be operated on aircraft for urban mapping or vertical profiles.

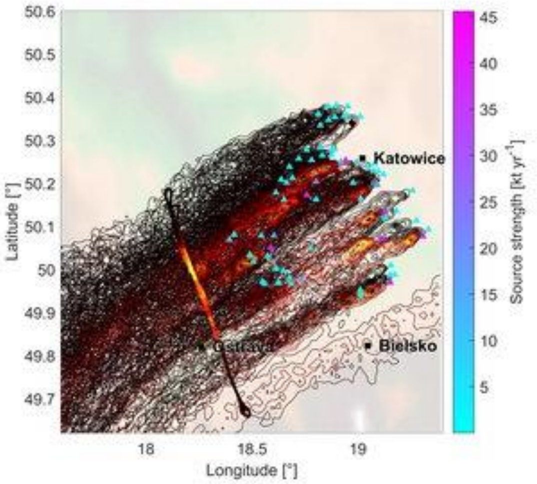

Atmos. Chem. Phys., 20, 12675–12695, 2020
https://doi.org/10.5194/acp-20-12675-2020

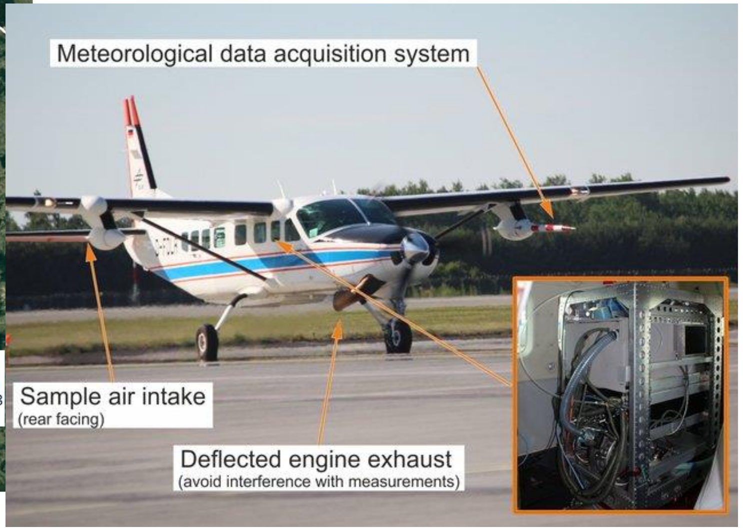
Article Assets Peer review Metrics Related articles
Research article 03 Nov 2020

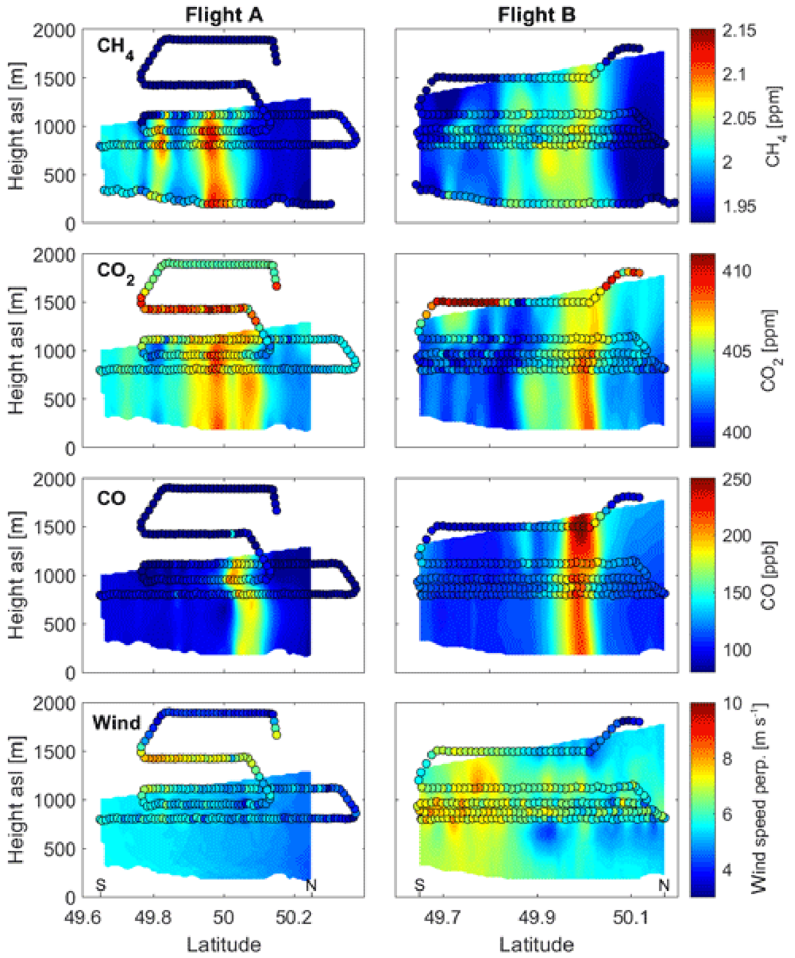
Estimating CH_4, CO_2 and CO emissions from coal mining and industrial activities in the Upper Silesian Coal Basin using an aircraft-based mass balance approach

Alina Fiehn[1], Julian Kostinek[1], Maximilian Eckl[1], Theresa Klausner[1], Michał Gałkowski[2,3], Jinxuan Chen[2], Christoph Gerbig[2], Thomas Röckmann[4], Hossein Maazallahi[4], Martina Schmidt[5], Piotr Korbeń[5], Jarosław Nęcki[3], Paweł Jagoda[3], Norman Wildmann[1], Christian Mallaun[6], Rostyslav Bun[7,8], Anna-Leah Nickl[1], Patrick Jöckel[1], Andreas Fix[1], and Anke Roiger[1]
[1]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany
[2]Max-Planck-Institut für Biogeochemie (MPI-BGC), Jena, Germany
[3]Faculty of Physics and Applied Computer Science, AGH University of Science and Technology, Cracow, Poland
[4]Institute for Marine and Atmospheric research Utrecht, Utrecht University, Utrecht, the Netherlands
[5]Institute of Environmental Physics, University of Heidelberg, Heidelberg, Germany
[6]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Flugexperimente, Oberpfaffenhofen, Germany
[7]Department of Applied Mathematics, Lviv Polytechnic National University, Lviv, Ukraine
[8]Faculty of Applied Sciences, WSB University, Dąbrowa Górnicza, Poland
Correspondence: Alina Fiehn (alina.fiehn@dlr.de)









Methane to Go

Polska, Oman

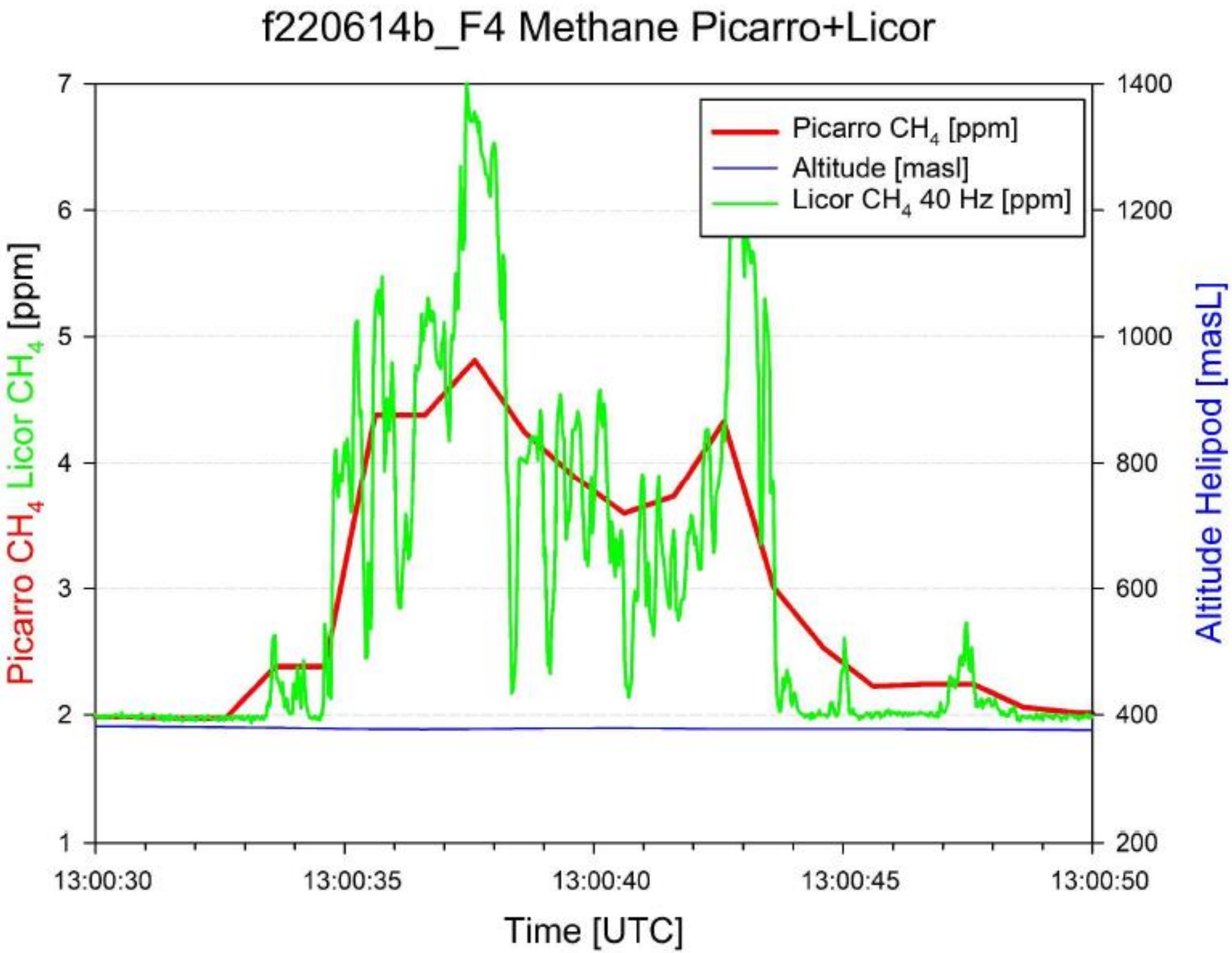
2022 - 2023

Helipod

METHANE-To-Go-Poland: Main instrumentation on HELiPOD

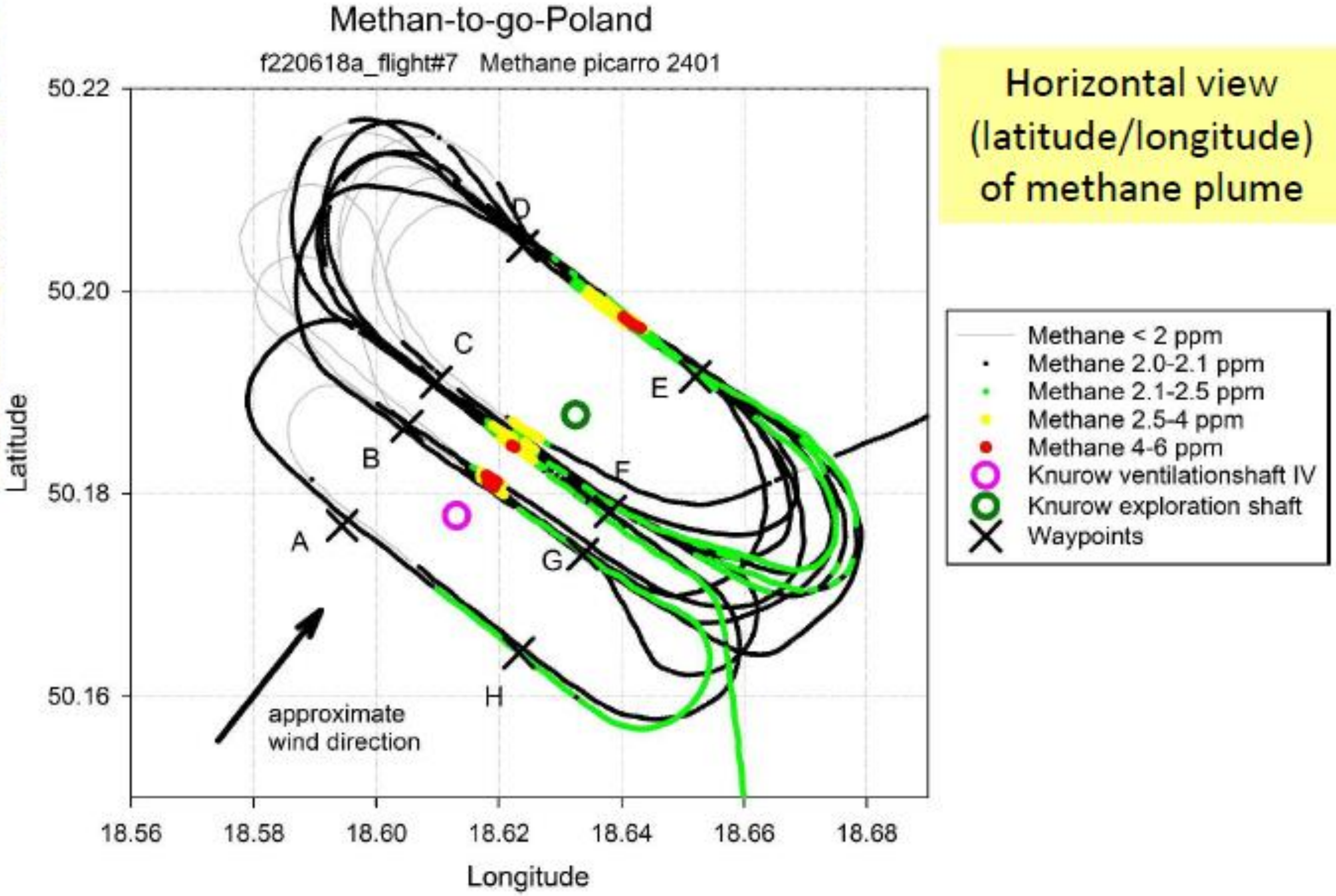
10 flights in 10 days
(each flight 2-3 h)

Instrument	Species/Parameter	
Picarro 2401-m (precision: ~1 ppb, Δt= 1 Hz, no continuously measurement) (cavity ringdown spectroscopy)	**CH_4 & CO_2 & CO**	**DLR**
Li-7500A (open path gas analyzer, non-dispersive infrared gas analyzer)	**CO_2 & H_2O**	**TU-BS**
Meteorological sensors	**Wind, Temperature, Humidity**	**TU-BS**
Particle counters	**aerosols**	**TU-BS**
Li-7700 (Δt= 40 Hz → 5 Hz used, continuously measurement) (open path methane analyzer)	**CH_4**	**DLR/Uni-HH**
Envea-AF22E (UV-fluorescence-Gasanalyzator)	SO_2, H_2S	DLR ordered in July



f220614b_F4 Methane Picarro+Licor
Picarro CH4 [ppm]
Altitude [masl]
Licor CH4 40 Hz [ppm]
Picarro CH4 Licor CH4 [ppm]
Altitude Helipod [masL]
Time [UTC]
13:00:30
13:00:35
13:00:40
13:00:45
13:00:50
1
2
3
4
5
6
7
200
400
600
800
1000
1200
1400

METHANE-To-Go-Poland: example of airborne in-situ CH4 measurements (HELiPOD)



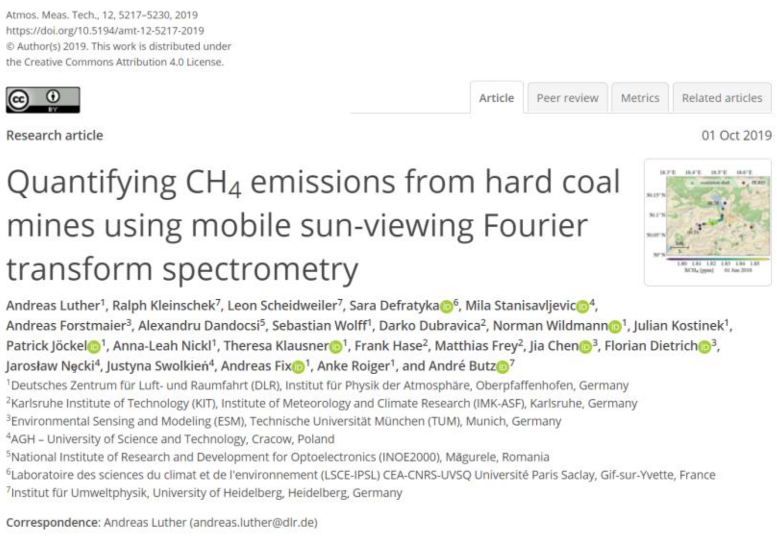
Horizontal view (latitude/longitude) of methane plume

Ventilation shaft Knurow-Szczyglowice IV

~10000 t CH_4 / a

→ 2h (sampling time): ~ 2300 kg CH_4

Mobile FTIR


Atmos. Meas. Tech., 12, 5217–5230, 2019
https://doi.org/10.5194/amt-12-5217-2019

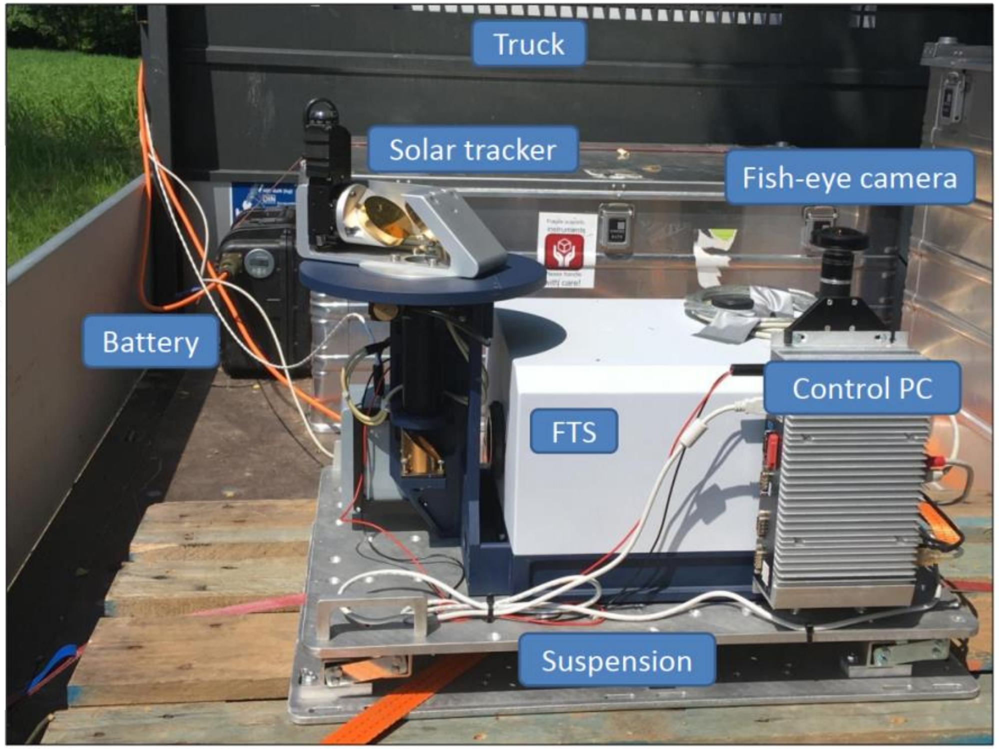
Article | Peer review | Metrics | Related articles

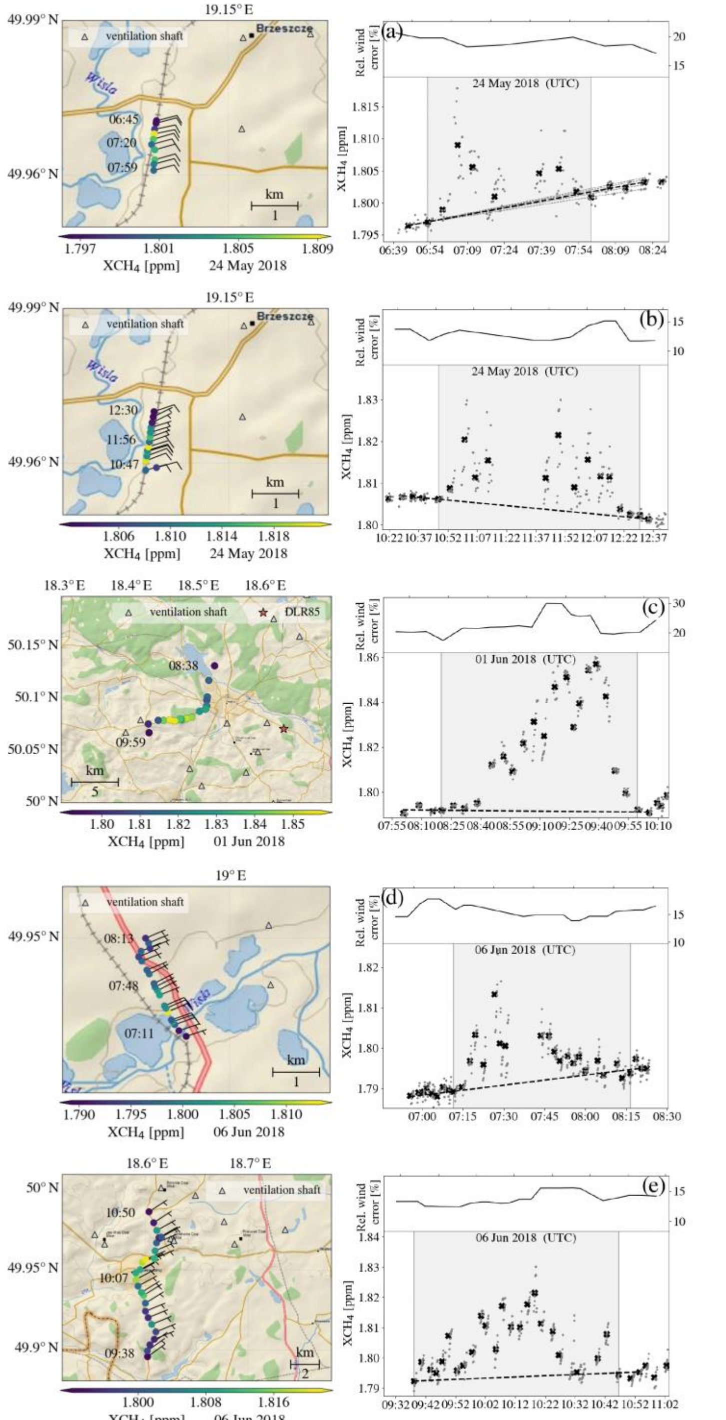
Research article

01 Oct 2019

Quantifying CH_4 emissions from hard coal mines using mobile sun-viewing Fourier transform spectrometry

Andreas Luther[1], Ralph Kleinschek[7], Leon Scheidweiler[7], Sara Defratyka[6], Mila Stanisavljevic[4], Andreas Forstmaier[3], Alexandru Dandocsi[5], Sebastian Wolff[1], Darko Dubravica[2], Norman Wildmann[1], Julian Kostinek[1], Patrick Jöckel[1], Anna-Leah Nickl[1], Theresa Klausner[1], Frank Hase[2], Matthias Frey[2], Jia Chen[3], Florian Dietrich[3], Jarosław Nęcki[4], Justyna Swolkień[4], Andreas Fix[1], Anke Roiger[1], and André Butz[7]
[1]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany
[2]Karlsruhe Institute of Technology (KIT), Institute of Meteorology and Climate Research (IMK-ASF), Karlsruhe, Germany
[3]Environmental Sensing and Modeling (ESM), Technische Universität München (TUM), Munich, Germany
[4]AGH – University of Science and Technology, Cracow, Poland
[5]National Institute of Research and Development for Optoelectronics (INOE2000), Măgurele, Romania
[6]Laboratoire des sciences du climat et de l'environnement (LSCE-IPSL) CEA-CNRS-UVSQ Université Paris Saclay, Gif-sur-Yvette, France
[7]Institut für Umweltphysik, University of Heidelberg, Heidelberg, Germany
Correspondence: Andreas Luther (andreas.luther@dlr.de)





Date and time UTC	Esti. emissions ($kt\,a^{-1}$)	Combined σ ($kt\,a^{-1}$)	Combined σ (%)	E-PRTR ($kt\,a^{-1}$)
24 May 07:00 to 08:00	**6**	**1**	19	**9.63**
24 May noon	**10**	**1**	15	**9.63**
1 June 08:00 to 10:00	**109**	**33**	30	–
6 June 07:00 to 08:00	**17**	**3**	16	**24.3**
6 June noon	**81**	**13**	16	**~80**

Airplane techniques (LIDAR):

Determination of the emission rates of CO₂ point sources with airborne lidar

April 2021 · Atmospheric Measurement Techniques 14(4):2717-2736 · Follow journal
DOI: 10.5194/amt-14-2717-2021

Sebastian Wolff · Gerhard Ehret · Christoph Kiemle · Show all 7 authors · Andreas Fix

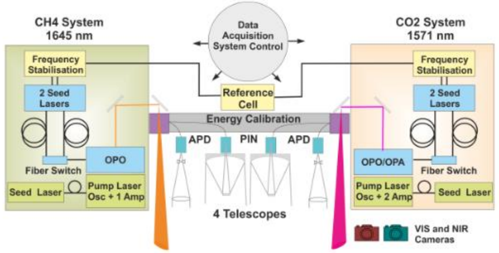


Figure 2: *Schematic set-up of the airborne CO_2 and CH_4 integrated path differential absorption lidar.*

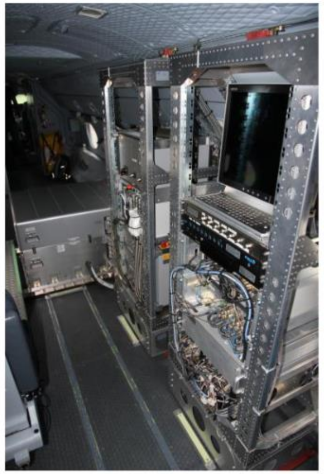
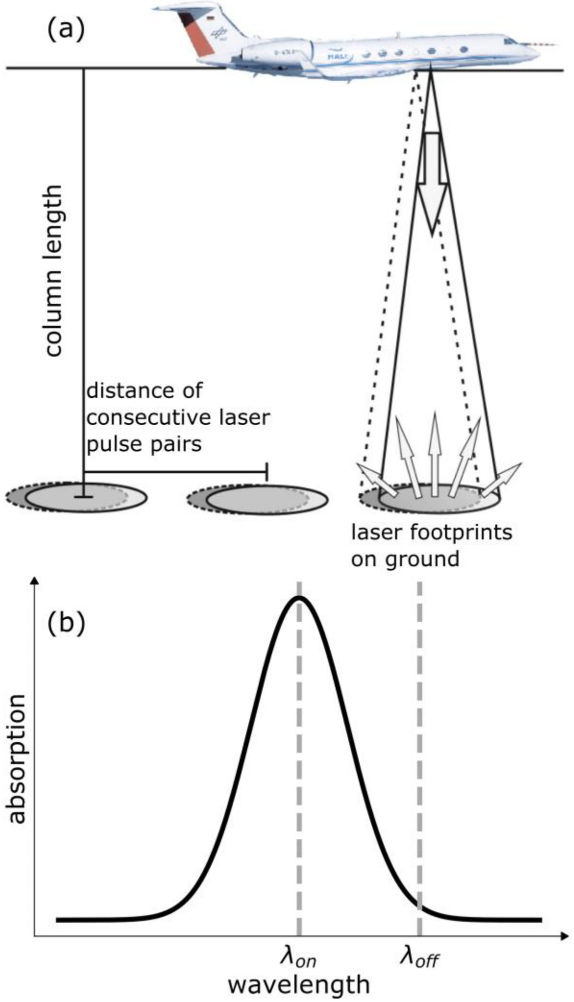


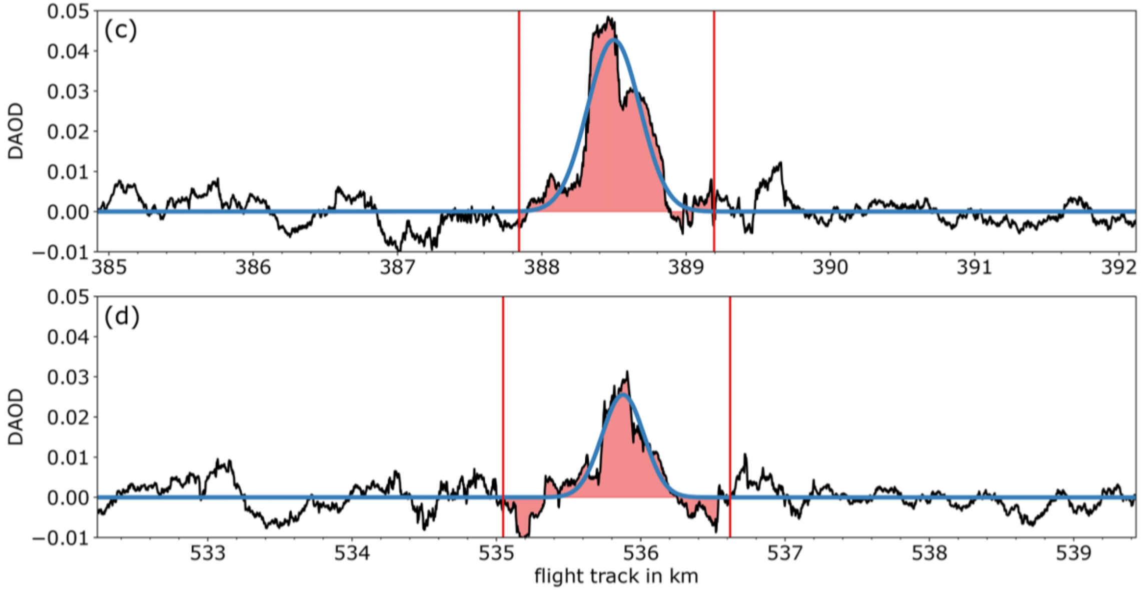
Figure 3: *Photograph of the CO_2 and CH_4 IPDA lidar as installed into the cabin of HALO.*

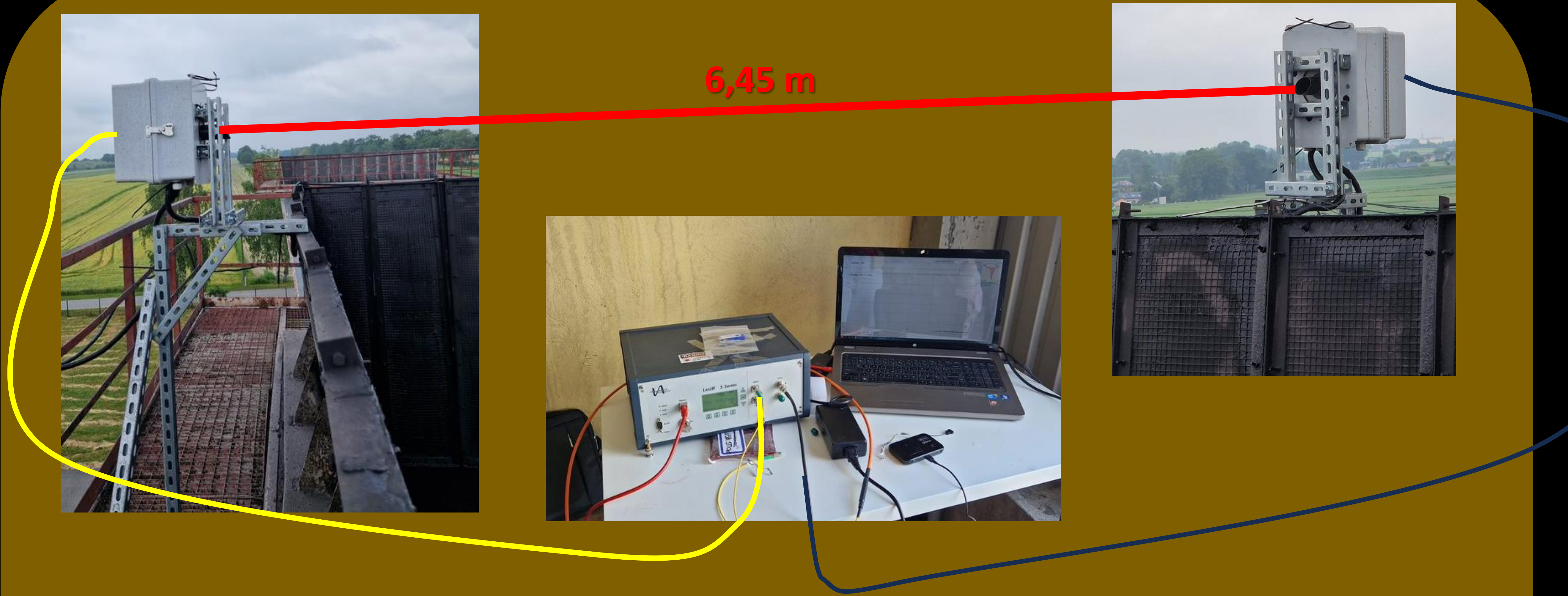


CH_4 AND CO_2 IPDA LIDAR MEASUREMENTS DURING THE COMET 2018 AIRBORNE FIELD CAMPAIGN

Andreas Fix[1*], Axel Amediek[1], Christian Büdenbender[1], Gerhard Ehret[1], Christoph Kiemle[1], Mathieu Quatrevalet[1], Martin Wirth[1], Sebastian Wolff [1], Heinrich Bovensmann[2], André Butz[3], Michał Gałkowski[4], Christoph Gerbig[4], Patrick Jöckel[1], Julia Marshall[4], Jarosław Nęcki[5], Klaus Pfeilsticker[3], Anke Roiger[1], Justyna Swolkień[5], Martin Zöger[6], and the CoMet team

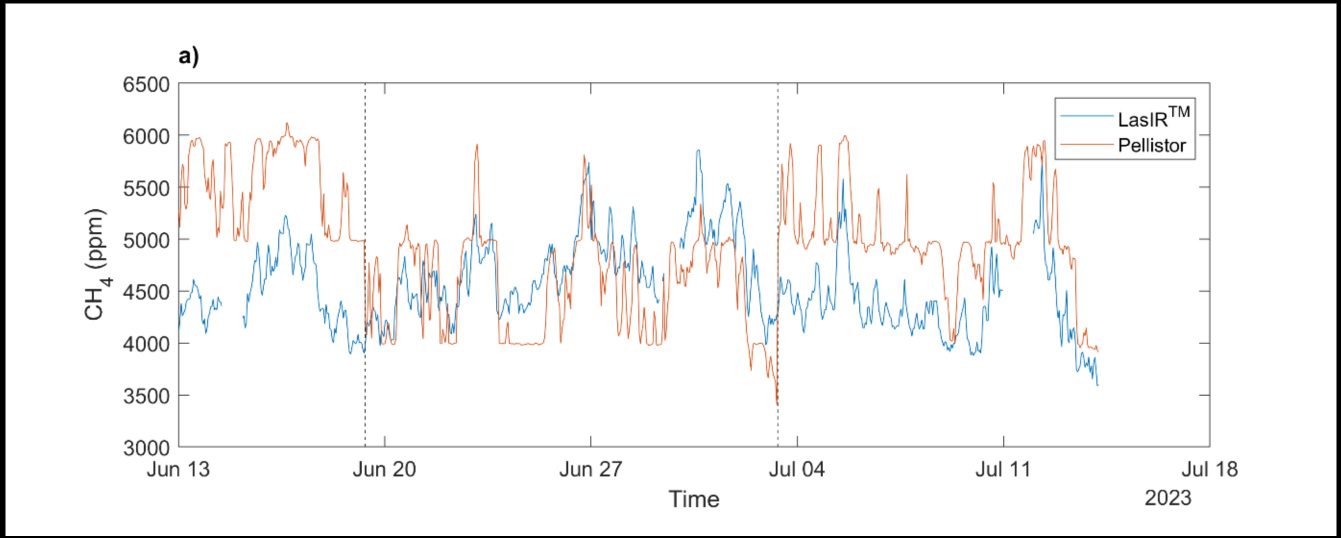
[1] *German Aerospace Center (DLR), Institute of Atmospheric Physics, Oberpfaffenhofen, Germany*
2 *University of Bremen, Institute of Environmental Physics, Bremen, Germany*
[3] *University of Heidelberg, Institute of Environmental Physics, Heidelberg, Germany*
[4] *Max Planck Institute for Biogeochemistry, Jena, Germany*
[5] *AGH University of Science and Technology, Kraków, Poland*
[6] *German Aerospace Center (DLR), Flight Experiments, Oberpfaffenhofen, Germany*
**Email: andreas.fix@dlr.de*

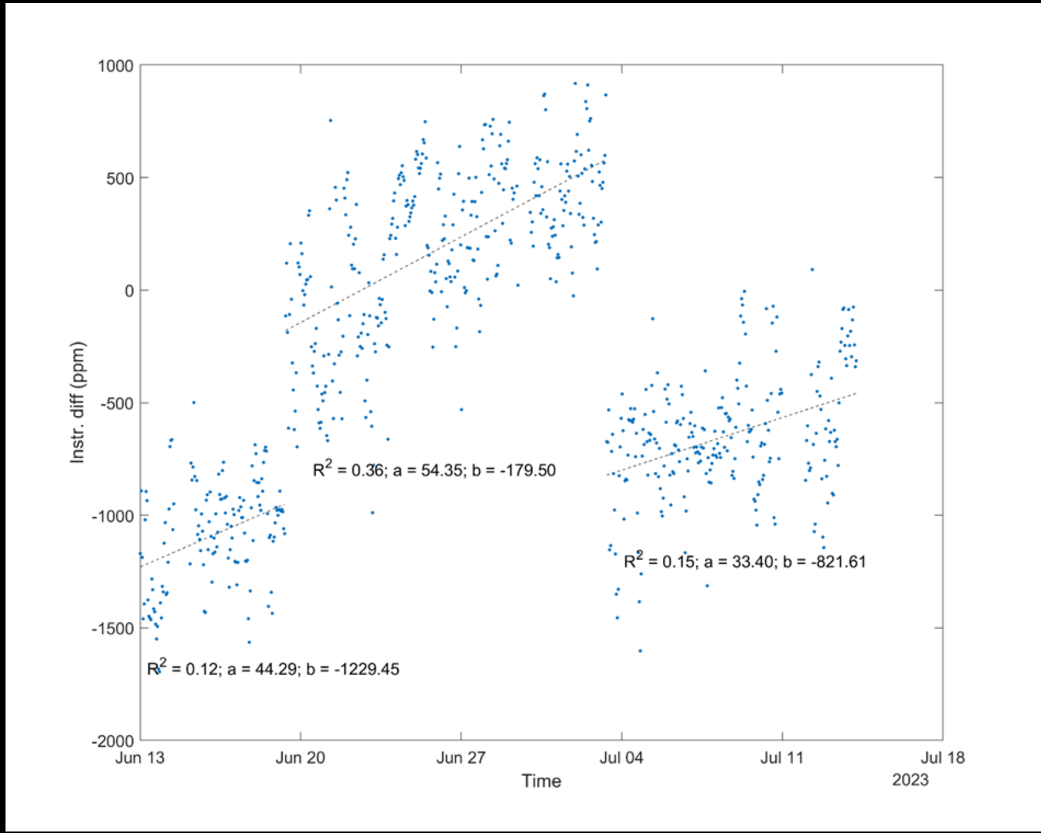




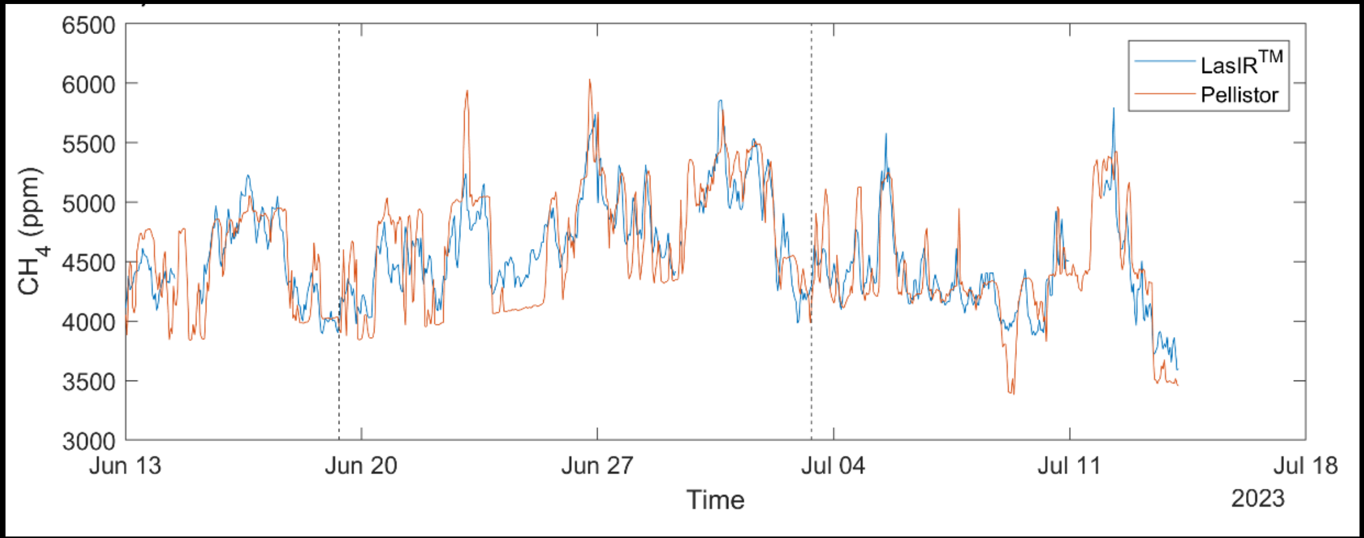
Unisearch Associates Inc TDLAS analyser LasIR , Series 5 with open path laser beam on the distance 6.5m over the diffuser of ventilation shaft.

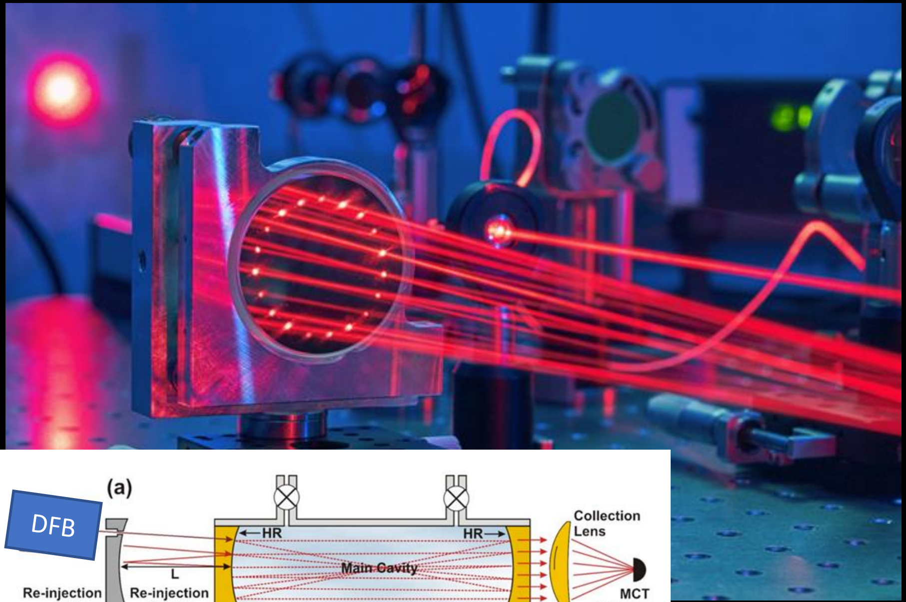
UNISEARCH ASSOCIATES INC

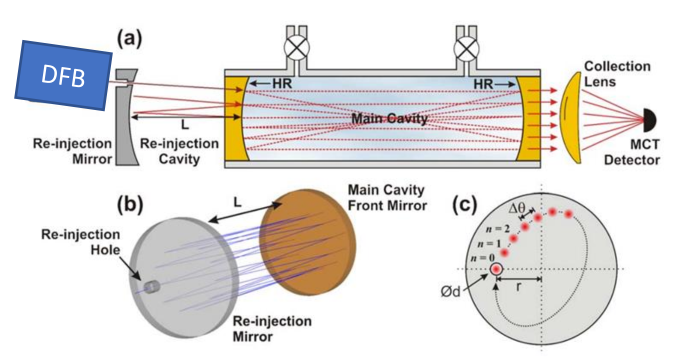

a)
6500
6000
5500
5000
4500
4000
3500
3000
CH4 (ppm)
Jun 13
Jun 20
Jun 27
Jul 04
Jul 11
Jul 18
Time
2023
LasIRTM
Pellistor

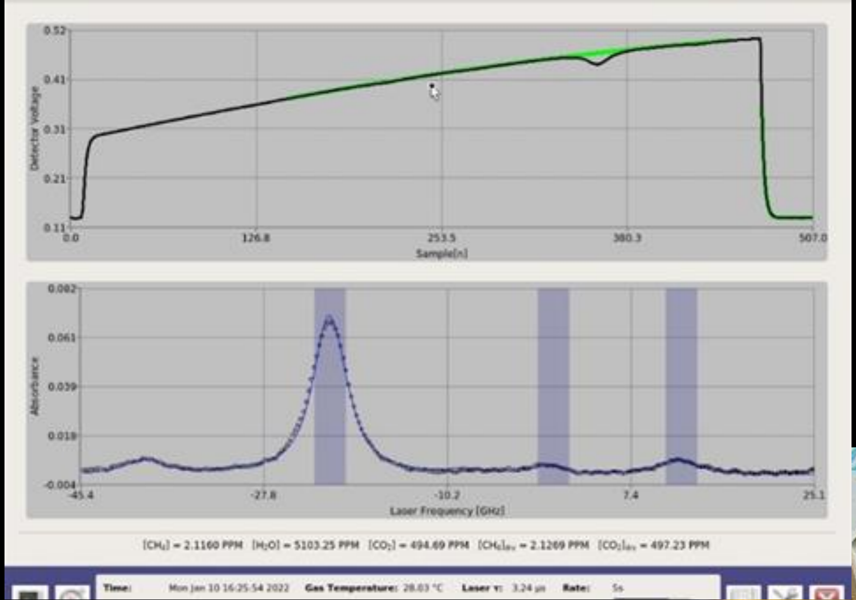

1000
500
0
-500
-1000
-1500
-2000
Instr. diff (ppm)
R2 = 0.36; a = 54.35; b = -179.50
R2 = 0.15; a = 33.40; b = -821.61
R2 = 0.12; a = 44.29; b = -1229.45
Jun 13
Jun 20
Jun 27
Jul 04
Jul 11
Jul 18
Time
2023

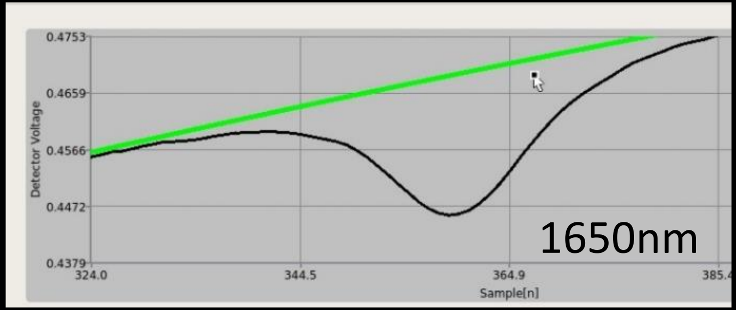

EMAG-SERWIS
DXX

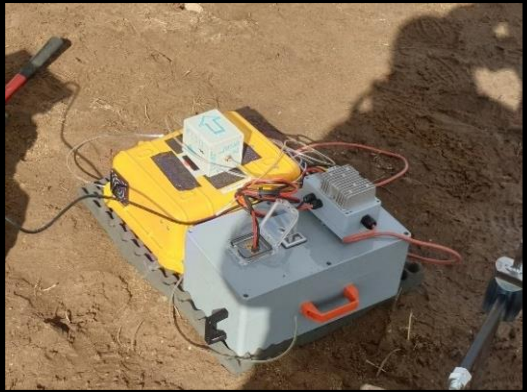

6500
6000
5500
5000
4500
4000
3500
3000
CH4 (ppm)
LasIRTM
Pellistor
Jun 13
Jun 20
Jun 27
Jul 04
Jul 11
Jul 18
Time
2023

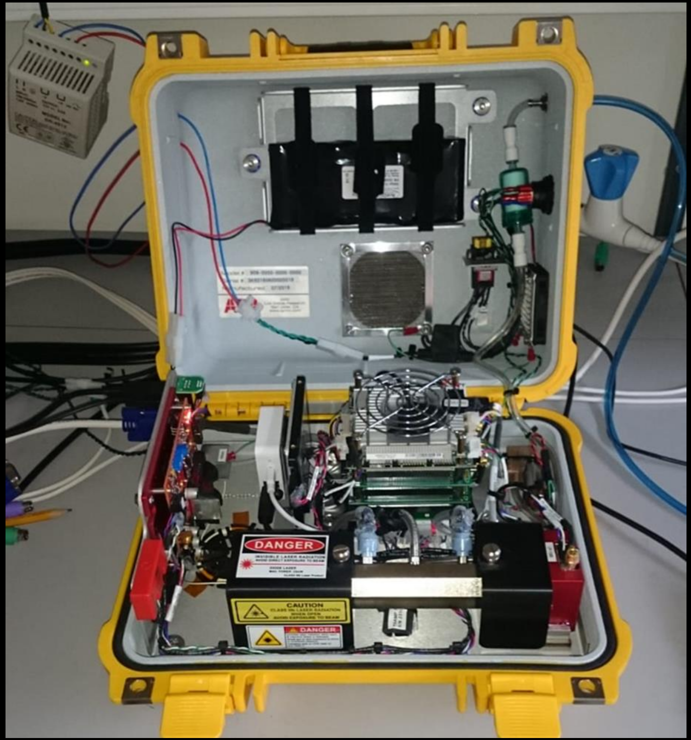



(a)
DFB
HR
HR
Main Cavity
L
Collection Lens
MCT Detector
Re-injection Mirror
Re-injection Cavity
(b)
L
Main Cavity Front Mirror
Re-injection Hole
Re-injection Mirror
(c)
Δθ
n = 2
n = 1
n = 0
Ød
r


Detector Voltage
Sample[n]
Absorbance
Laser Frequency [GHz]
$[CH_4]$ = 2.1160 PPM $[H_2O]$ = 5103.25 PPM $[CO_2]$ = 494.69 PPM $[CH_4]_{dry}$ = 2.1269 PPM $[CO_2]_{dry}$ = 497.23 PPM
Time: Mon Jan 10 16:25:54 2022 Gas Temperature: 28.03 °C Laser v: 3.24 μs Rate: 5s

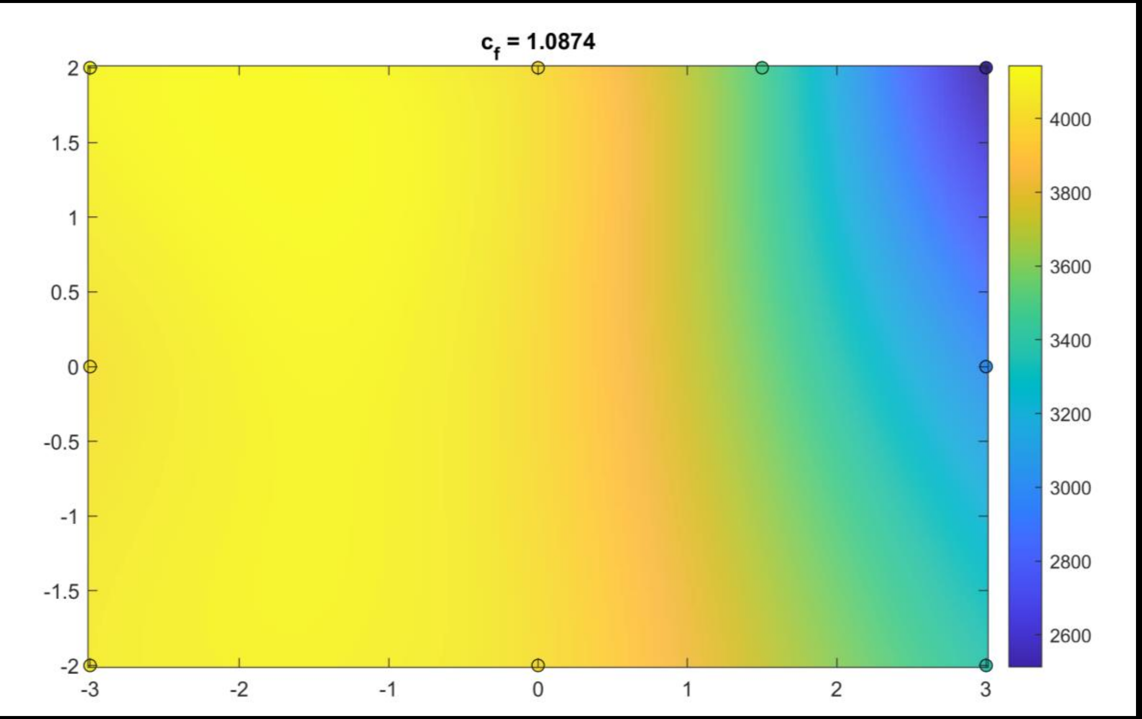

Detector Voltage
1650nm
Sample[n]



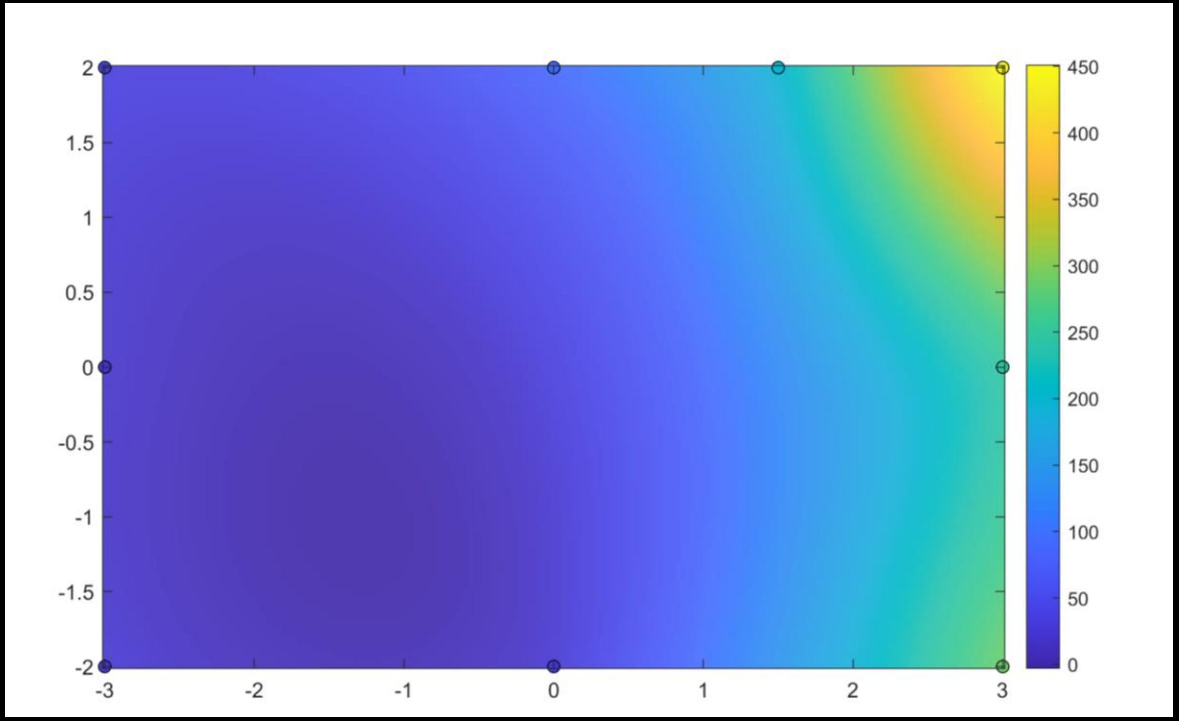

DANGER
CAUTION


TO INLET
SKC

OA-ICOS

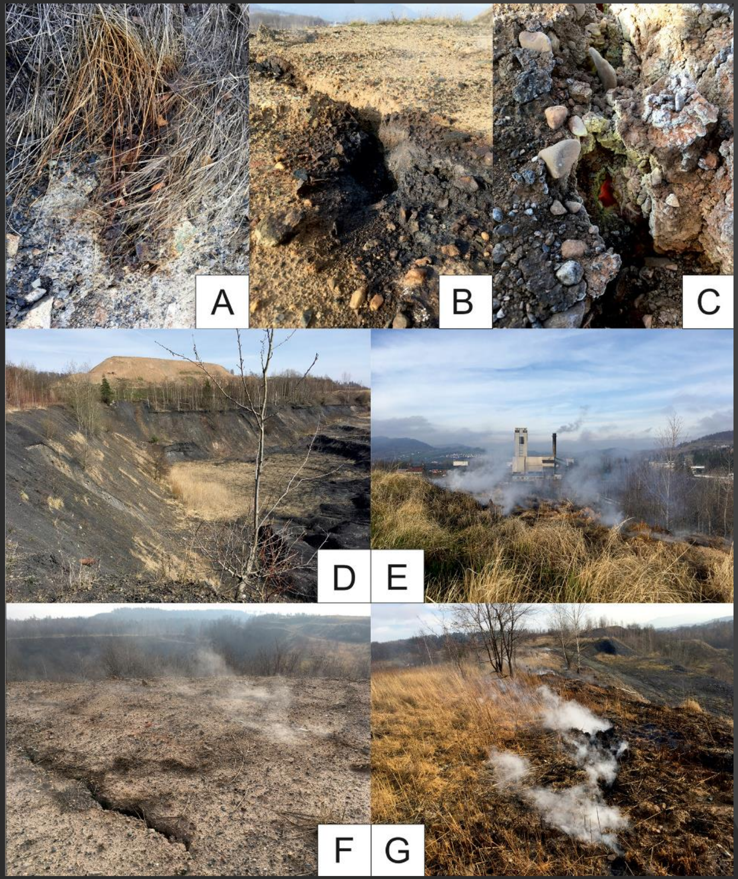


c_f = 1.0874
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-3
-2
-1
0
1
2
3
4000
3800
3600
3400
3200
3000
2800
2600



2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-3
-2
-1
0
1
2
3
450
400
350
300
250
200
150
100
50
0

Coal and rock debris dupm sites and closed coal mines

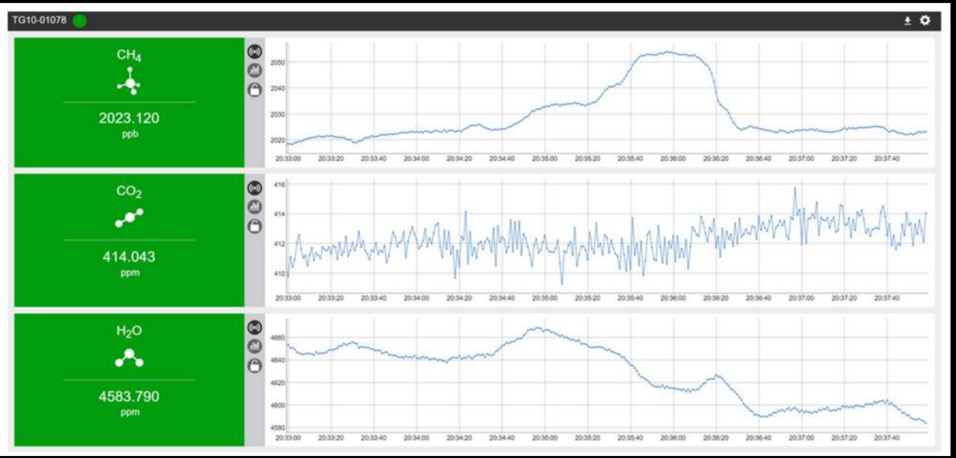


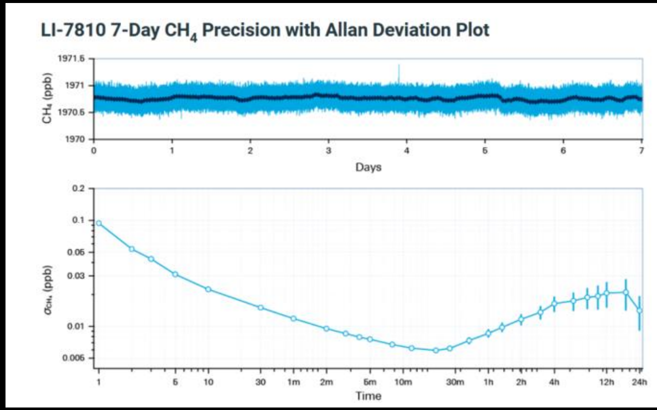
Closed mines
min 25 t CH_4 per year

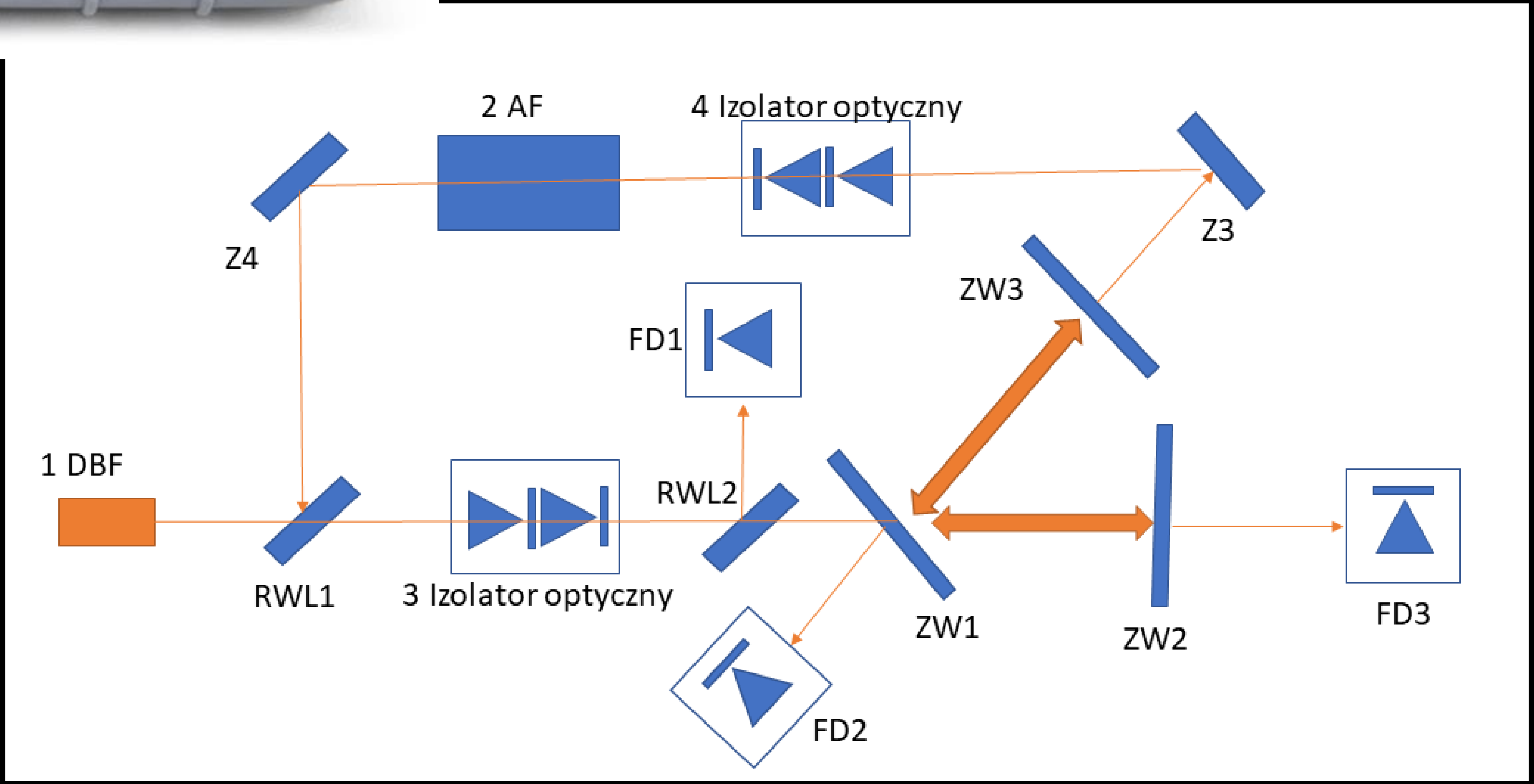
Heaps
51 t CH_4 per year

Coal magasines (piles)
2 kt CH_4 per year

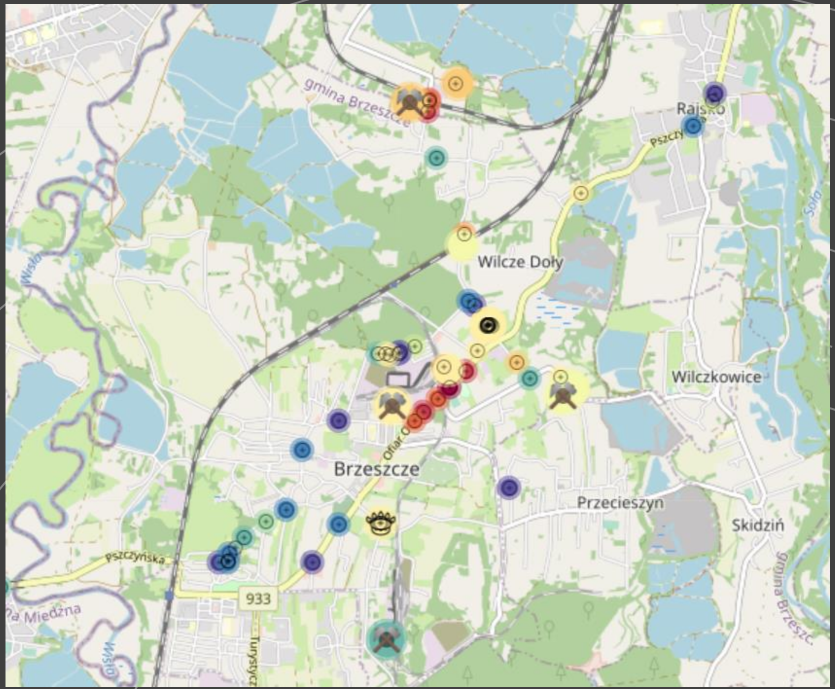

2041
460
8363

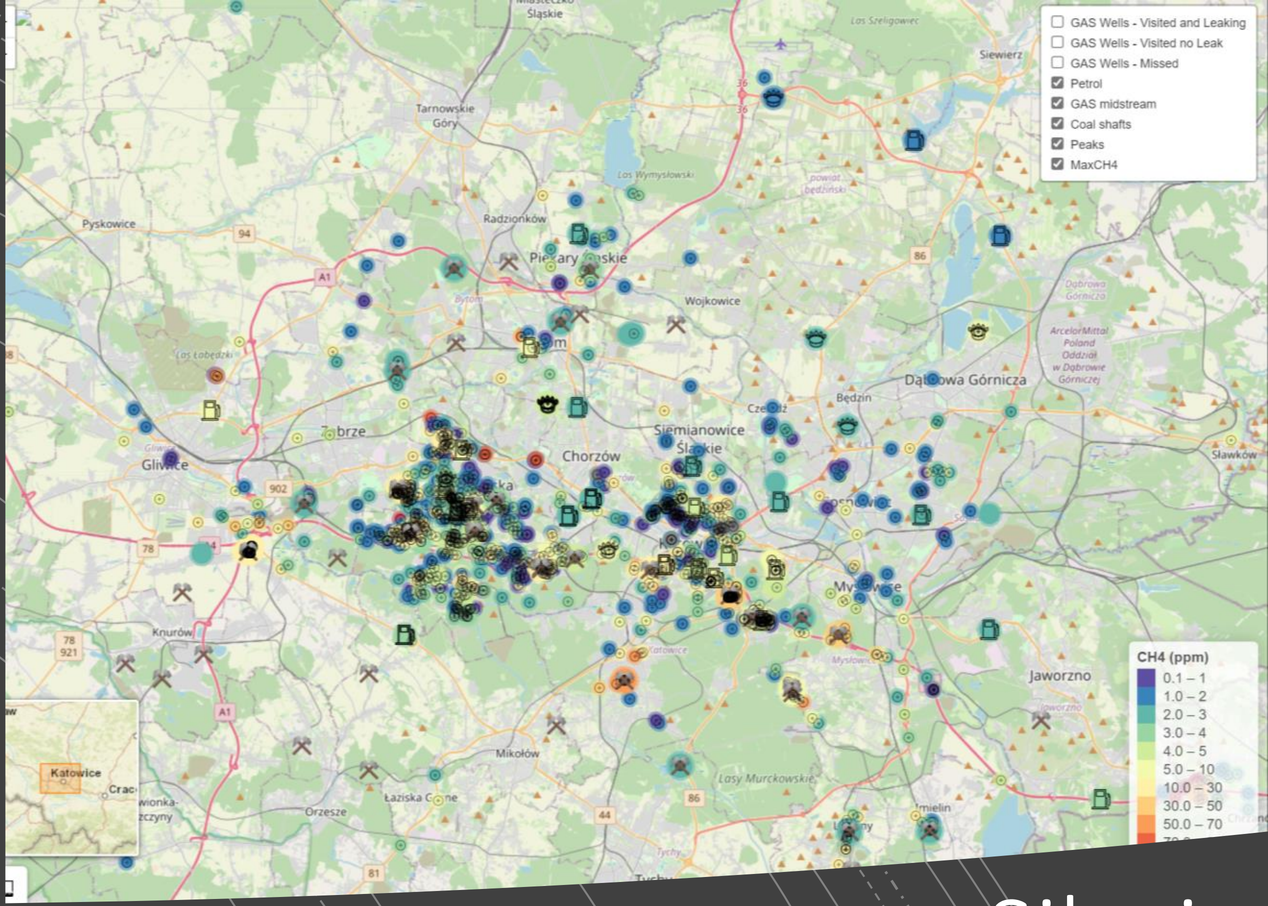

TG10-01078
CH4
2023.120
ppb
CO2
414.043
ppm
H2O
4583.790
ppm


LI-7810 7-Day CH4 Precision with Allan Deviation Plot
CH4 (ppb)
Days
Time


2 AF
4 Izolator optyczny
Z4
Z3
ZW3
FD1
1 DBF
RWL2
RWL1
3 Izolator optyczny
ZW1
ZW2
FD3
FD2

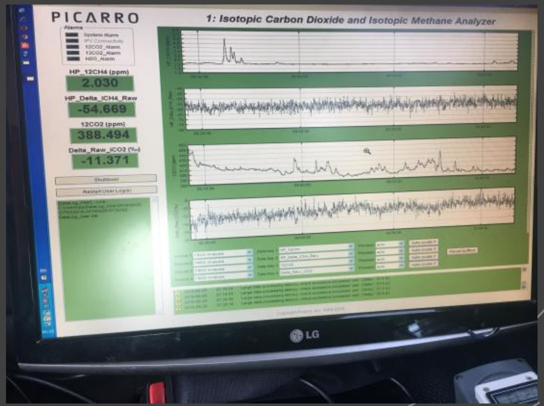
OF-CEAS



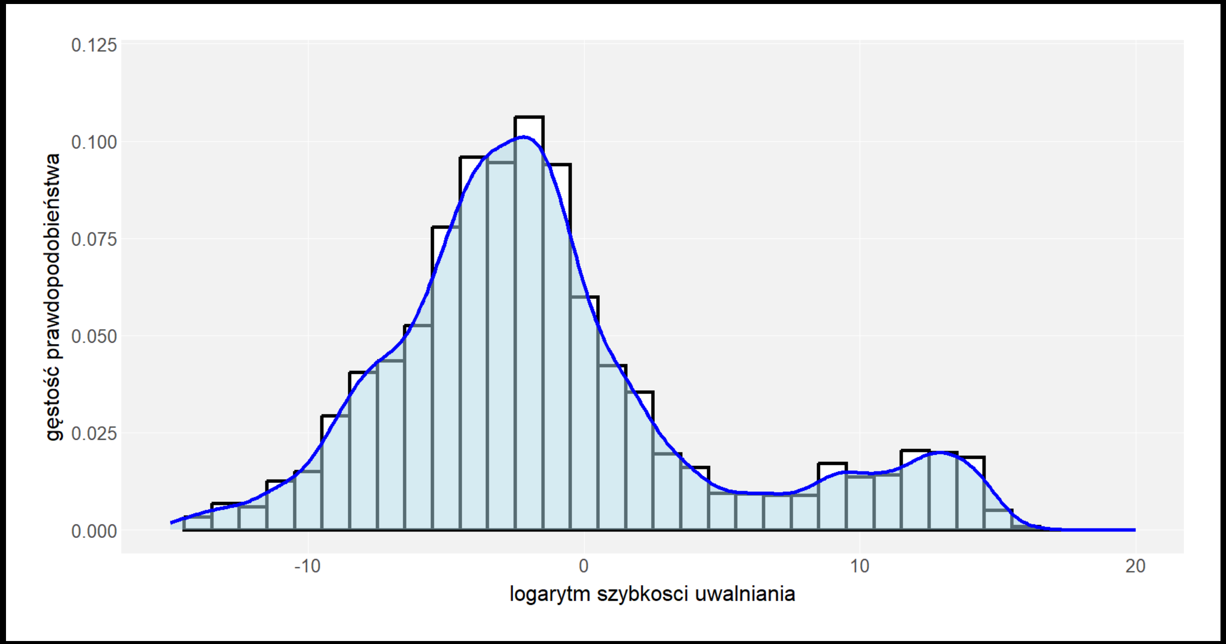


Silesia

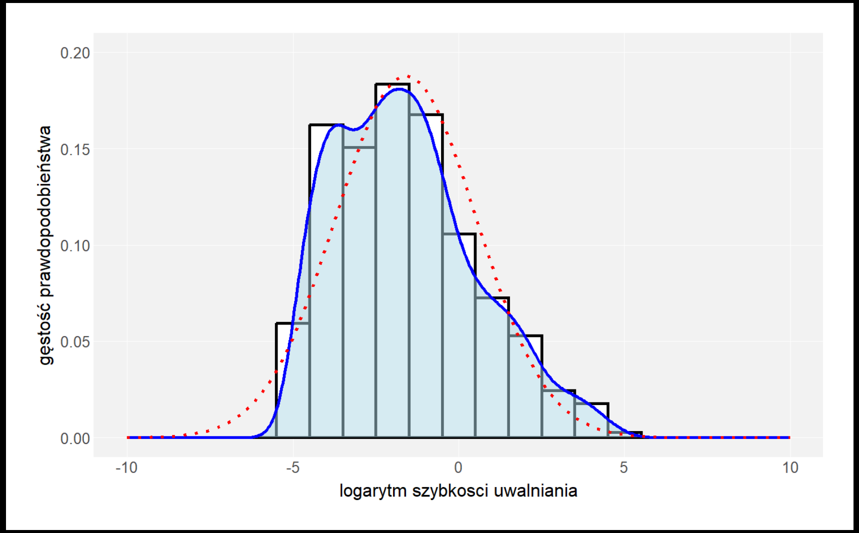
NG distribution
min. 20kt/rok



Results (low pressure network in Katowice)

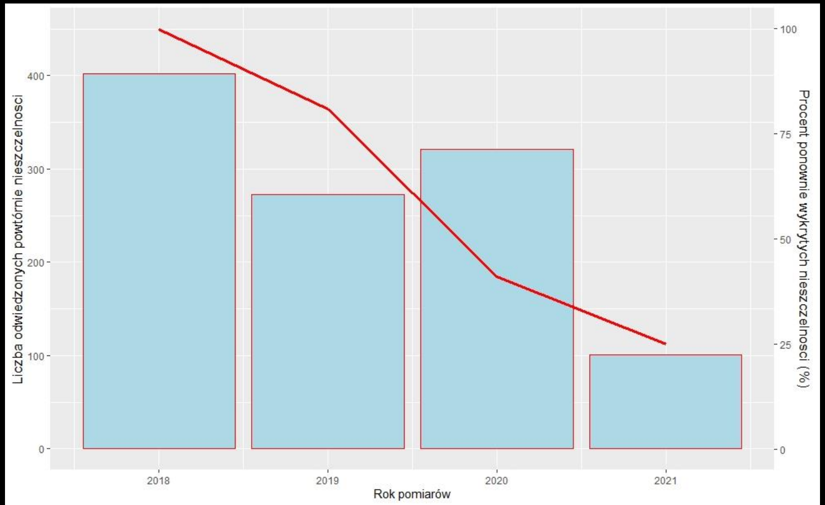


Rok badań	Średnia ilość zinwentaryzowanych wycieków gazu na 1km zbadanej drogi (szt./km)	Średnia roczna gęstość powierzchniowa strumienia metanu (kg/km^2)	Średnia roczna emisja metanu na 1km sieci gazowej dystrybucyjnej (kg/km)
2018	6.1 ± 2.3	1840	370
2019	8.3 ± 1.9	2390	480
2020	14.0 ± 5.4	3500	700
2021	10.7 ± 3.8	2900	590

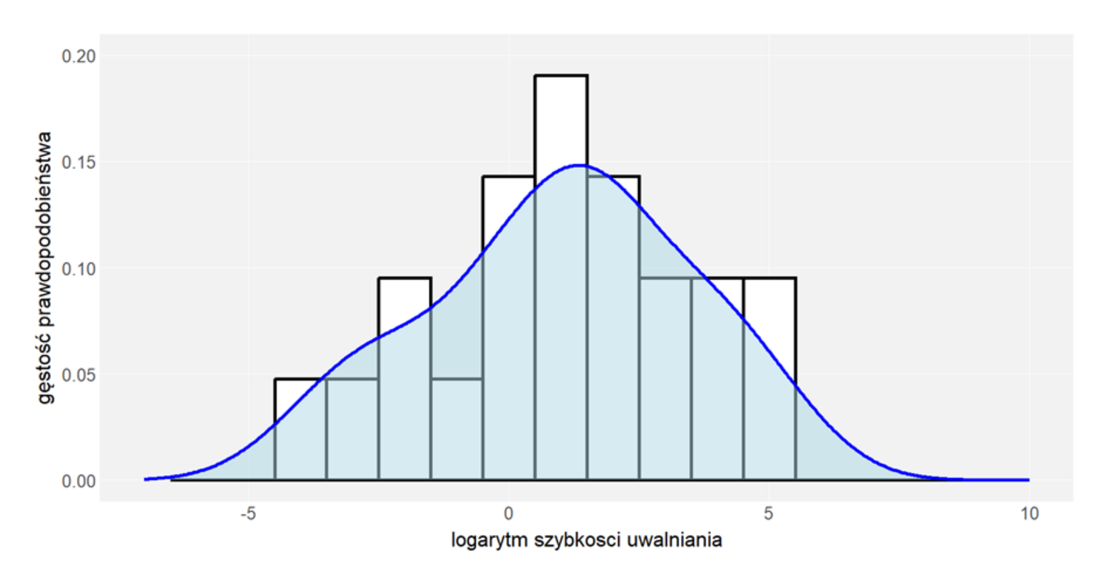


Katowice
Min. 300 t CH_4 per year

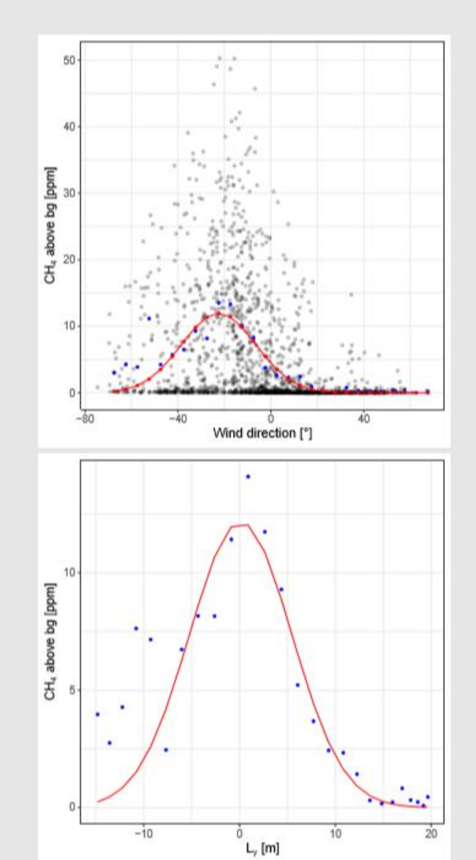
GOP – min. 9 kt CH_4 per year
(approx. 55 mln PLN)
90% of emission comes from
10% of the largest leaks



Results (pressure reduction stations)

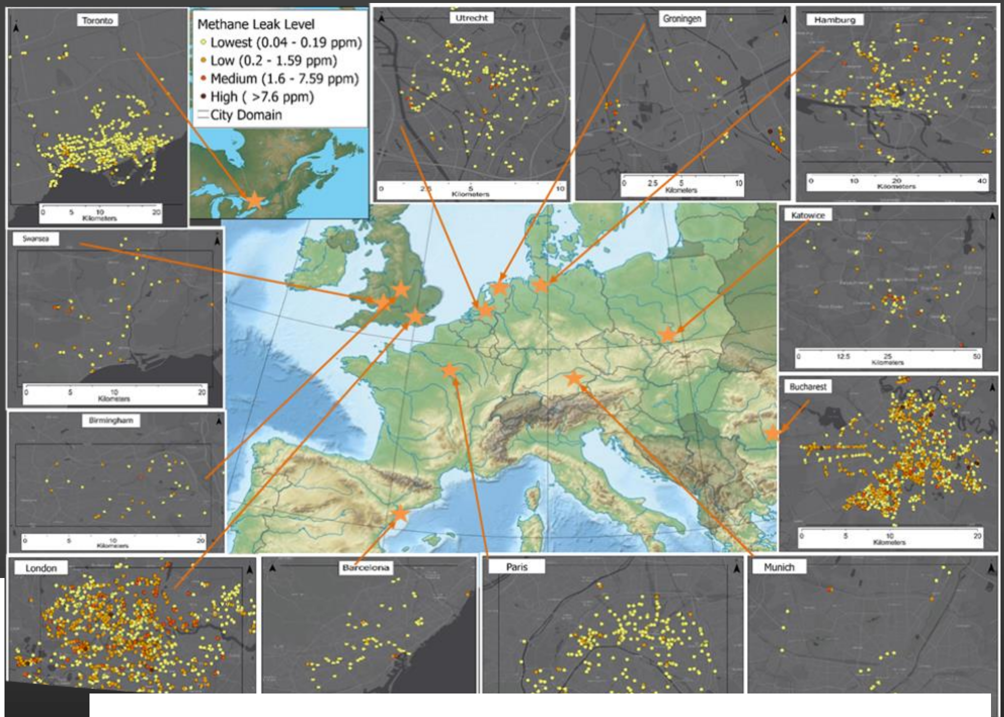


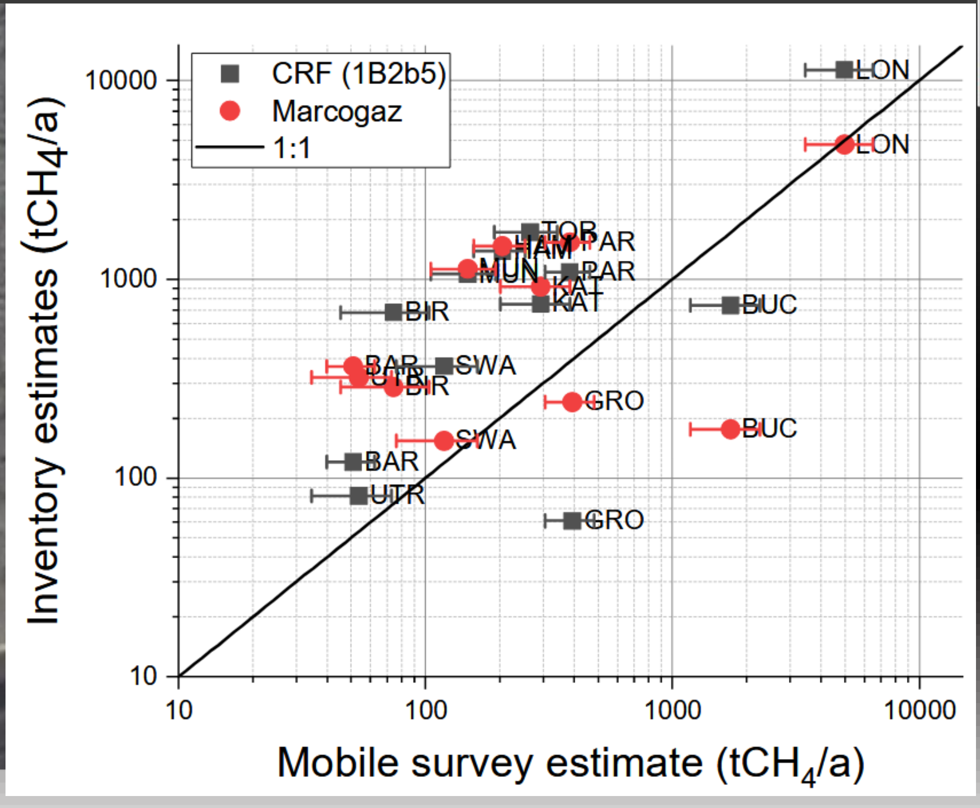
Katowice - 26 checked PRS,
Single emission max. 2 t CH_4 per year
Total emission min 4 t CH_4 per year

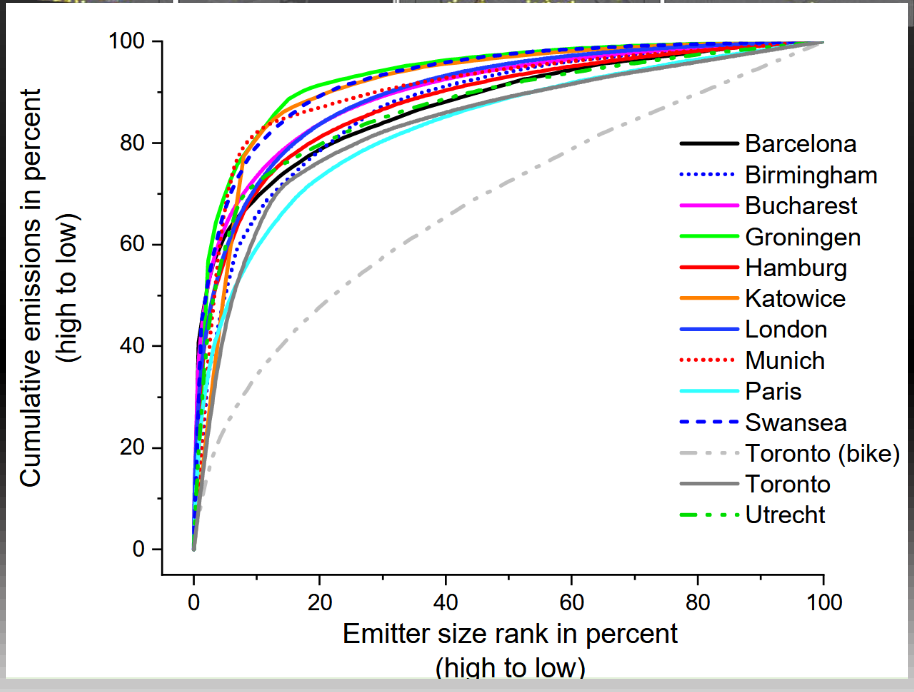


GOP – 336 PRS in total release min 4 t possibly up to 18 kt methane per year.
Expected value is 300 t CH_4 per year – 2 000 000 PLN.

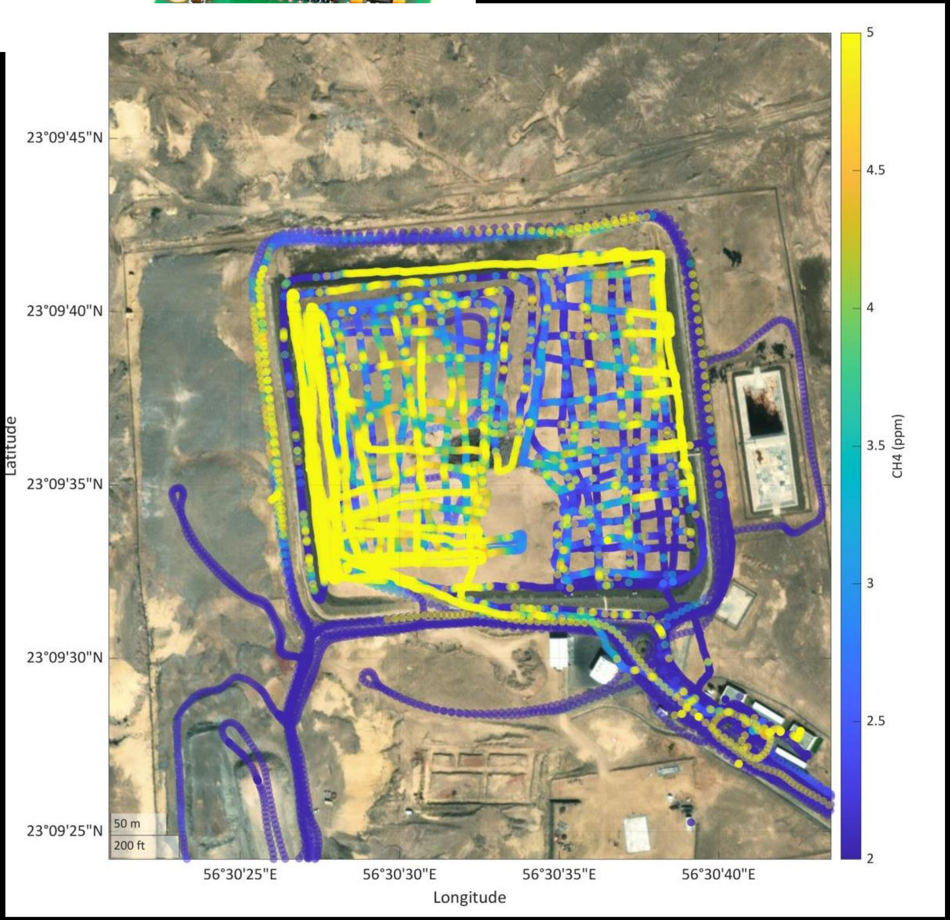
Other cities

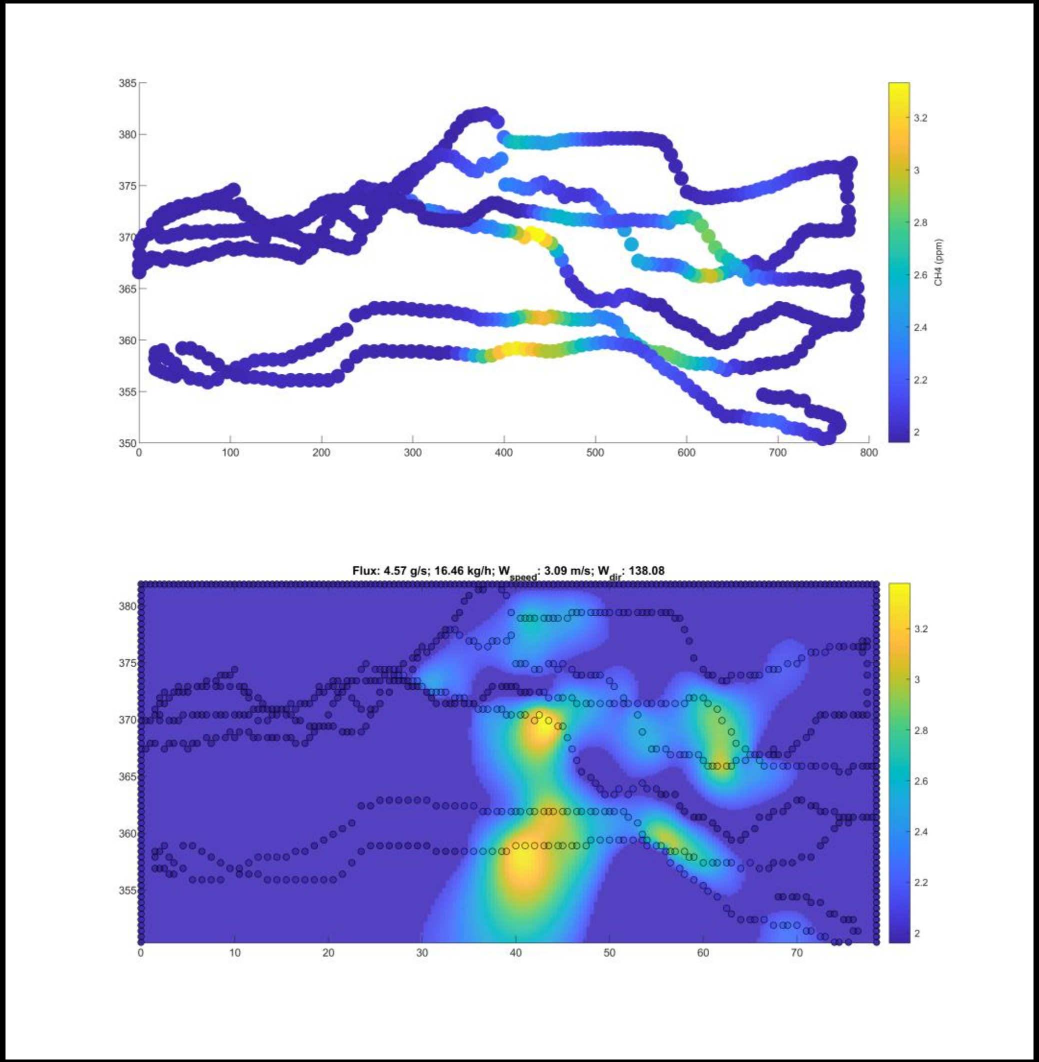


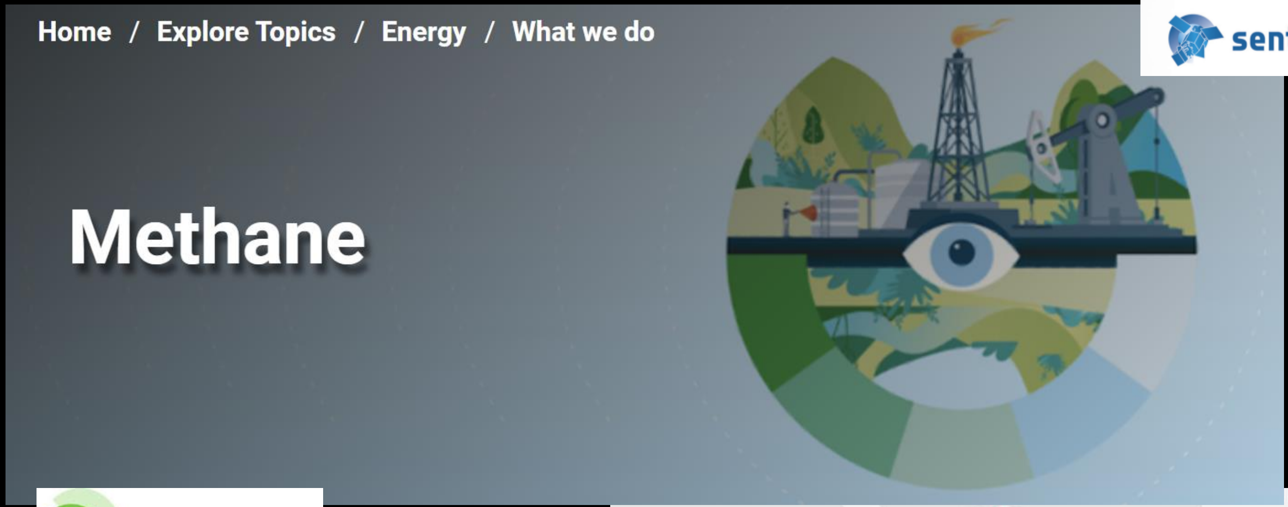




Budget analysers: Axetris TDLAS

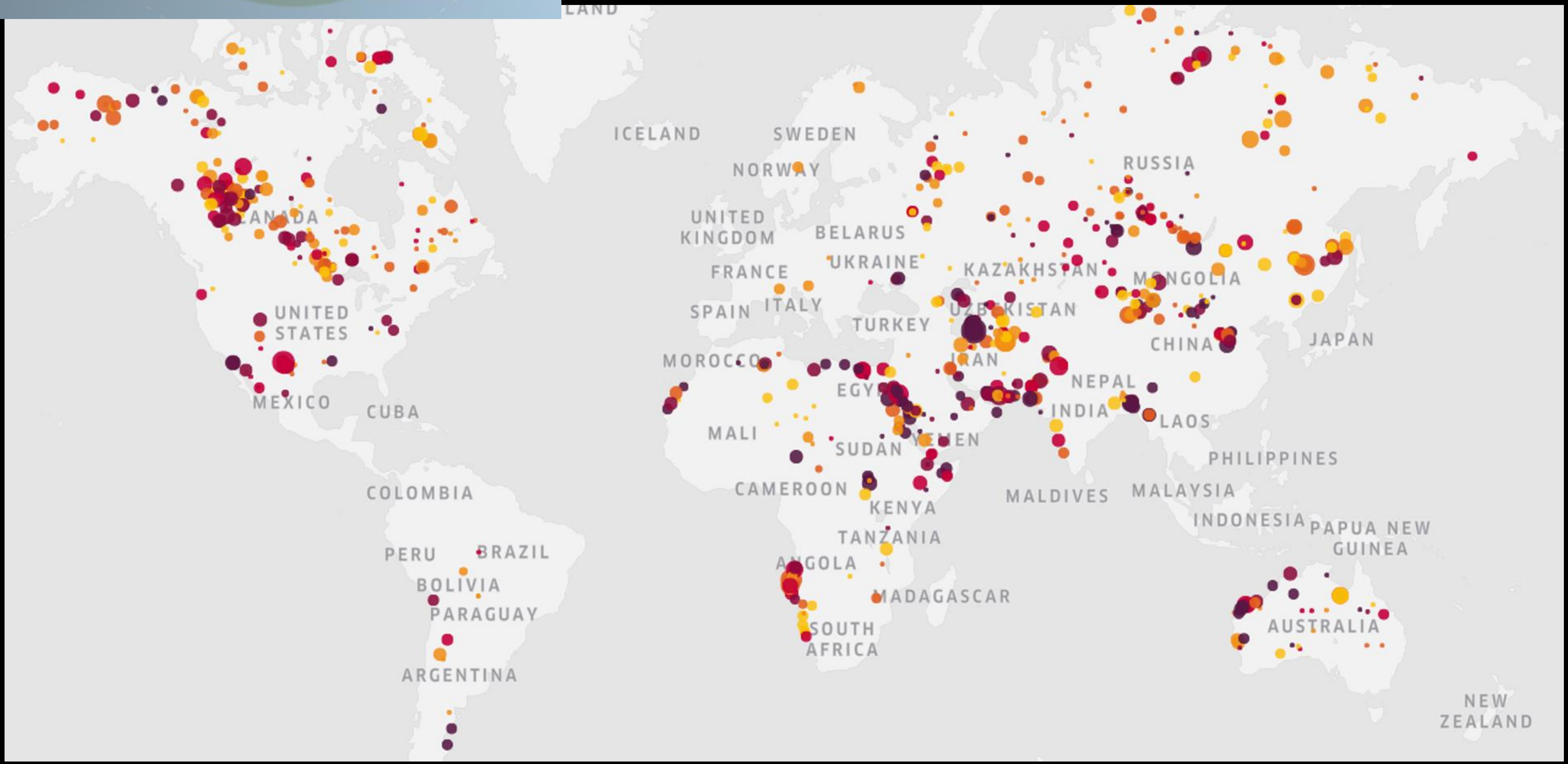




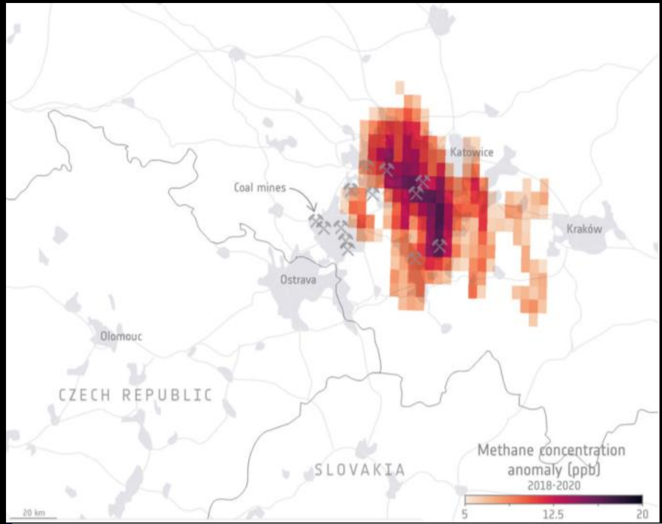


sentinel-5p

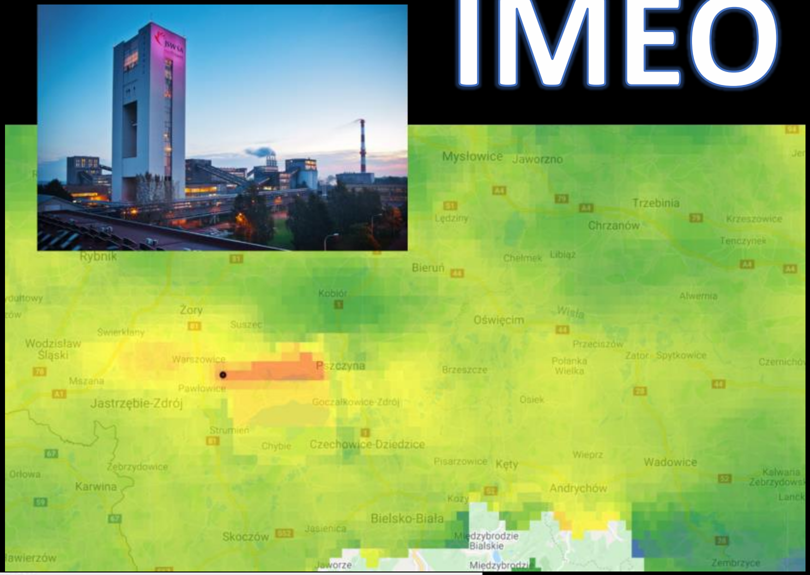
GHGSAT



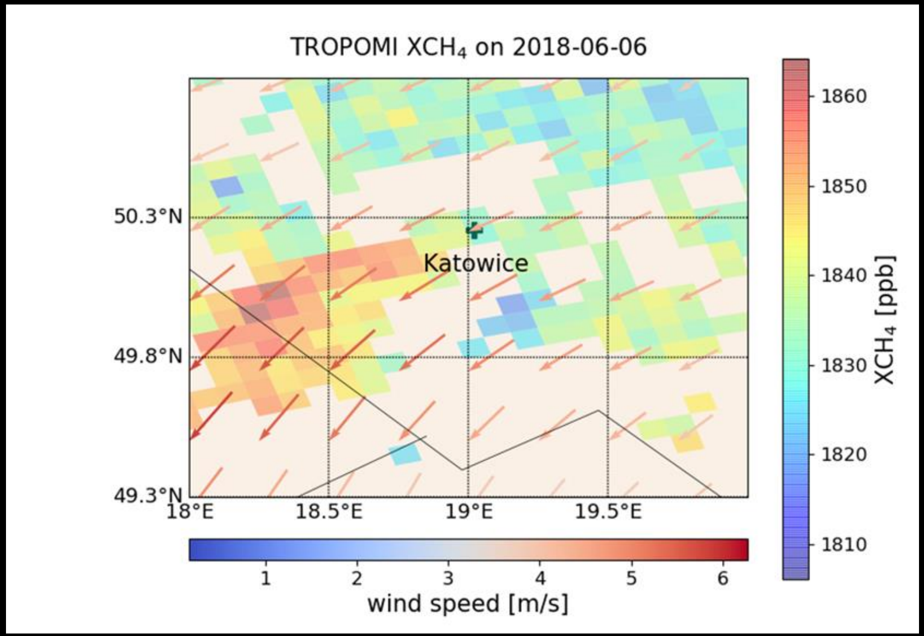
IMEO



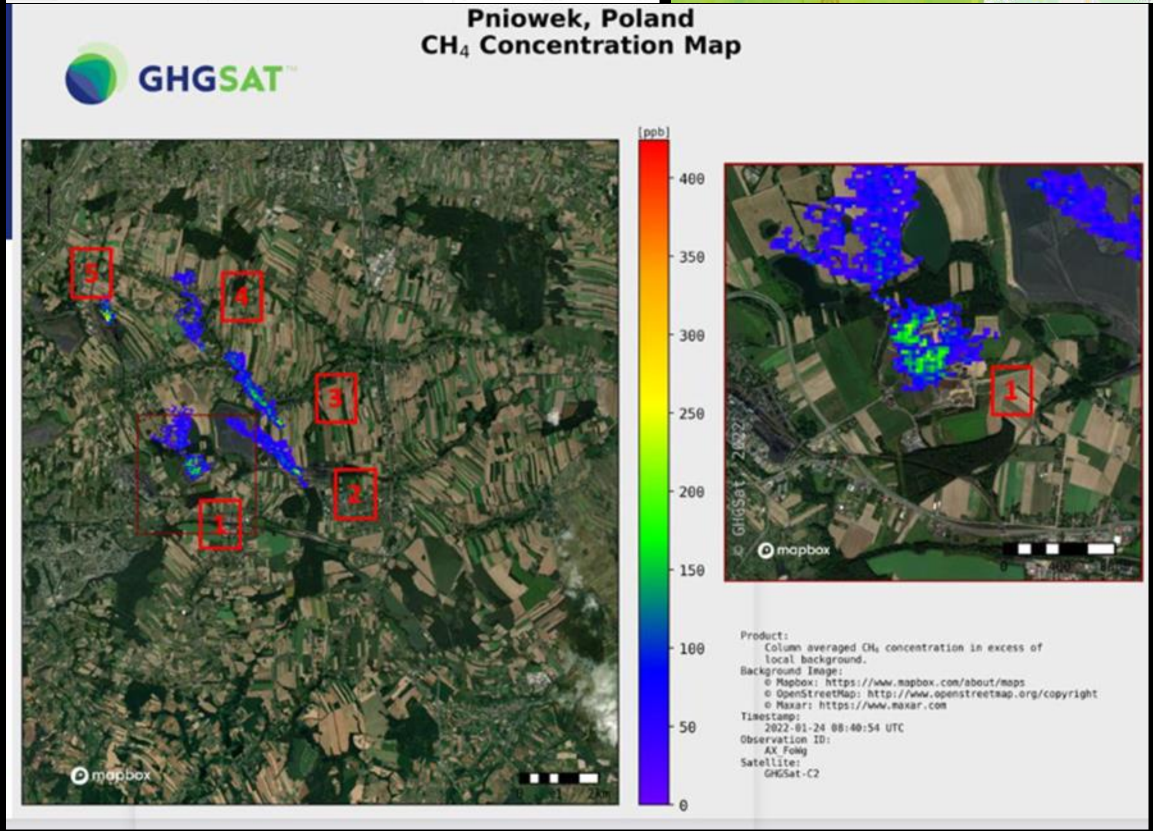
Katowice
Coal mines
Kraków
Ostrava
Olomouc
CZECH REPUBLIC
SLOVAKIA
Methane concentration anomaly (ppb)
2018-2020
5
12.5
20
20 km



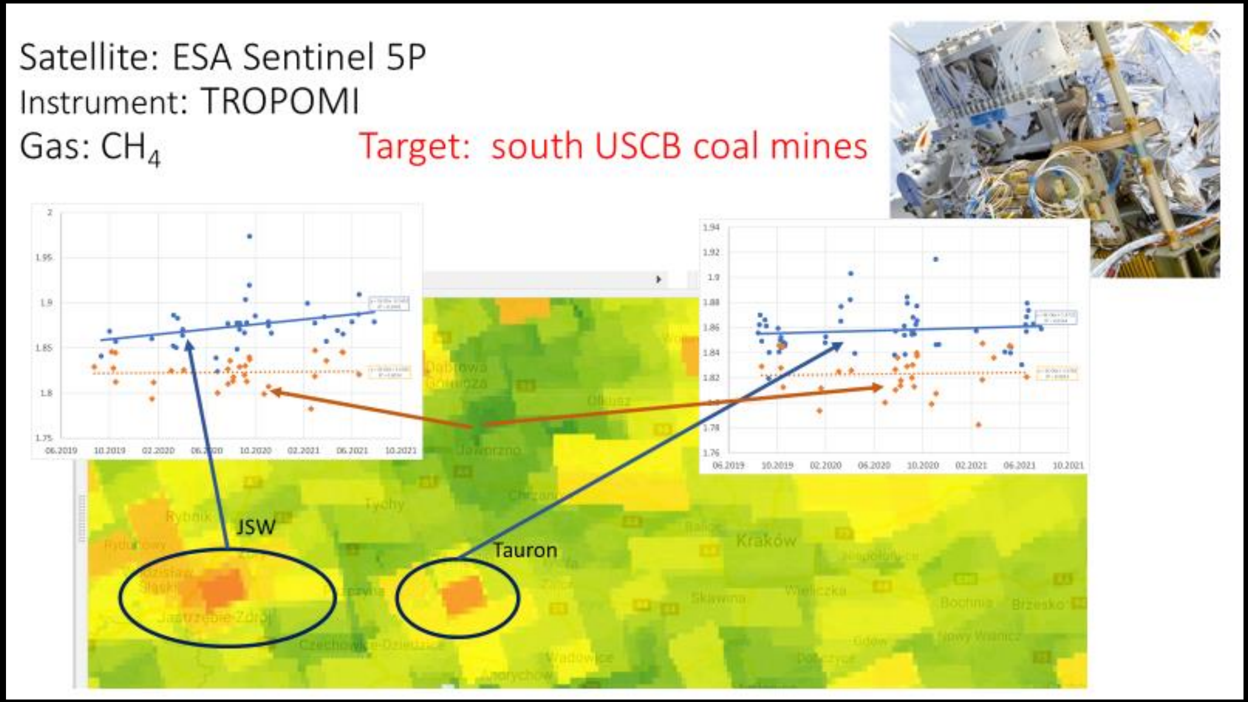
Mysłowice
Jaworzno
Trzebinia
Chrzanów
Rybnik
Bieruń
Żory
Oświęcim
Wodzisław Śląski
Pszczyna
Jastrzębie-Zdrój
Czechowice-Dziedzice
Karwina
Wadowice
Andrychów
Bielsko-Biała
Skoczów



TROPOMI XCH4 on 2018-06-06
50.3°N
49.8°N
49.3°N
18°E
18.5°E
19°E
19.5°E
Katowice
1860
1850
1840
1830
1820
1810
XCH4 [ppb]
1
2
3
4
5
6
wind speed [m/s]

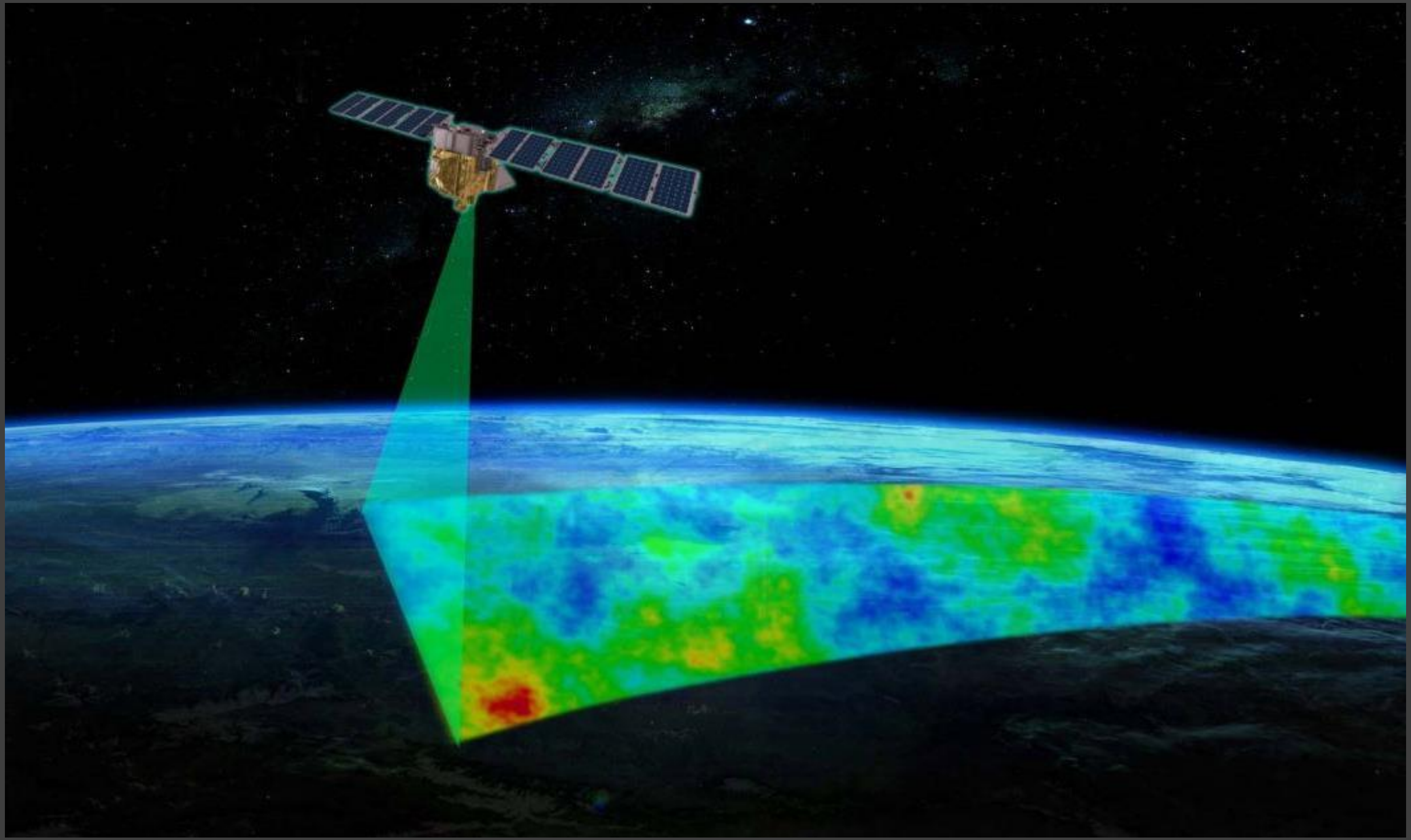


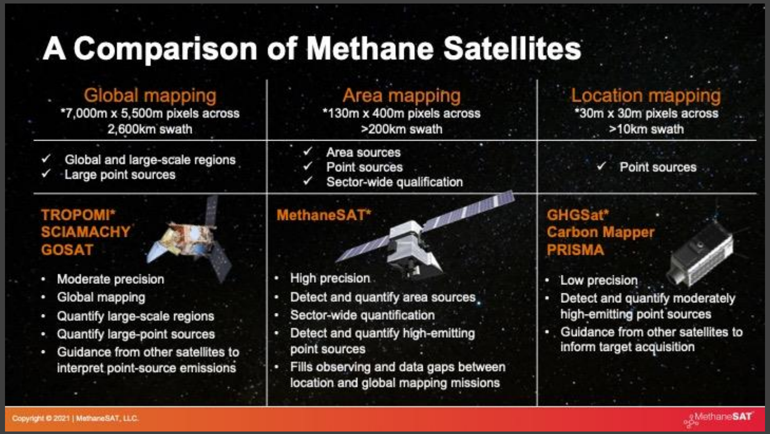
Pniowek, Poland
CH4 Concentration Map
GHGSAT
[ppb]
400
350
300
250
200
150
100
50
0
1
2
3
4
5
mapbox
Product:
Column averaged CH4 concentration in excess of local background.
Background Image:
© Mapbox: https://www.mapbox.com/about/maps
© OpenStreetMap: http://www.openstreetmap.org/copyright
© Maxar: https://www.maxar.com
Timestamp:
2022-01-24 08:40:54 UTC
Observation ID:
AX_FoWg
Satellite:
GHGSat-C2



Satellite: ESA Sentinel 5P
Instrument: TROPOMI
Gas: CH4
Target: south USCB coal mines
JSW
Tauron
Rybnik
Jastrzębie-Zdrój
Kraków

MethaneSAT™




A Comparison of Methane Satellites
Global mapping
*7,000m x 5,500m pixels across 2,600km swath
✓ Global and large-scale regions
✓ Large point sources
TROPOMI* SCIAMACHY GOSAT
• Moderate precision
• Global mapping
• Quantify large-scale regions
• Quantify large-point sources
• Guidance from other satellites to interpret point-source emissions
Area mapping
*130m x 400m pixels across >200km swath
✓ Area sources
✓ Point sources
✓ Sector-wide qualification
MethaneSAT*
• High precision
• Detect and quantify area sources
• Sector-wide quantification
• Detect and quantify high-emitting point sources
• Fills observing and data gaps between location and global mapping missions
Location mapping
*30m x 30m pixels across >10km swath
✓ Point sources
GHGSat* Carbon Mapper PRISMA
• Low precision
• Detect and quantify moderately high-emitting point sources
• Guidance from other satellites to inform target acquisition
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