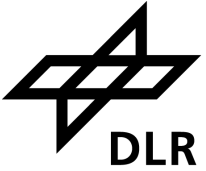


CORRELATED ALBEDO AND ELEVATION VARIABILITY LEADING TO RETRIEVAL ARTEFACTS

Julia Marshall and Theo Glauch, following helpful discussions with Chris O'Dell,
Michael Buchwitz, and Michael Weimer



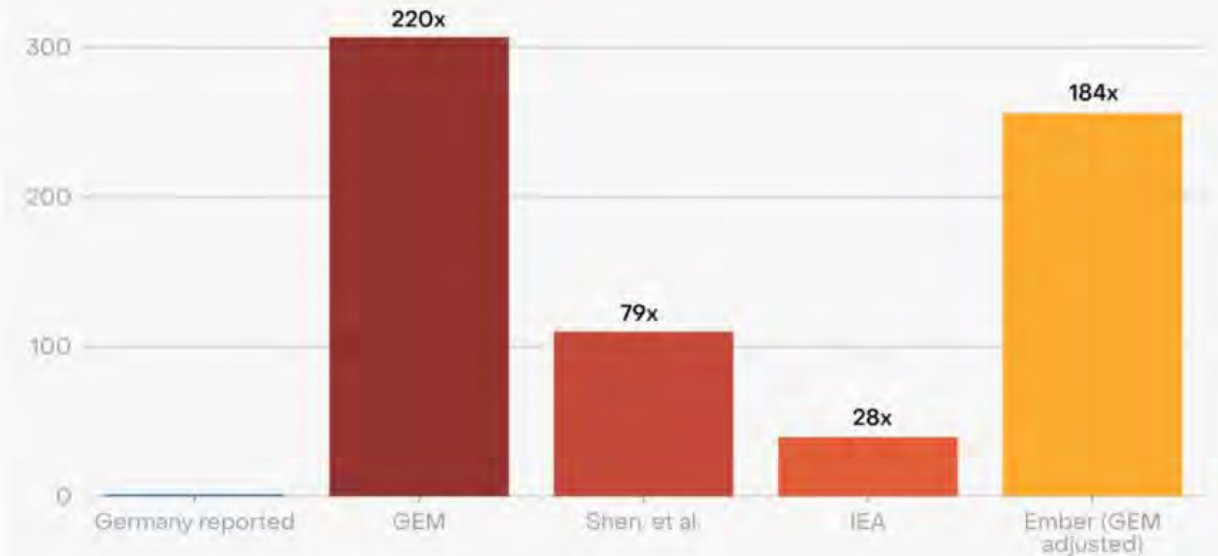
Motivation: report suggesting that Germany was grossly underreporting its methane emissions from coal mines



- Commissioned by a non-profit environmental group, the report was released the same week as the national emissions reporting
- The emission factor used for the open-pit lignite mines is 75 times lower than the IPCC default value
- Satellite measurements – also through an inversion study – were used as one line of evidence

Germany's coal mine methane emissions estimated to be between 28 - 200 times larger than reported

Coal mine methane emissions (thousand tonnes)



Source: Shen et al. (2023), International Energy Agency (IEA), Global Energy Monitor (GEM)

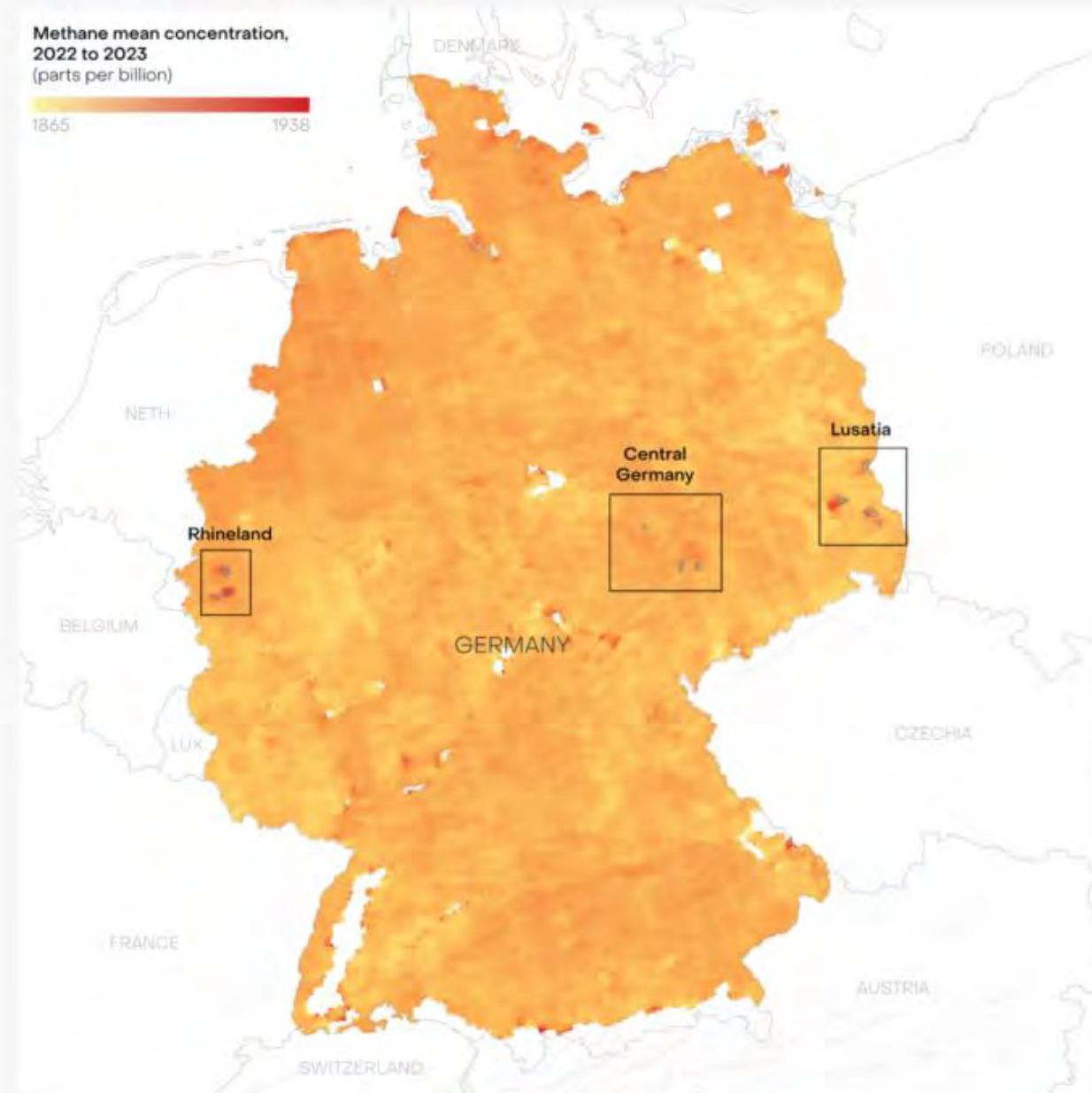
EMBER

[Urgency to update Germany's coal mine methane emission factor | Ember](#)

Seen by TROPOMI?

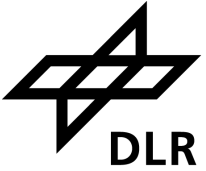
- When averaging over all good soundings from 2022-2023, they found that some hot spots – including the open-pit coal regions – pop out

Methane from coal mines visible from space



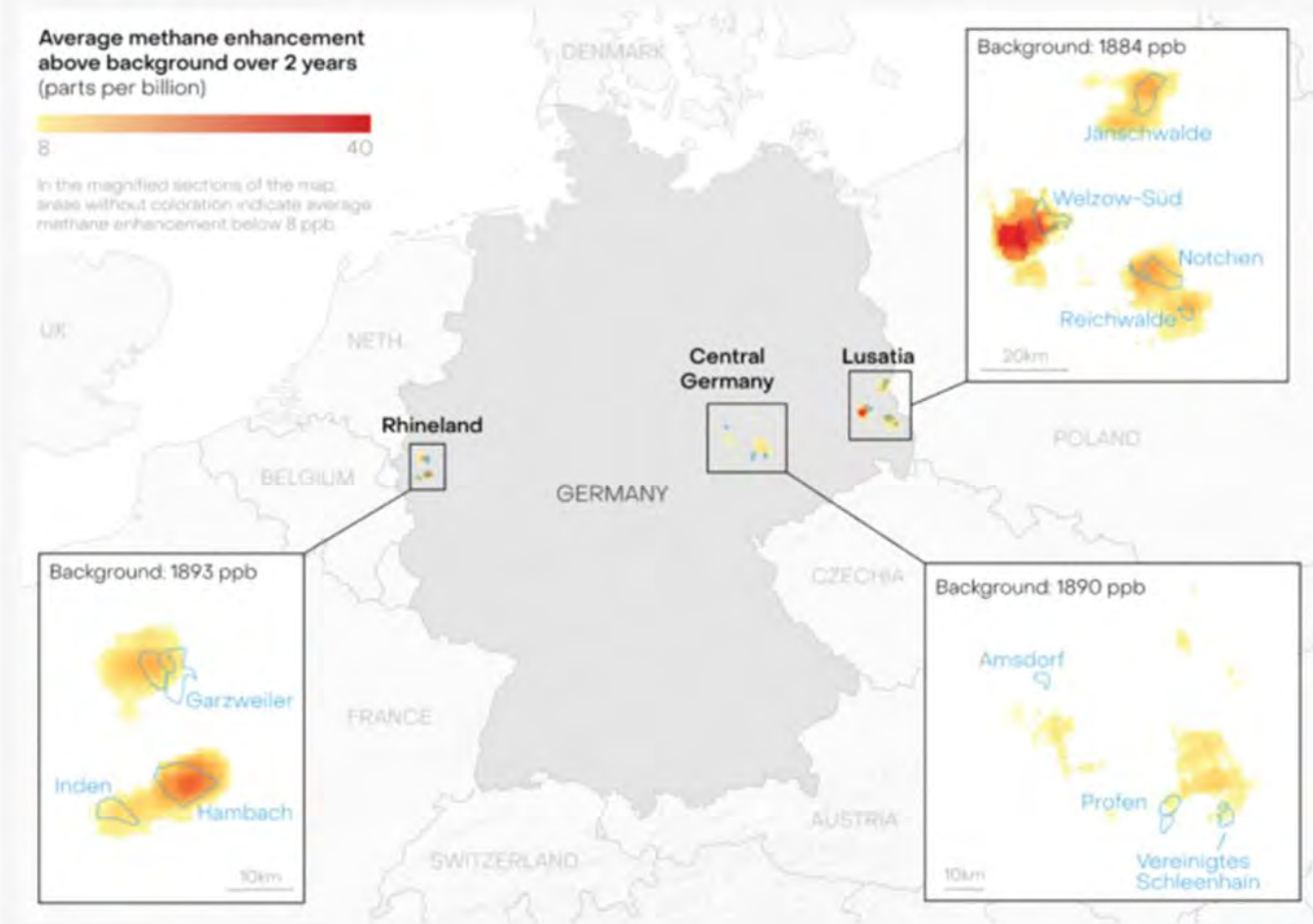
Source: Ember

Seen by TROPOMI?

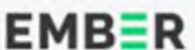


- When averaging over all good soundings from 2022-2023, they found that some hot spots – including the open-pit coal regions – pop out
- Regional enhancements are quite substantial
- This shows up in both the operational SRON product and the WFMD retrieval from IUP-Bremen (v1.8, [Schneising et al., 2023](#))

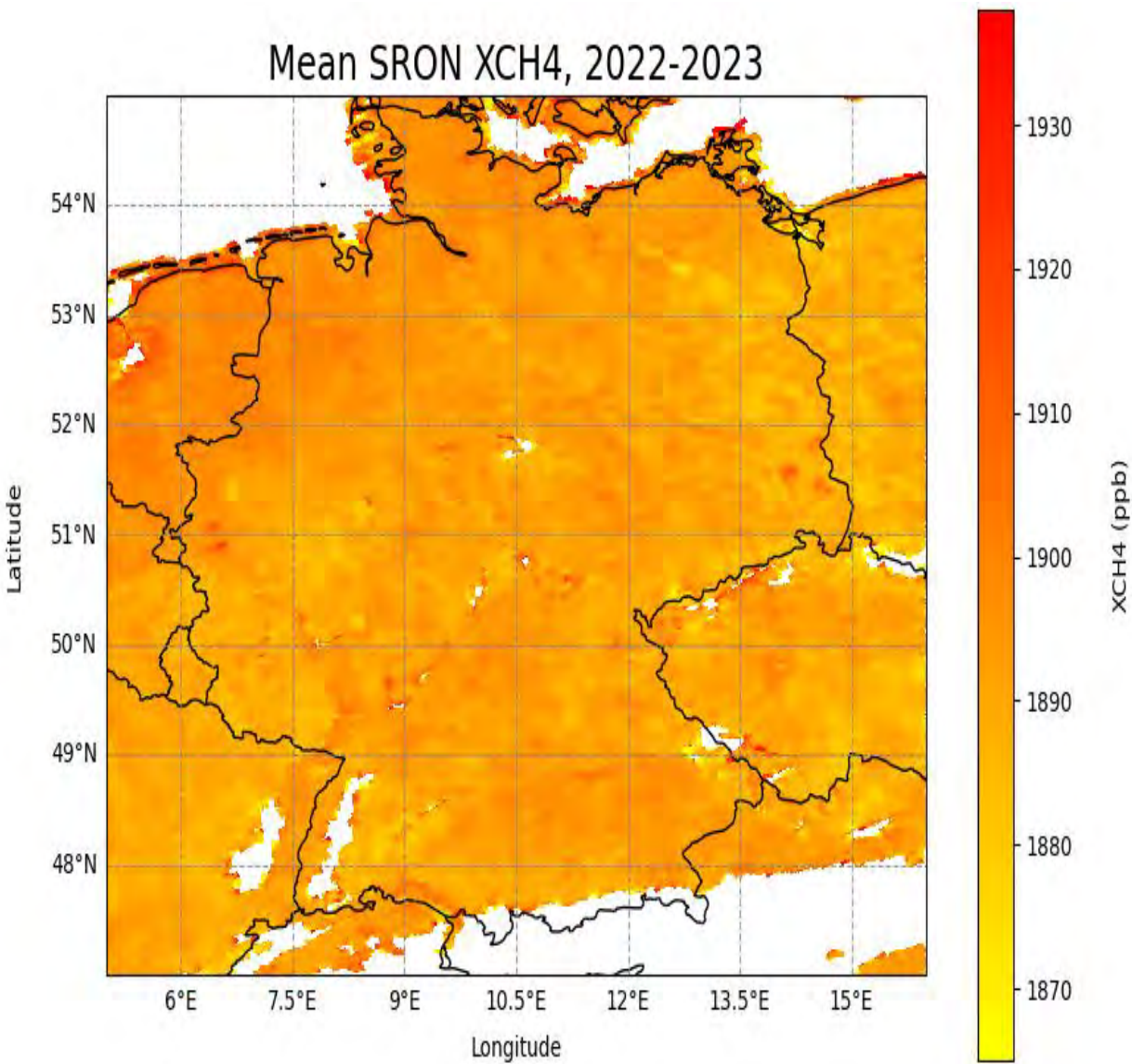
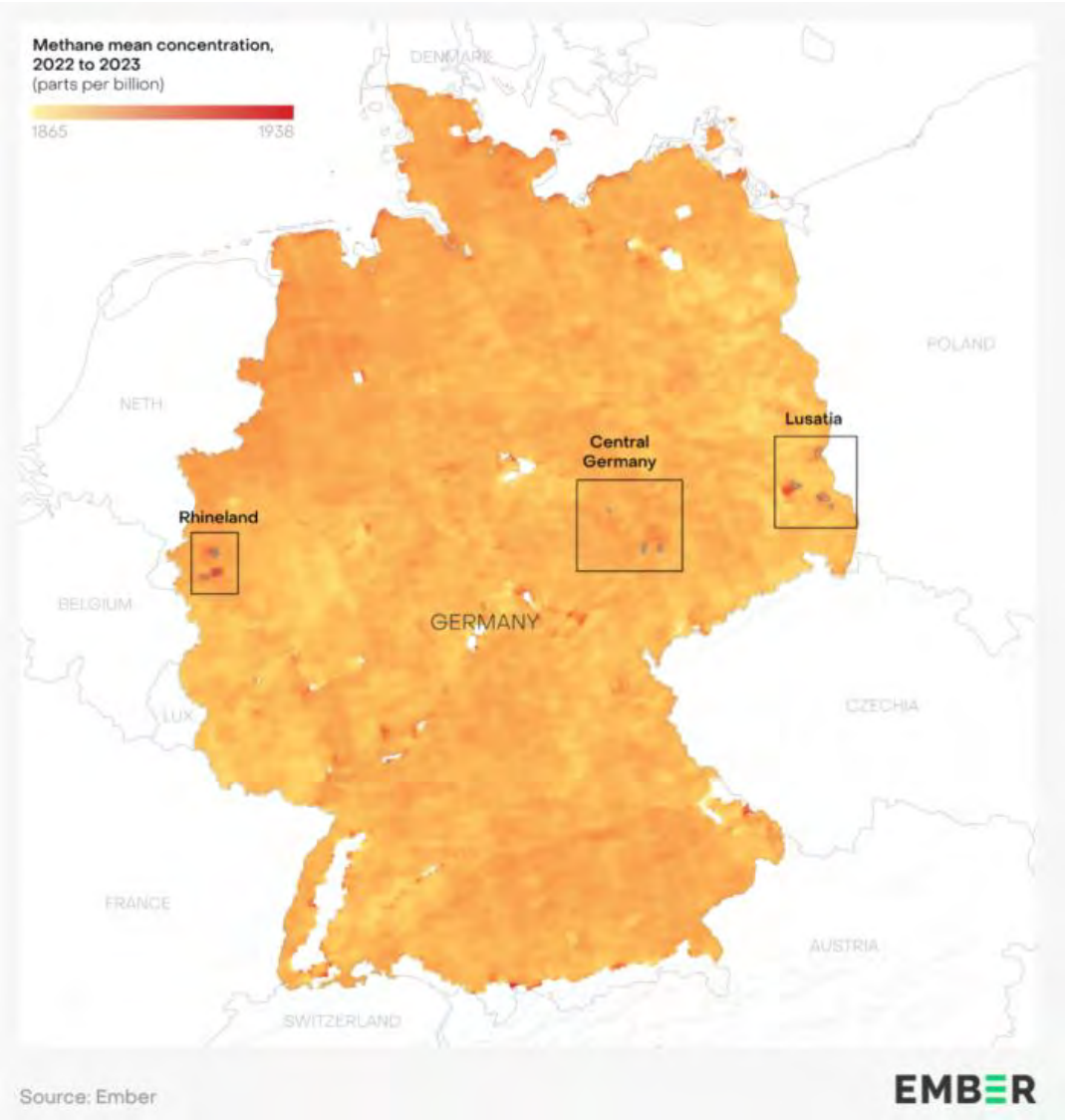
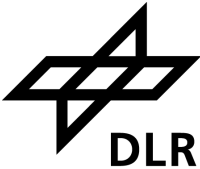
Methane enhancements over Germany's active coal mining regions



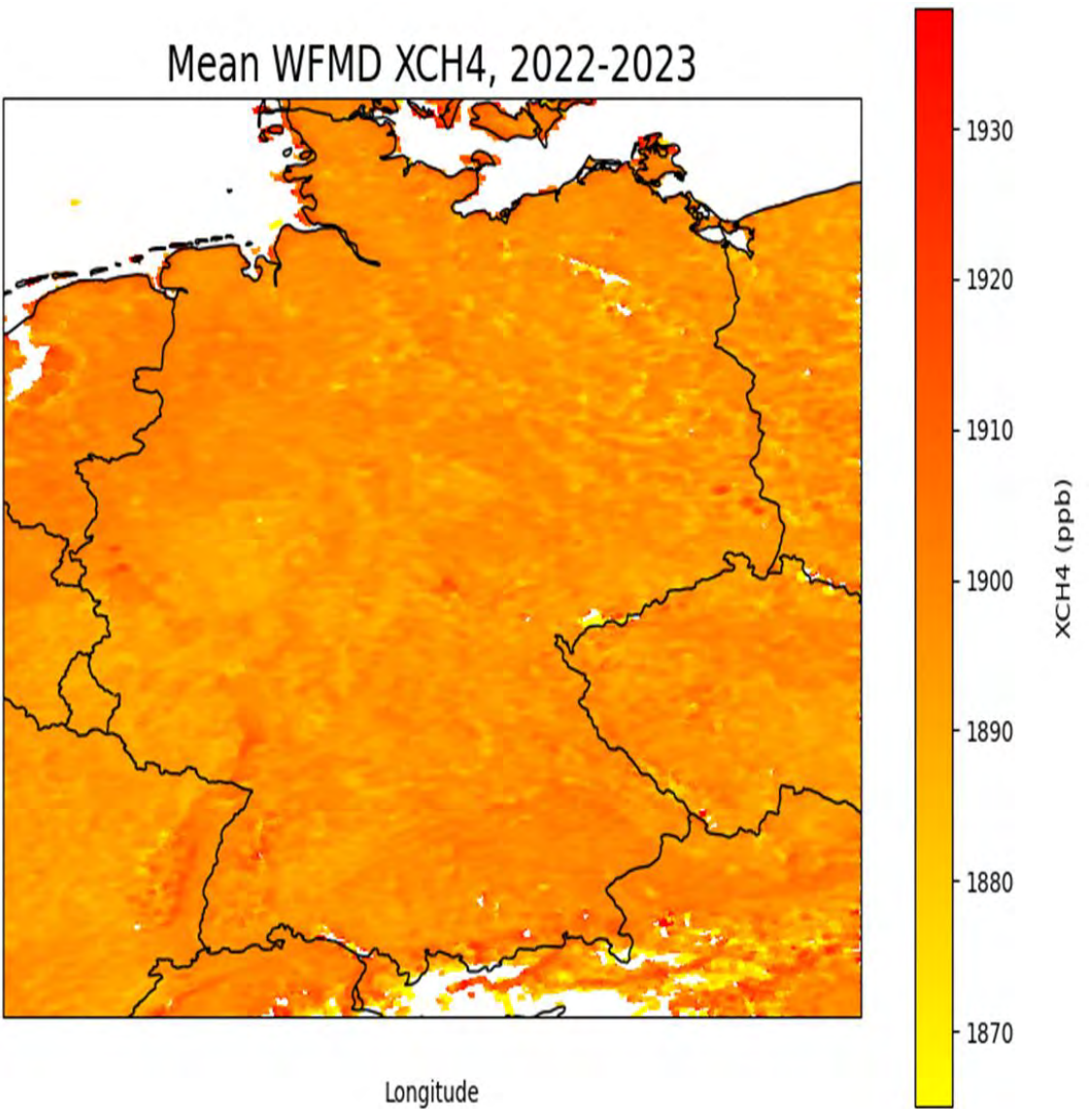
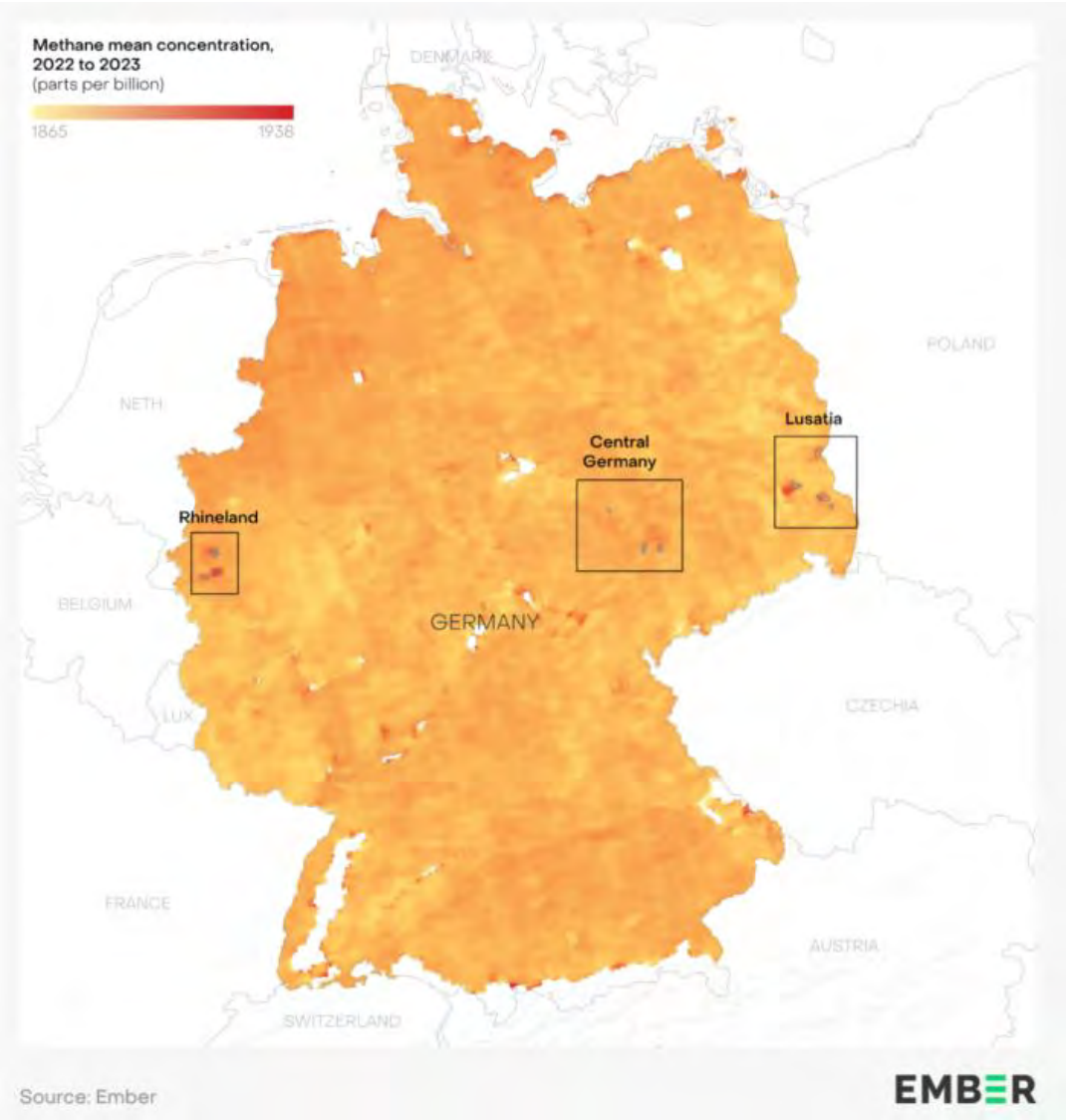
Source: Ember



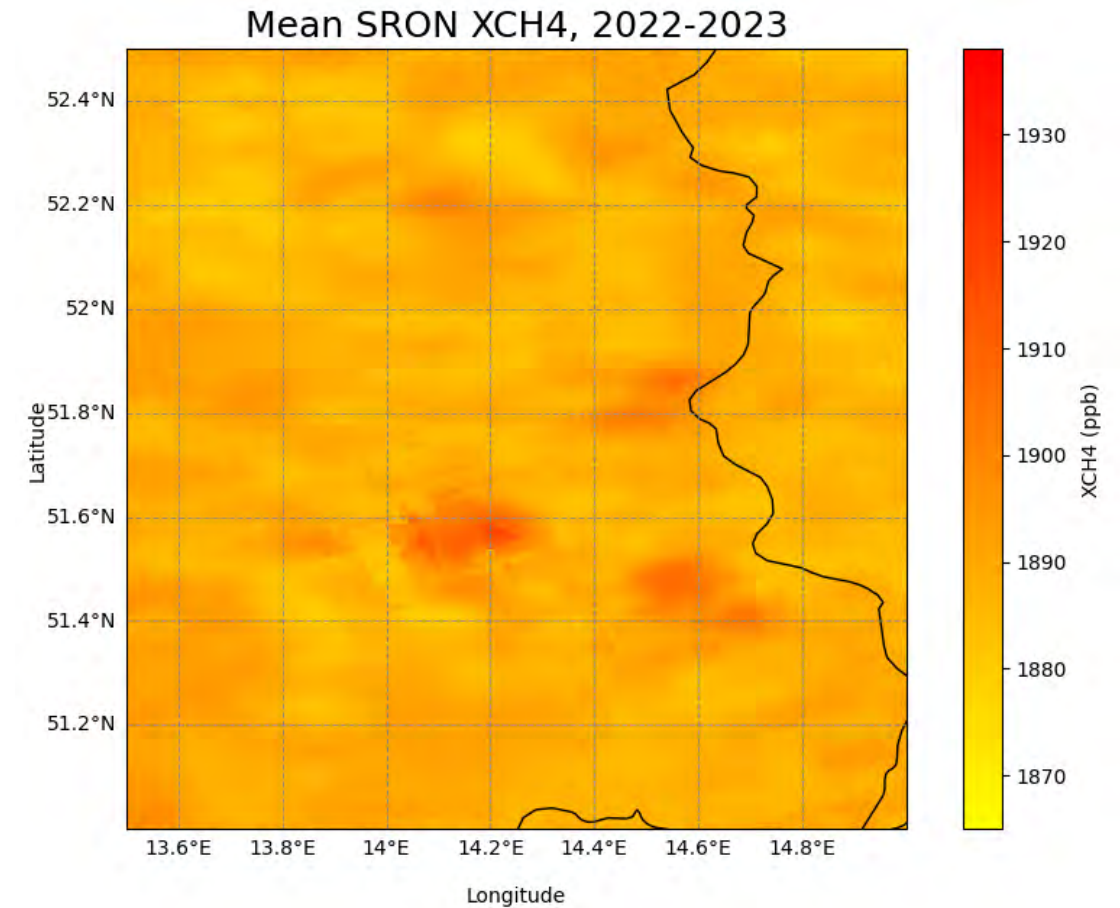
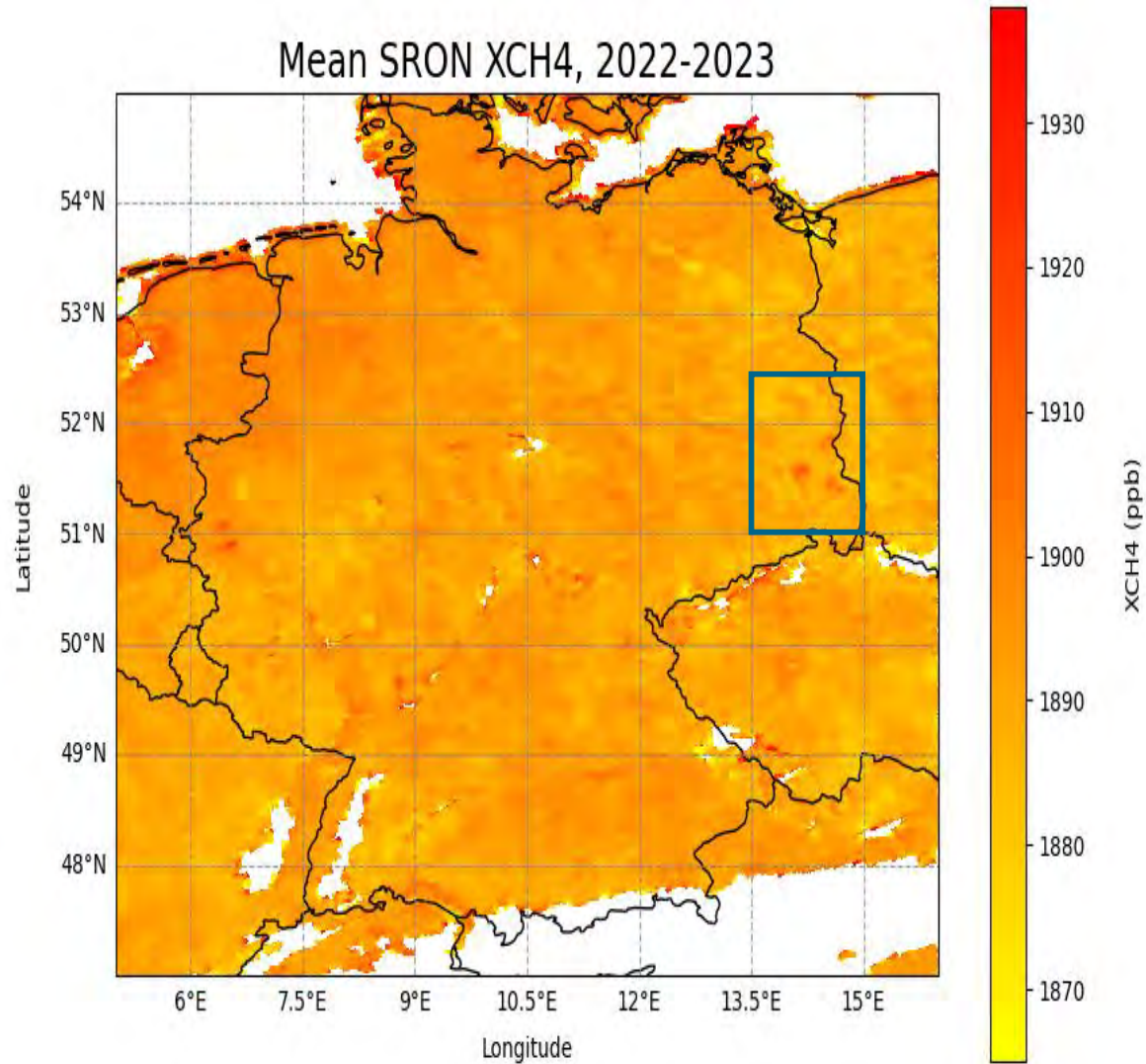
Seen by TROPOMI?



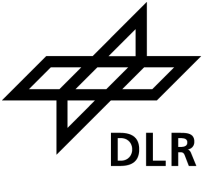
Seen by TROPOMI?



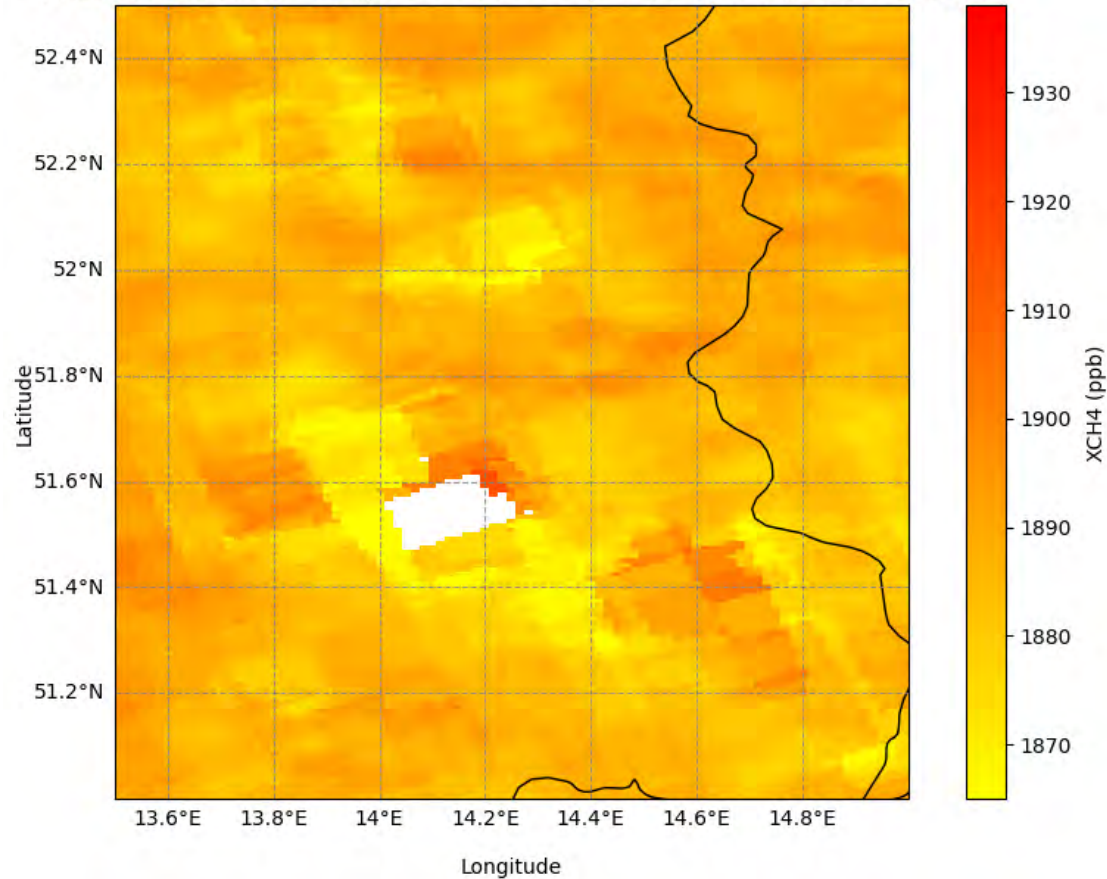
Do we see a plume?



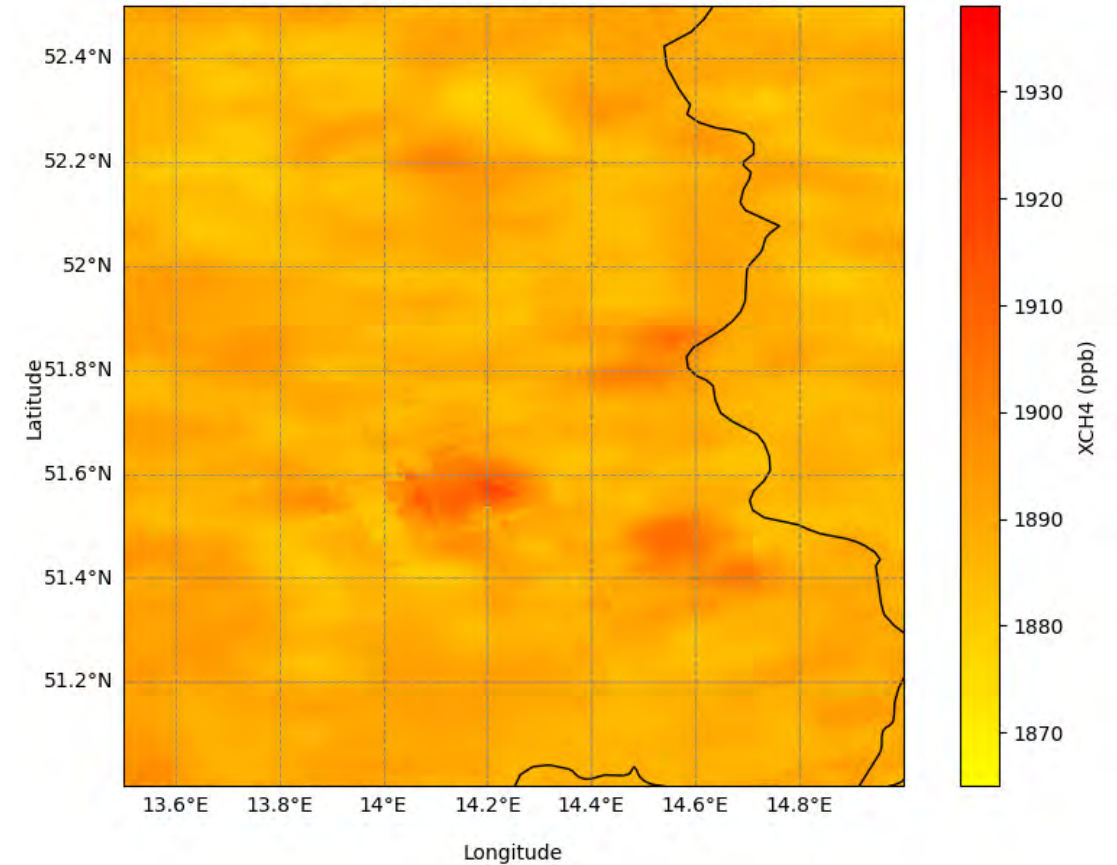
Do we see a plume?



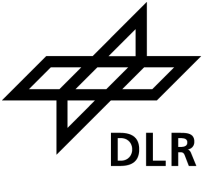
Mean SRON XCH₄, 2022-2023, wind from the south



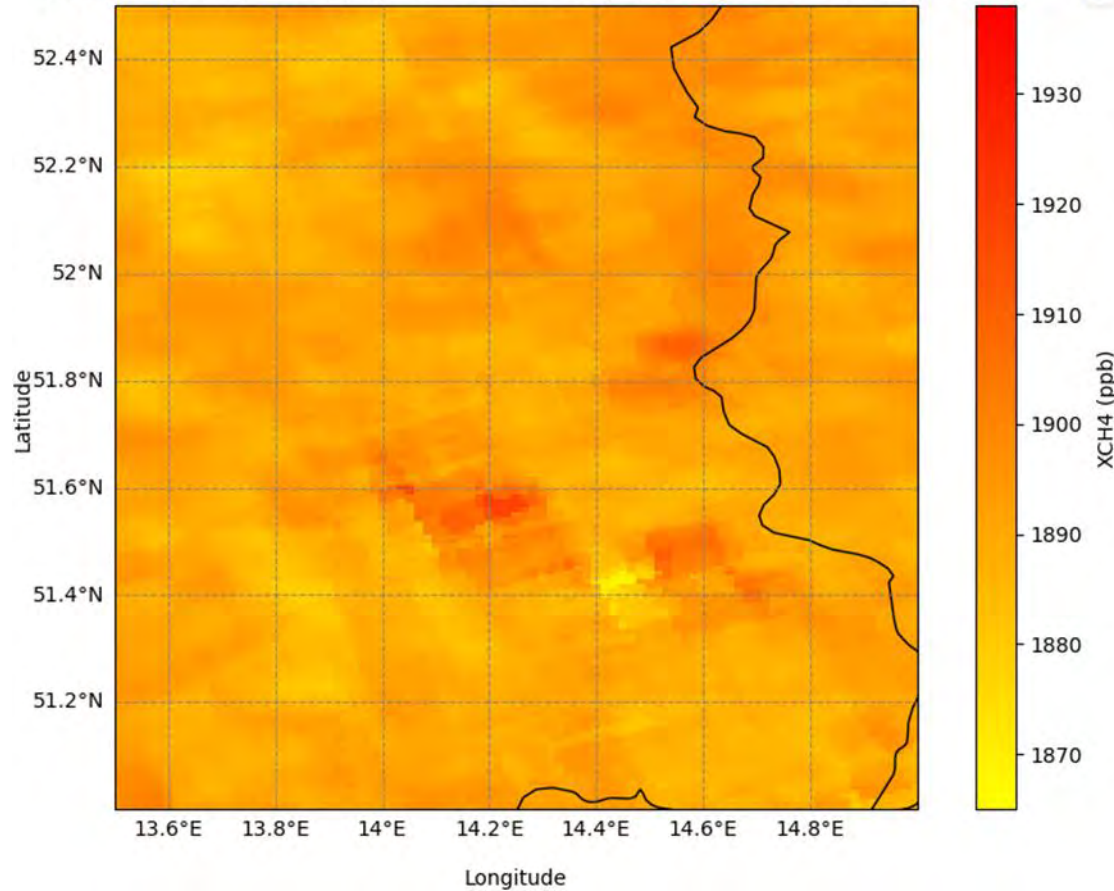
Mean SRON XCH₄, 2022-2023



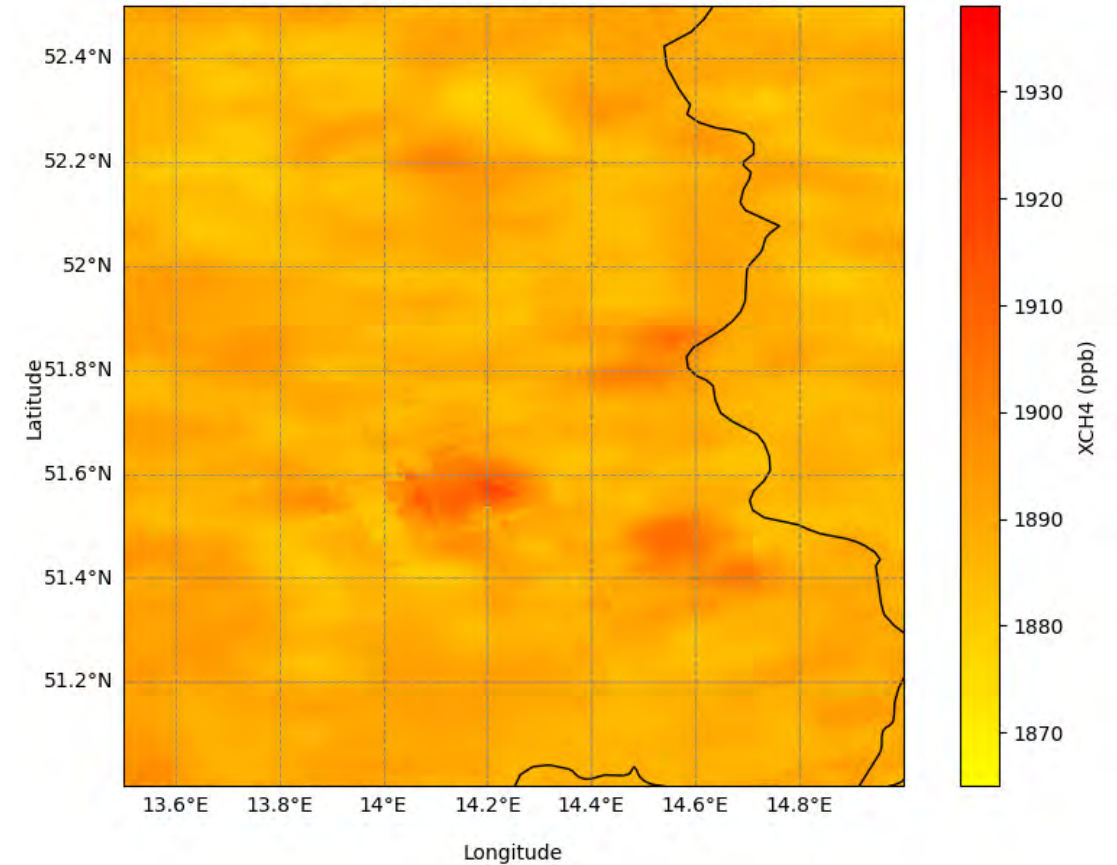
Do we see a plume?



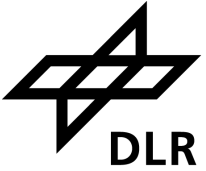
Mean SRON XCH₄, 2022-2023, wind from the west



Mean SRON XCH₄, 2022-2023



Do we see a plume?



EMBER

Addendum: Satellite sees Germany's CMM

The TROPOMI instrument onboard Sentinel-5P provides methane concentration measurements globally. Using Google Earth Engine, Ember calculated average methane concentrations from 2022–2023 from repeat daily overpasses.

The TROPOMI data indicated strong methane enhancements over the lignite mines. Further analysis by the SRON Netherlands Institute for Space Research found that the enhancements are caused by high surface reflectivity and are not correlated with wind direction. Due to this limitation, we cannot conclude how much methane is present over the mines using the TROPOMI data. Observations from other satellite sensors and ground-based observations would help to quantify this.

13.6°E 13.8°E 14°E 14.2°E 14.4°E 14.6°E 14.8°E

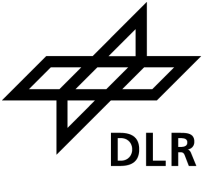
Longitude

Longitude

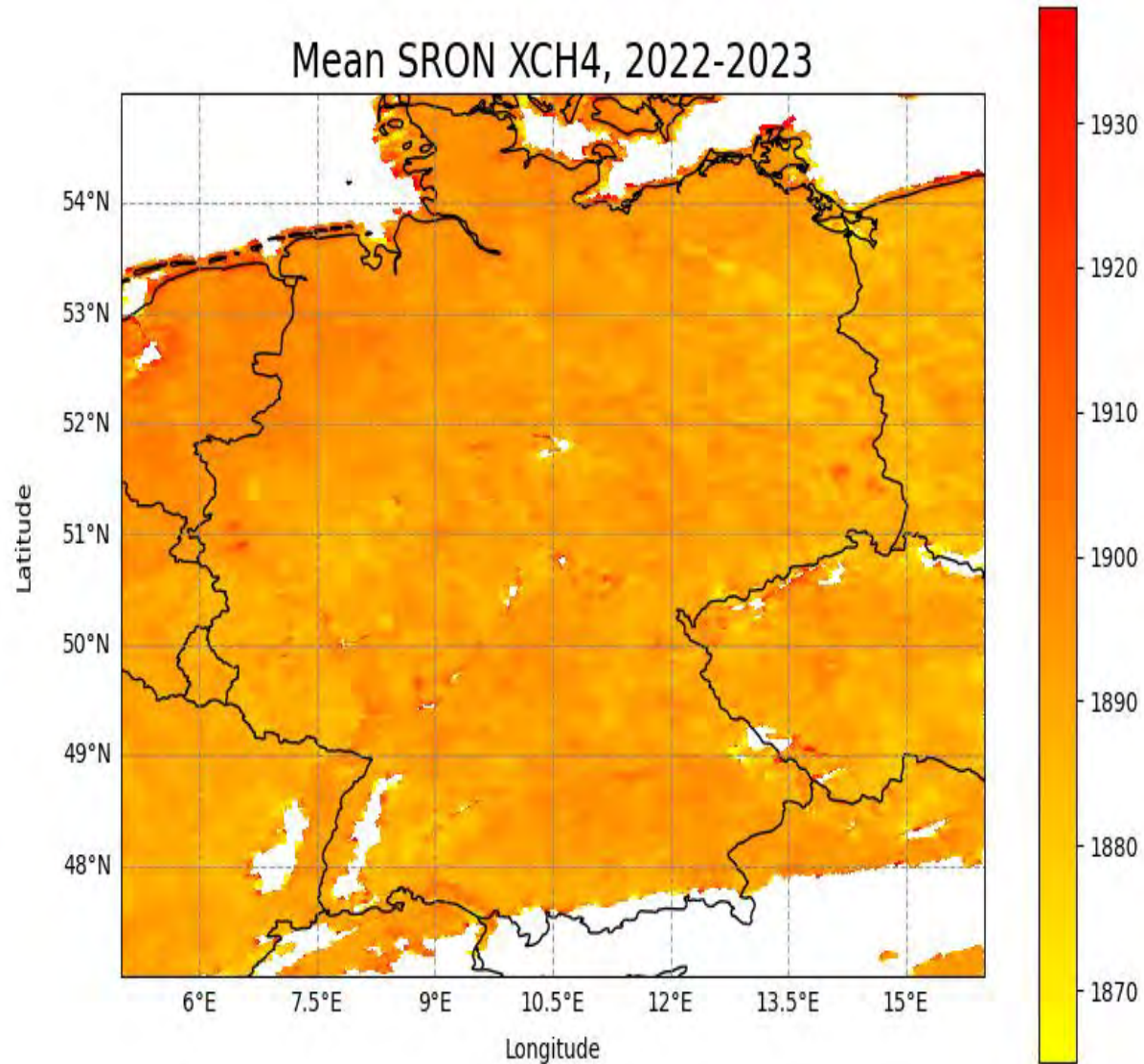
CH₄ (ppb)

30
20
10
0
30
30
70

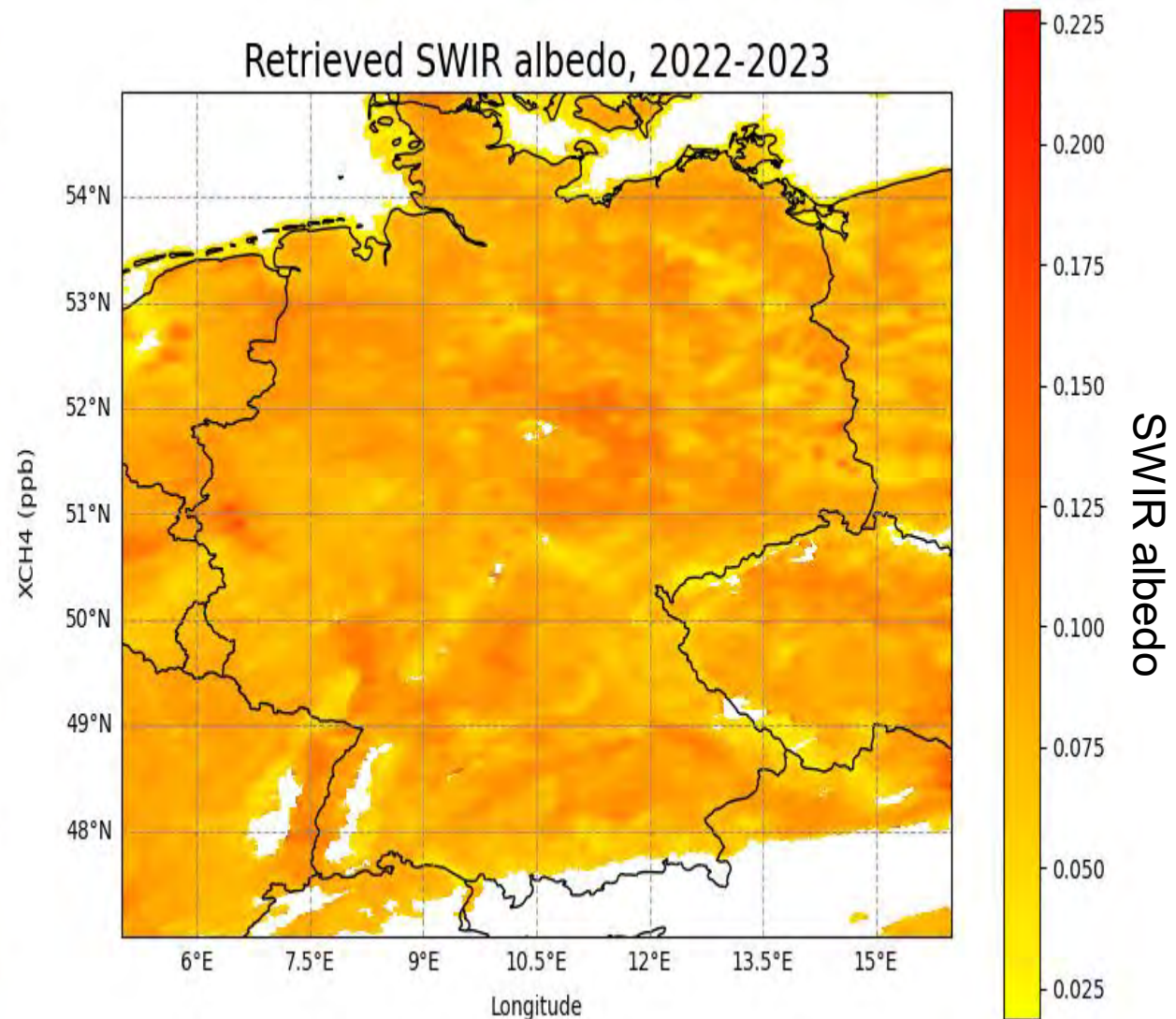
No plume – could it be albedo?



Mean SRON XCH4, 2022-2023



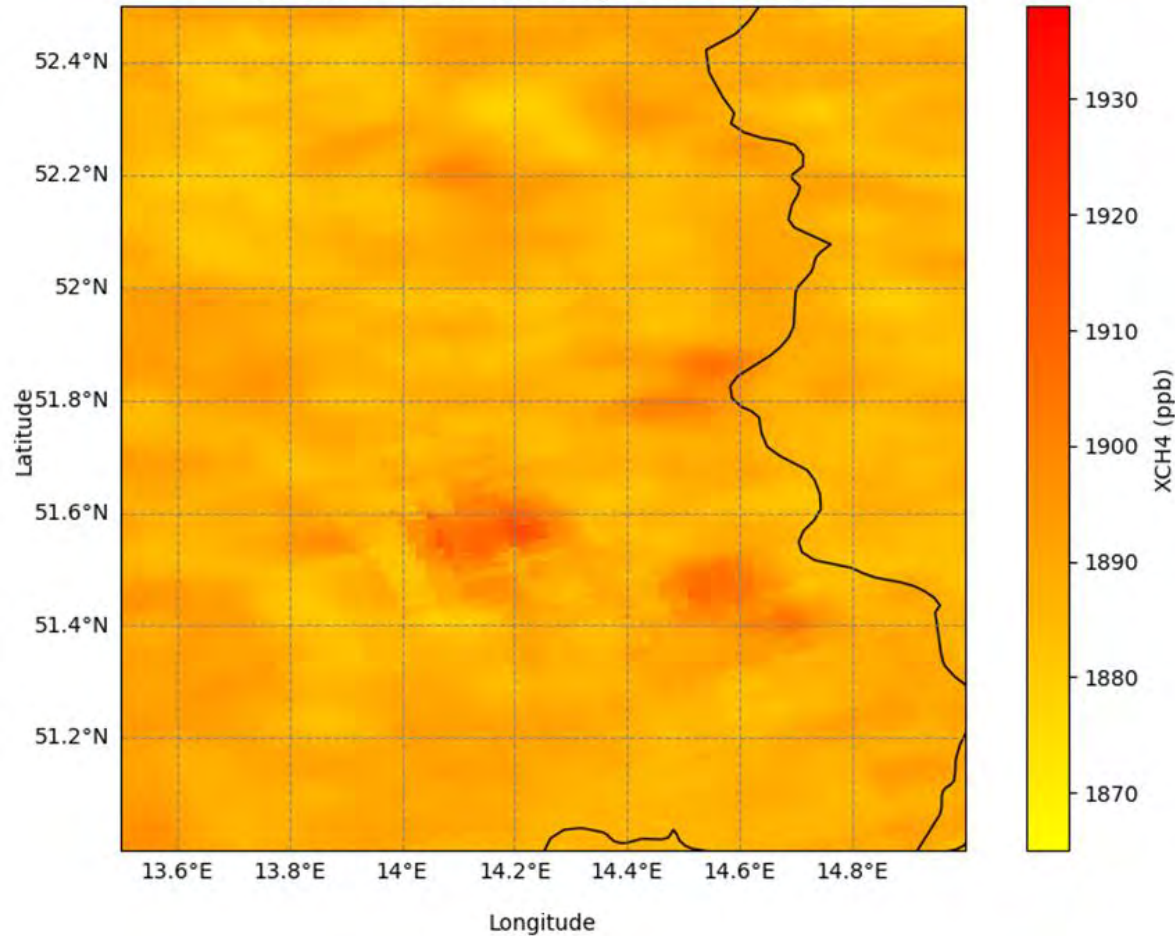
Retrieved SWIR albedo, 2022-2023



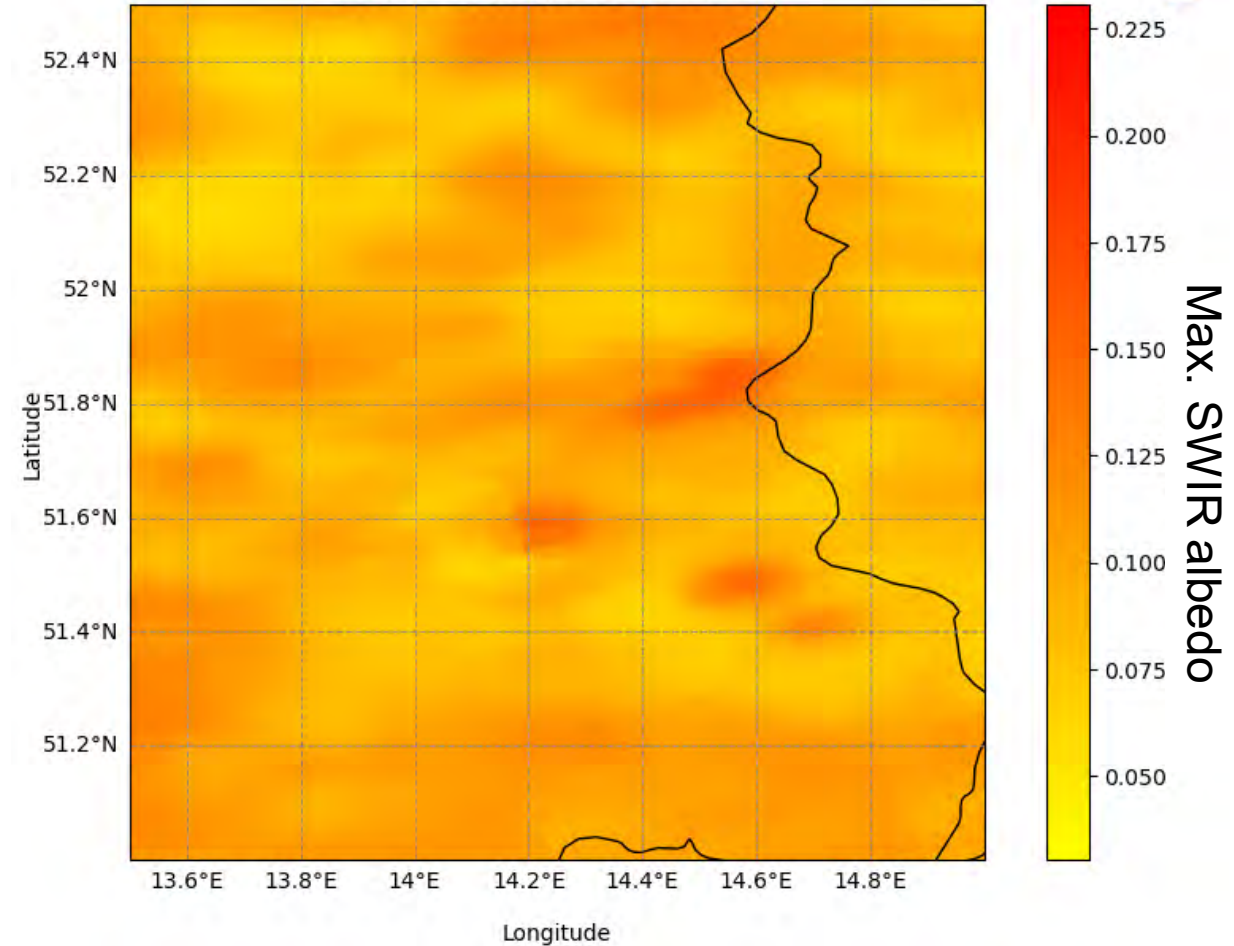
No plume – could it be albedo?



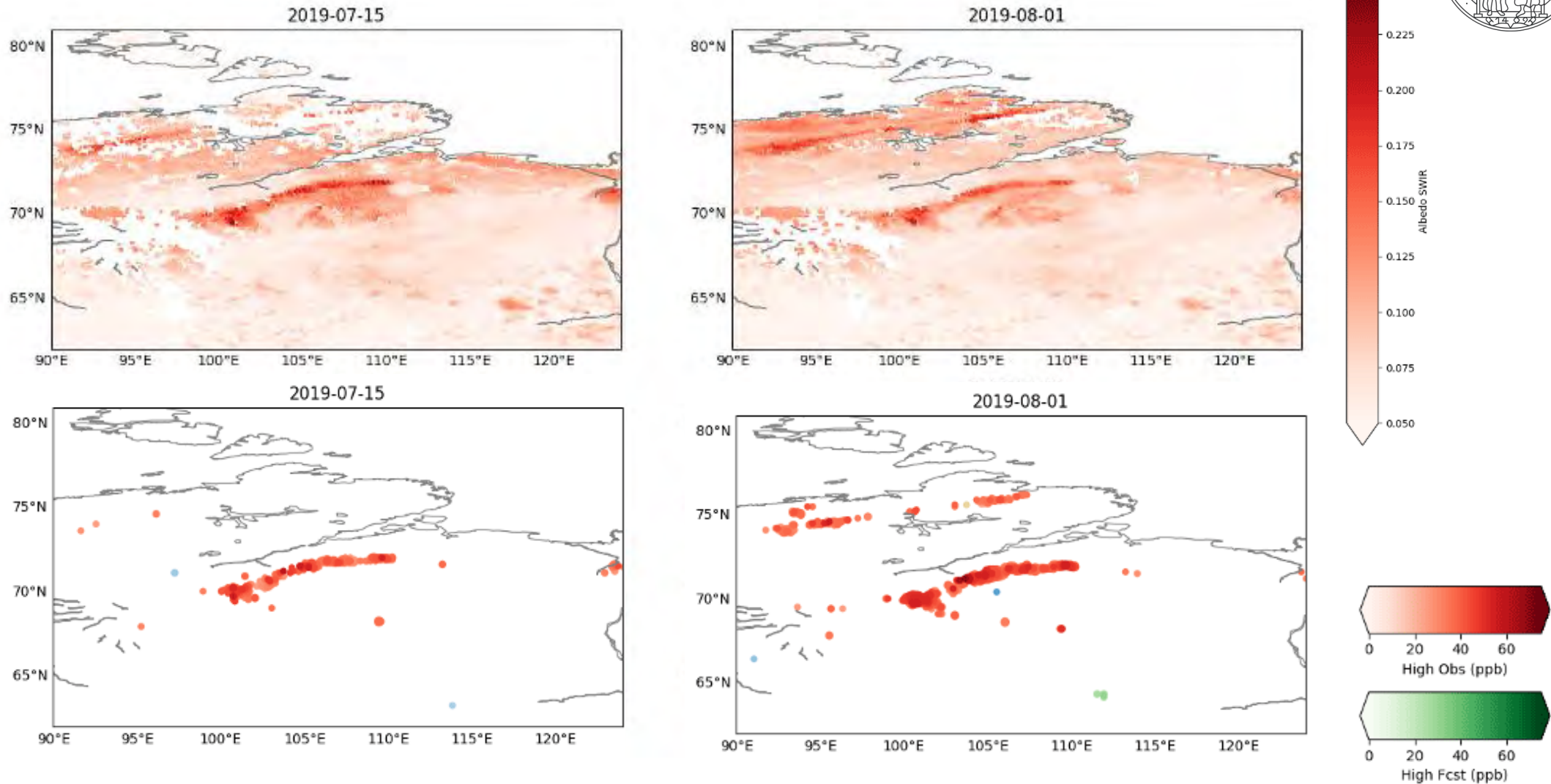
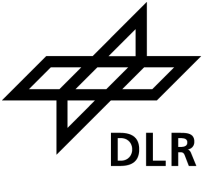
Mean SRON XCH₄, 2022-2023



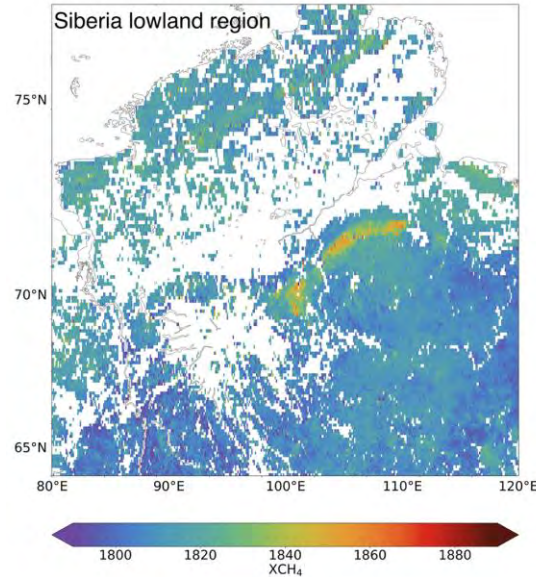
Max. SWIR, 2022-2023



But wasn't the albedo problem (mostly) solved?



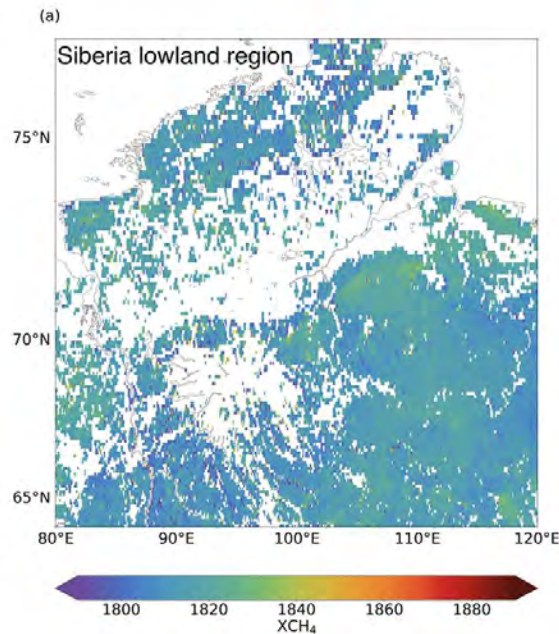
From [Barré et al., 2021](#)



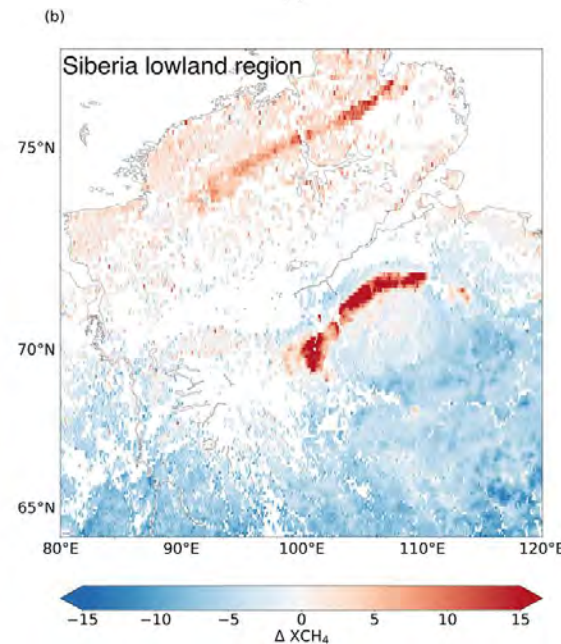
(a)



(b)



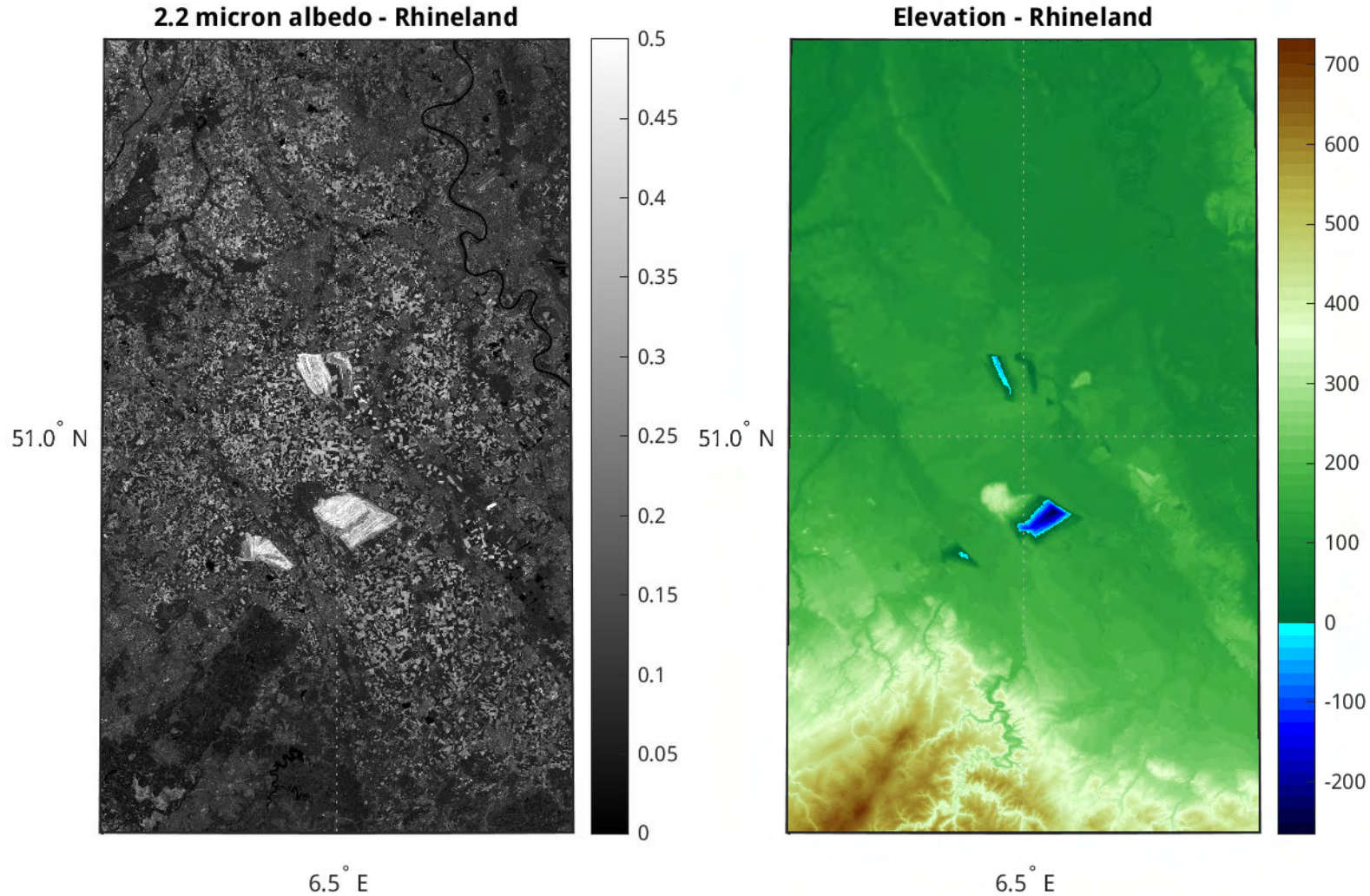
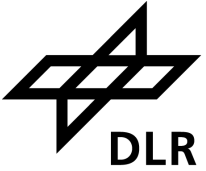
(a)



(b)

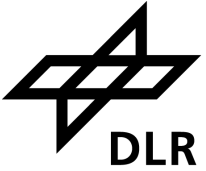
Accounting for surface reflectance features in spectral reflectance (e.g. [Lorente et al., 2023](#)) mostly made this go away

So what's special about open-pit coal mines?



SWIR albedo and elevation are negatively correlated here

A conceptual figure: the “deep, bright hole” problem



TROPOMI pixel, similar in size to the scale of the hole



- By estimating too high an elevation, the dry-air column (effective surface pressure) is underestimated
- Dividing by too small a number leads to an overestimate in XCH_4

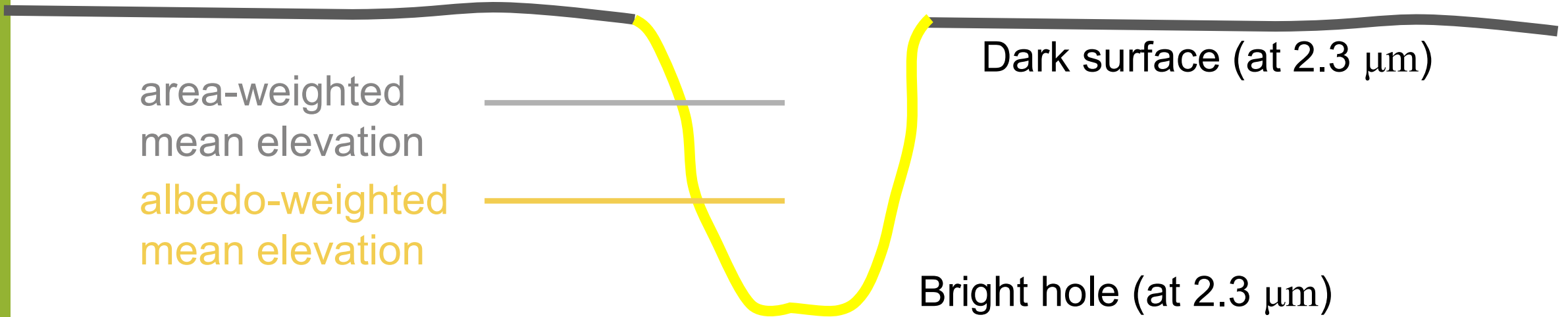
area-weighted
mean elevation

albedo-weighted
mean elevation

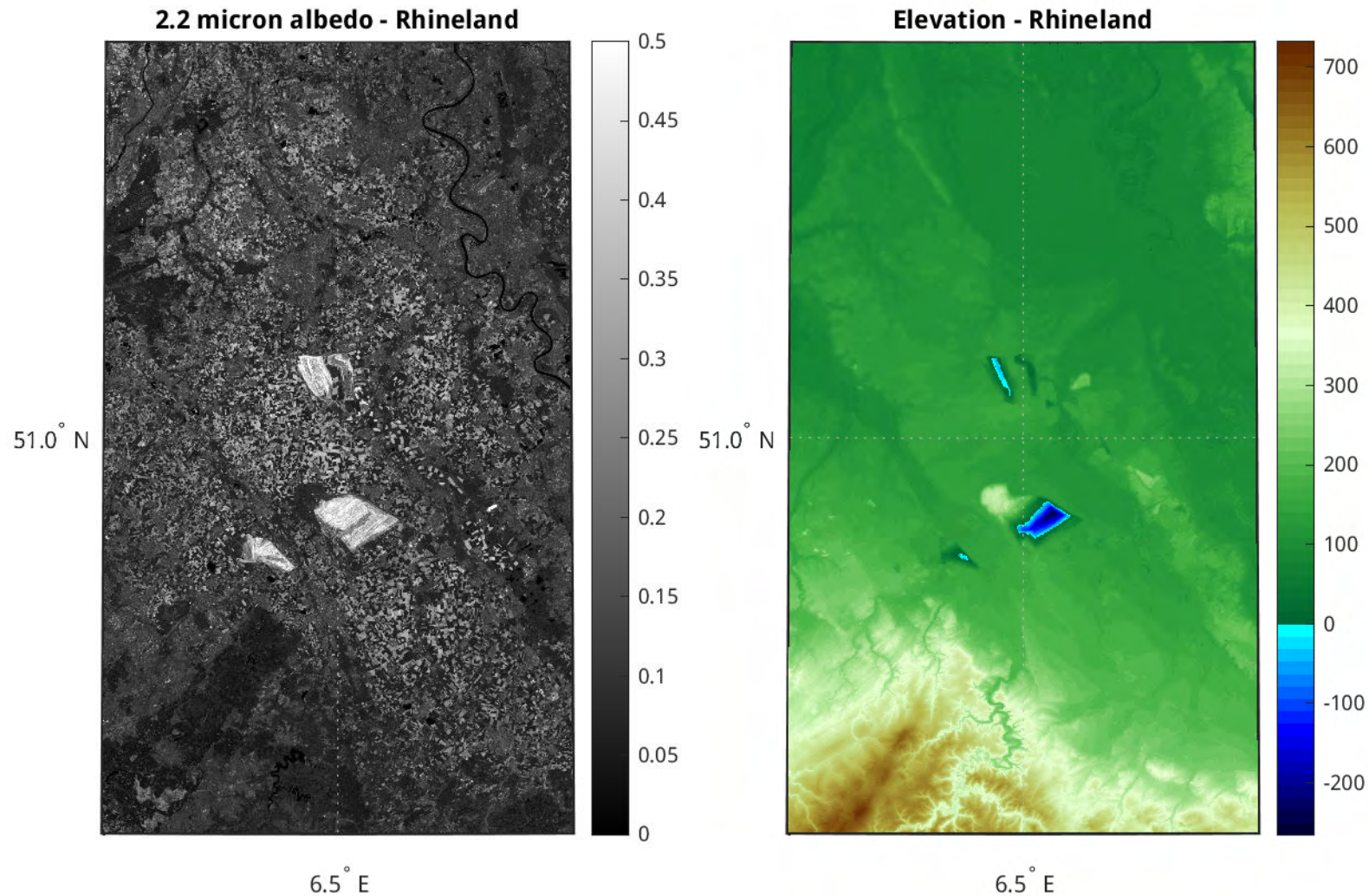
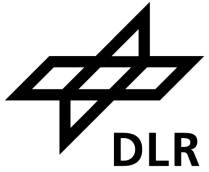


Dark surface (at $2.3 \mu\text{m}$)

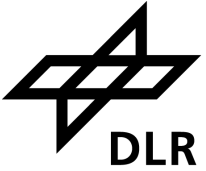
Bright hole (at $2.3 \mu\text{m}$)



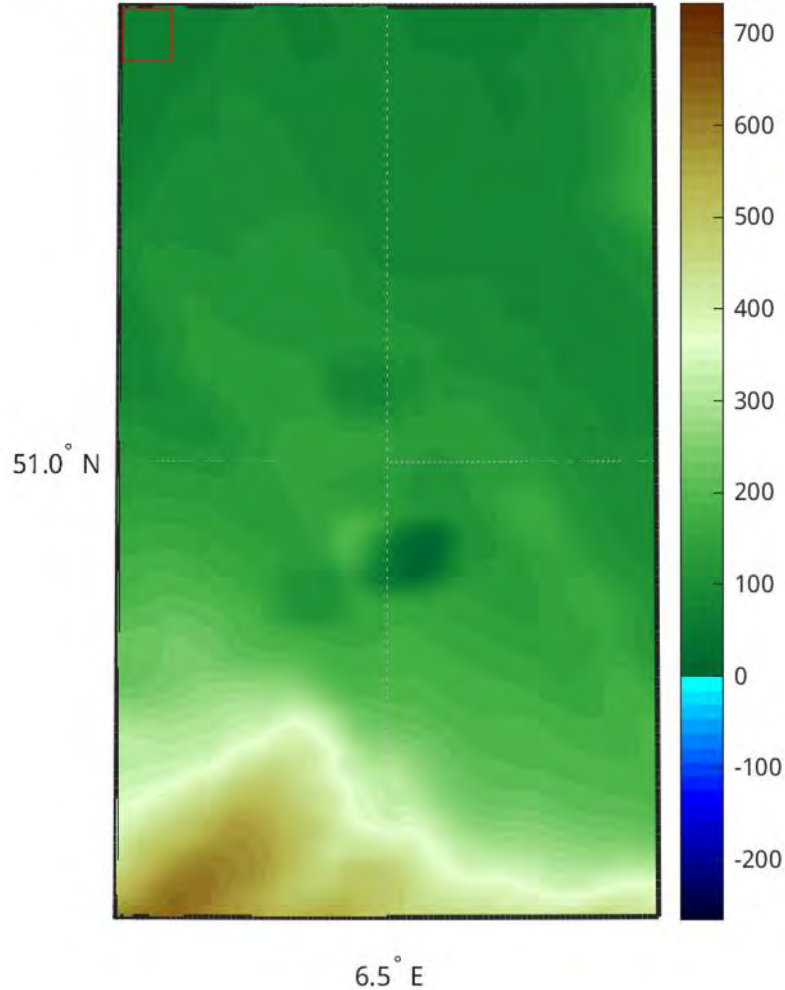
Albedo and elevation are negatively correlated here



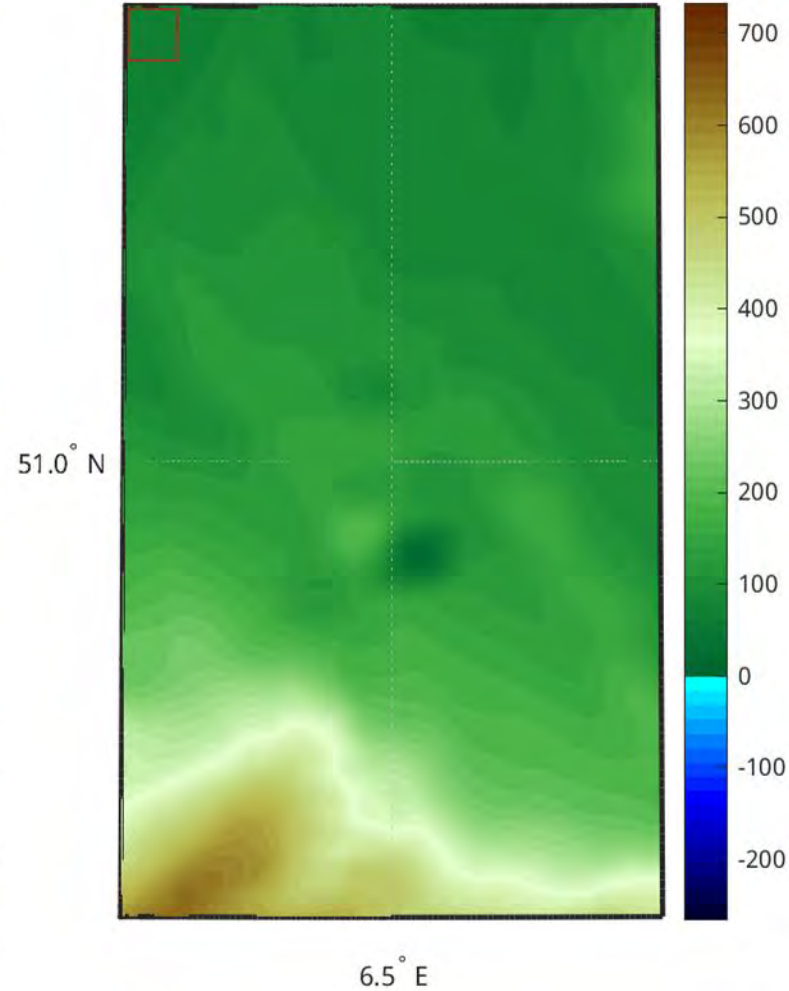
Albedo and elevation are negatively correlated here



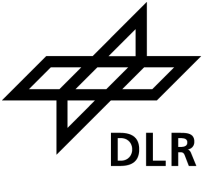
Mean albedo-weighted elevation over 5.5 km x 7 km pixel



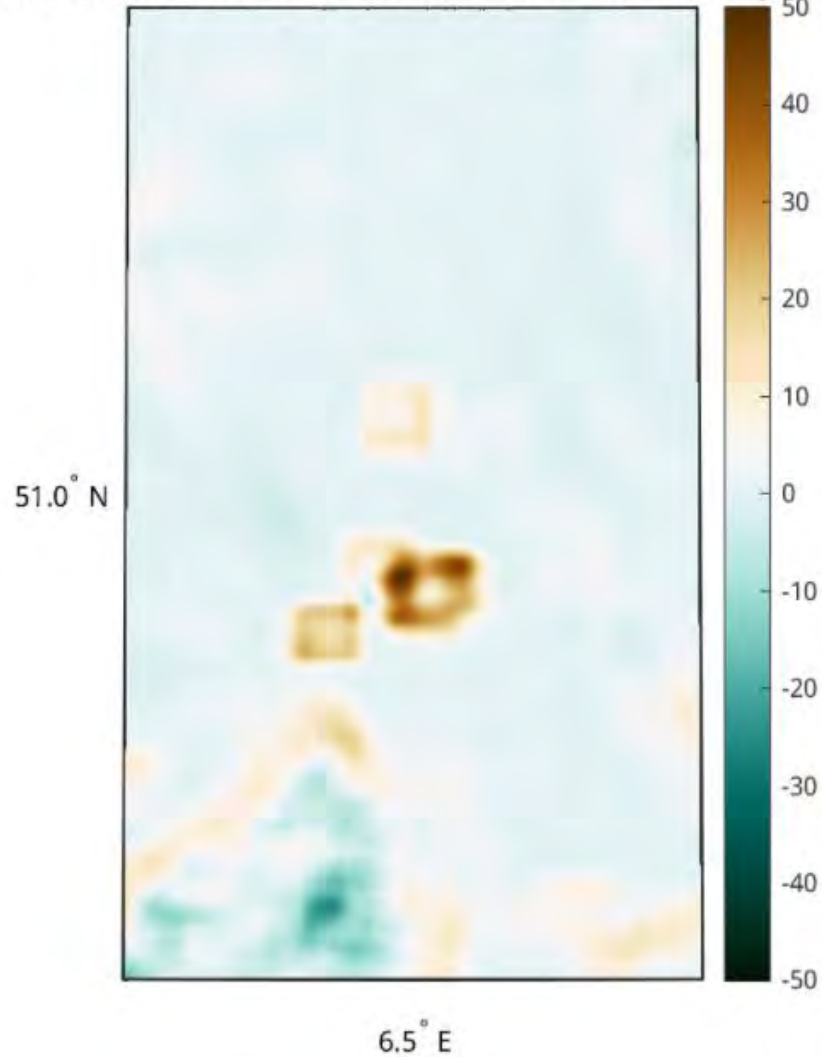
Mean elevation over 5.5 km x 7 km pixel



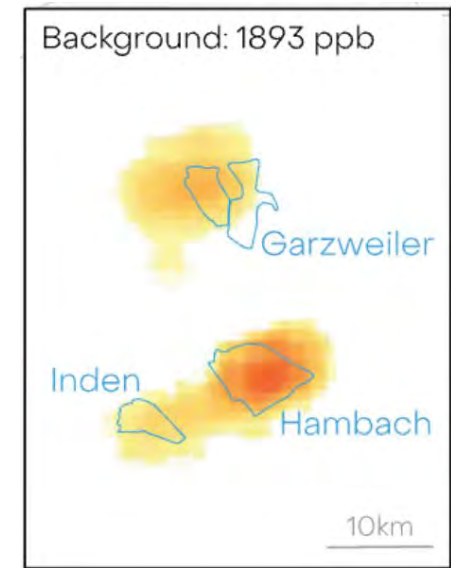
And the difference:



difference between mean elevations over 5.5 km x 7 km pixel (B12)



- Maximum differences of around 50 m for this scene
- Using the hypsometric equation, this results in a difference of around 0.6% in the surface pressure estimate, or about 12 ppb
- Maybe not the full story (neglecting complex scattering effects), but it explains the spatial pattern well



Background: 1893 ppb

Garzweiler

Inden

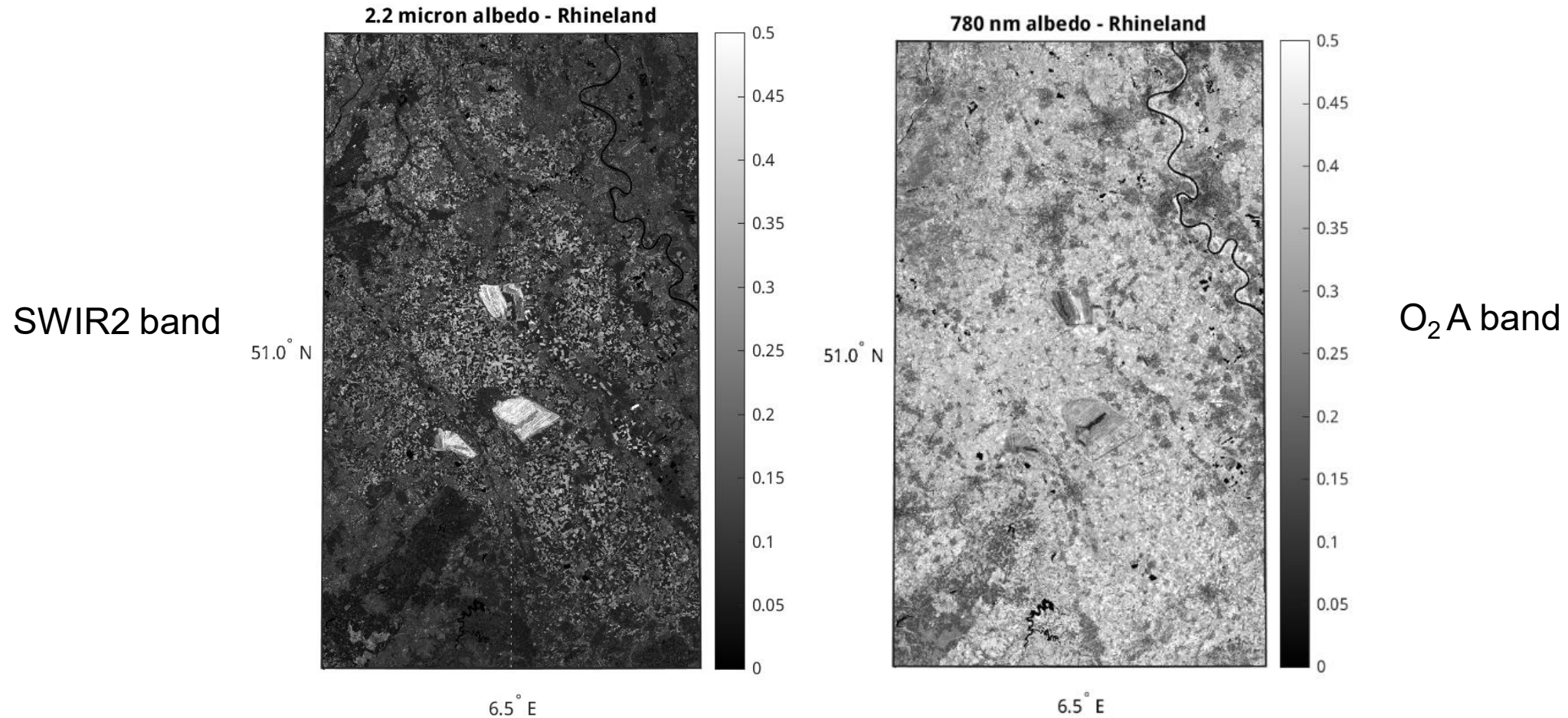
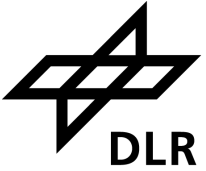
Hambach

10km

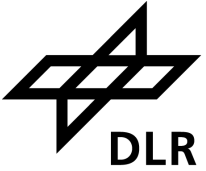
8

40

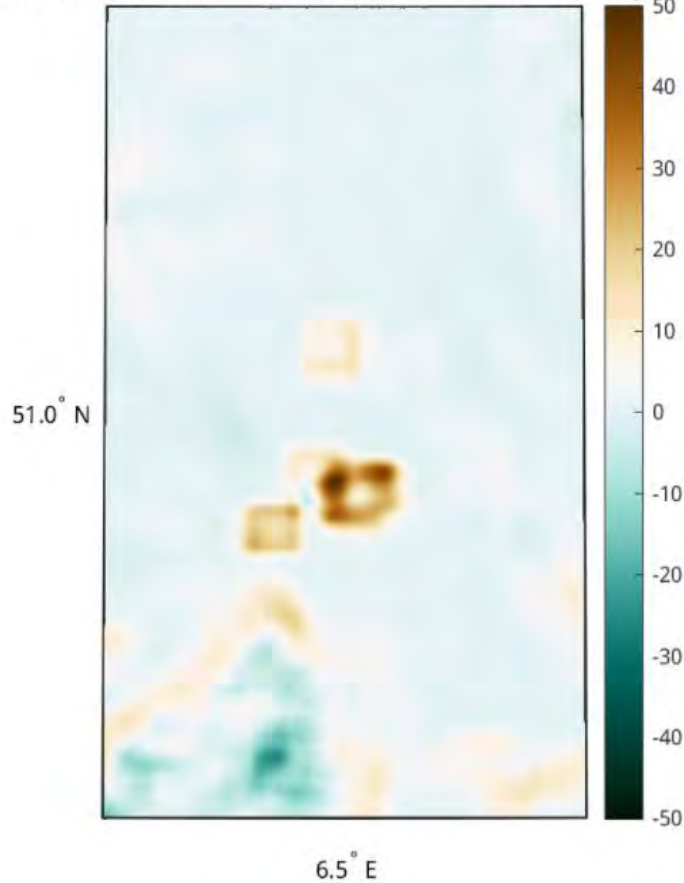
Note that the albedo in the O₂ A band is not always correlated with that of the SWIR 2 band...



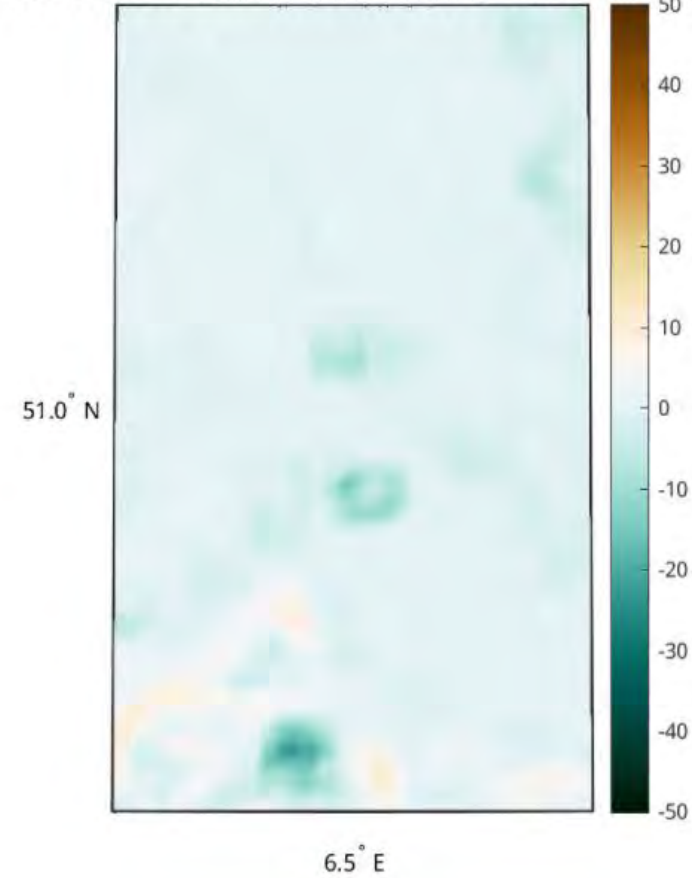
Note that the albedo in the O₂ A band is not always correlated with that of the SWIR 2 band...



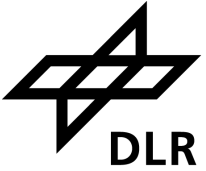
difference between mean elevations over 5.5 km x 7 km pixel (B12)



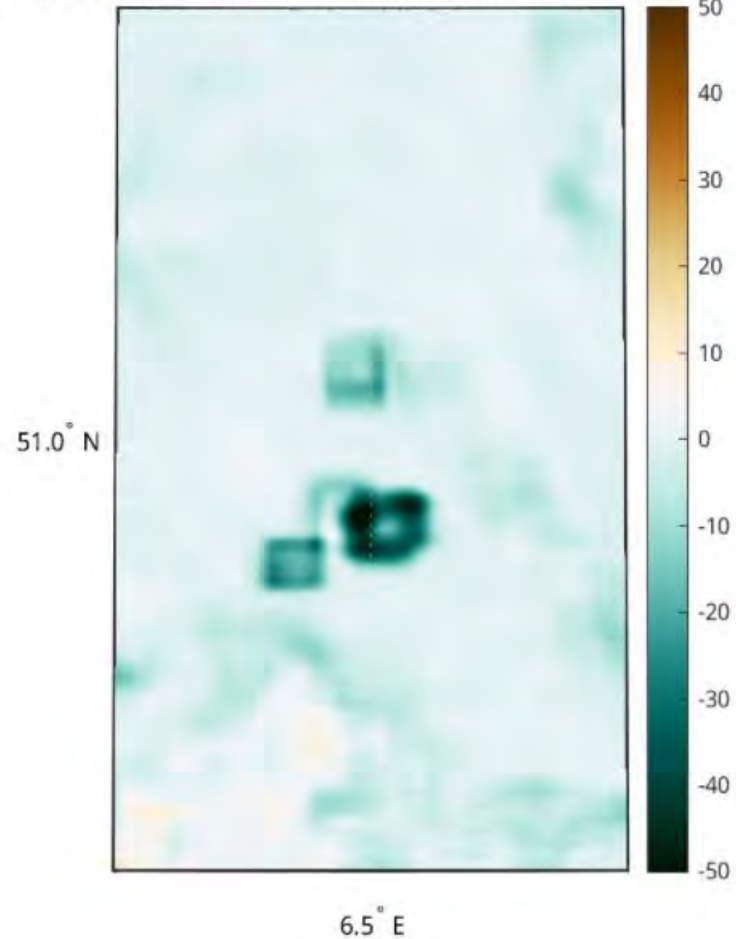
difference between mean elevations over 5.5 km x 7 km pixel (B7)



Note that the albedo in the O₂ A band is not always correlated with that of the SWIR 2 band...



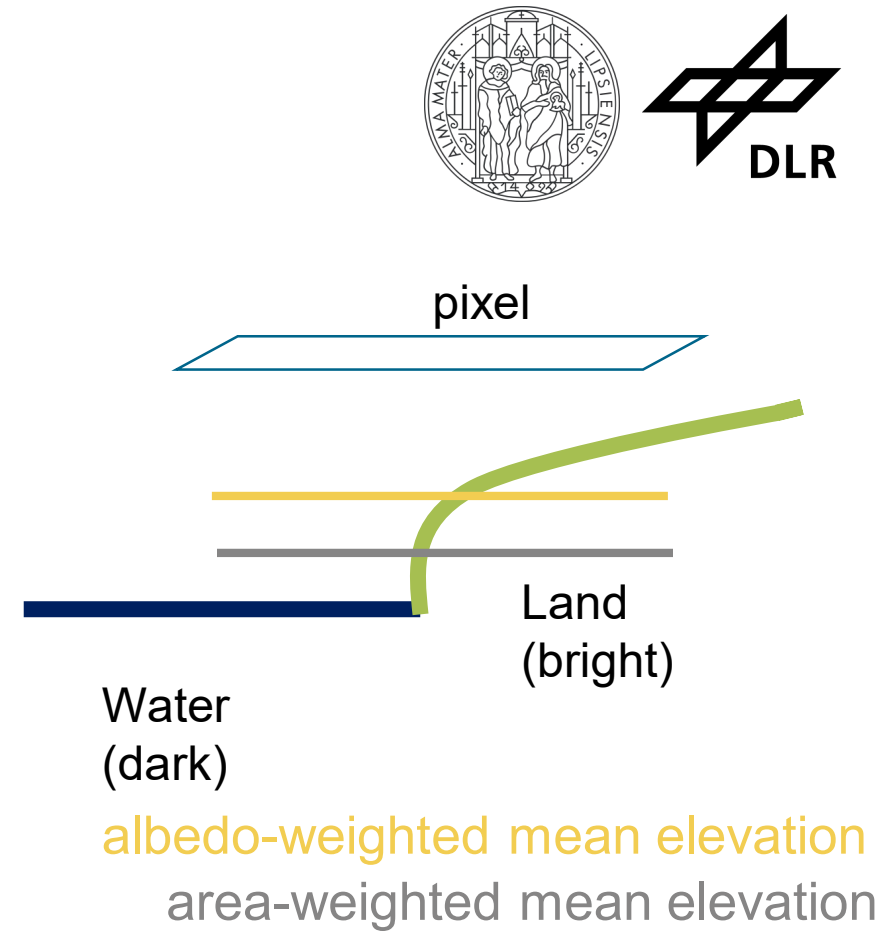
difference between B12 and B7 mean elevations over 5.5 km x 7 km pixel



The O₂ A band cannot fix this problem, even with perfect spectroscopy!

Conclusions

- A problem where sub-pixel albedo and elevation variability are strongly (anti-) correlated
- Scale-dependent (not shown), SWIR1 looks similar
- Simple linear correction can be applied for single-band retrievals, or at least a flag can be applied
- For multi-band retrievals, the effective elevation may be different between bands, and the correction is no longer linear (Michael Weimer at IUP-Bremen is looking into this for CO2M)
- Potentially relevant in partially water-covered pixels, where the lowest elevation is usually the darkest



With funding from the:



This work is funded by the German Federal Ministry of Research, Technology and Space (BMFTR) project DiSMISS under grant number 50EE2421.

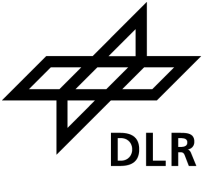
This work used resources of the Deutsches Klimarechenzentrum (DKRZ) granted by its Scientific Steering Committee (WLA) under project ID bd1231

EXTRA SLIDES

In case someone asks the right question ;-)

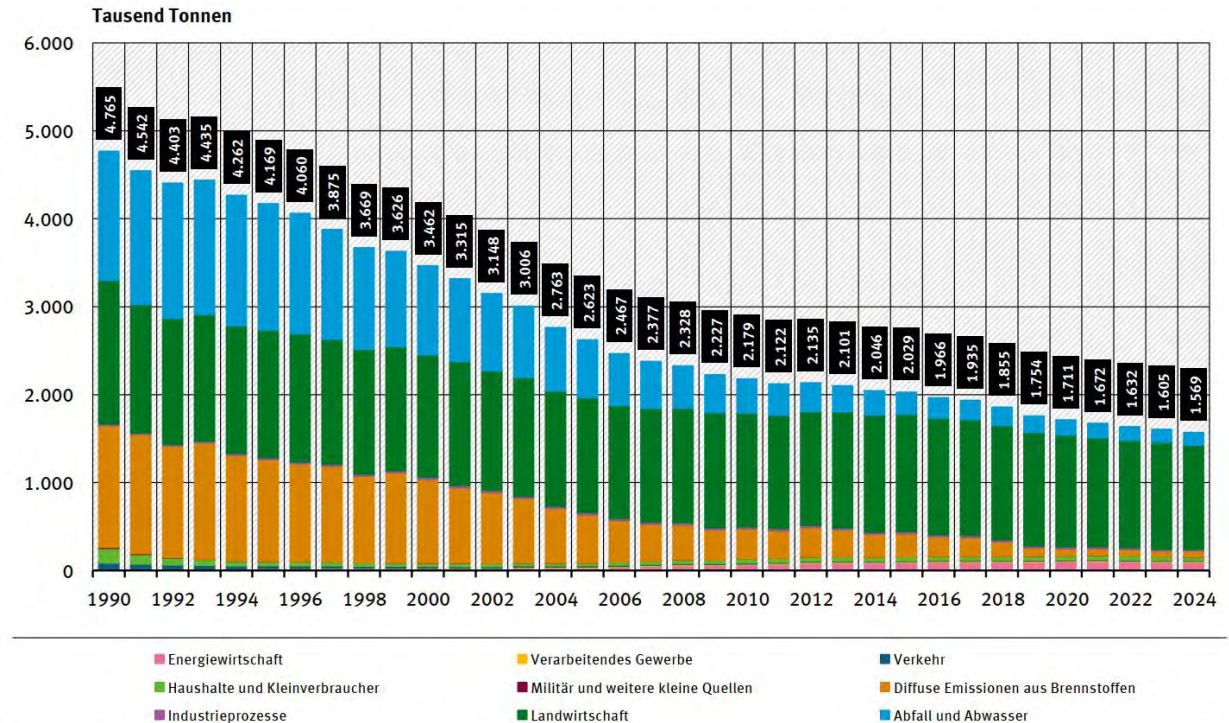


About the Shen et al. (2023) inversion



- Number given for coal emissions is 110 kt/yr, with a range of 6-280
- Very sensitive to the prior!
- 50-km resolution (transport and fluxes) for Germany
- No category-specific information on non-fossil posterior or prior emissions on the country scale
- ~75% of Germany's emissions are from agriculture ([UBA](#), right)

Methan-Emissionen nach Kategorien



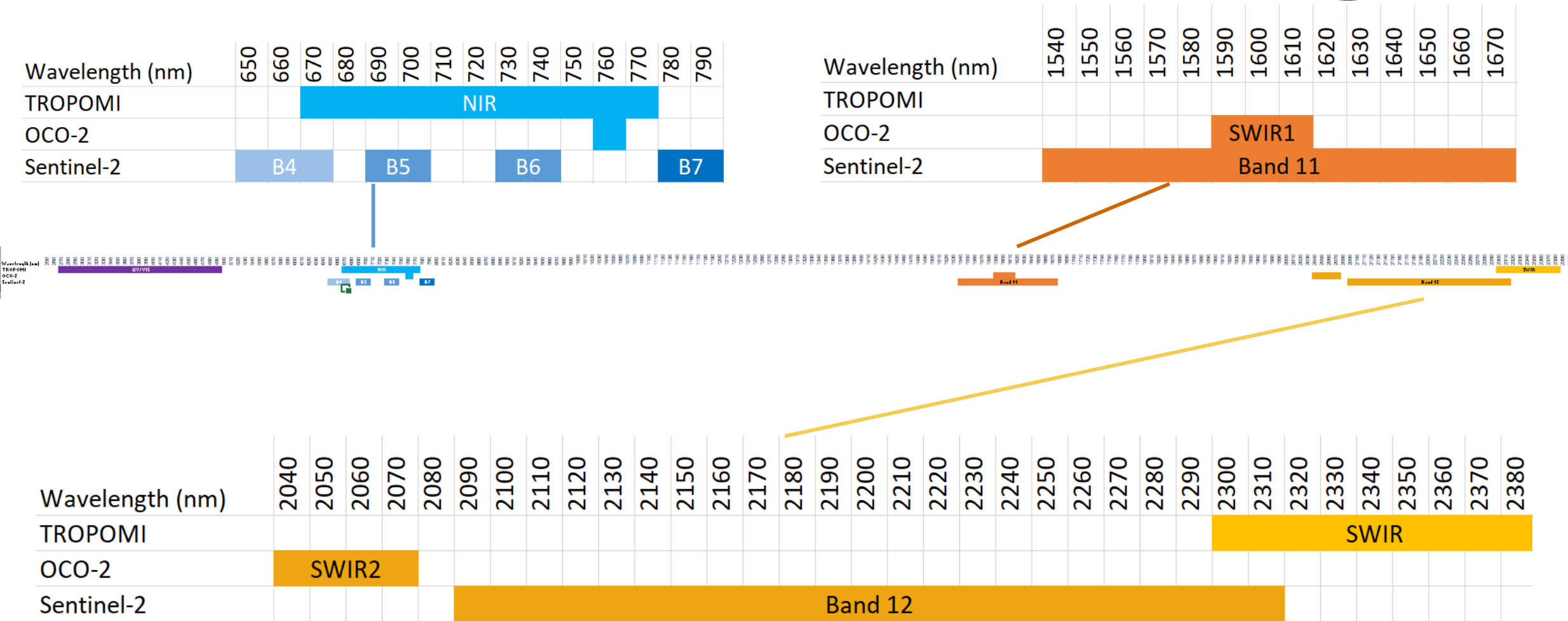
Emissionen ohne Landnutzung, Landnutzungsänderung und Forstwirtschaft
Verkehr: ohne land- und forstwirtschaftlichen Verkehr
Haushalte und Kleinverbraucher: mit Militär und weiteren kleinen Quellen (u.a. land- und forstwirtschaftlichem Verkehr)

Quelle: Umweltbundesamt, Nationale Treibhausgas-Inventare 1990-2023 (Stand 03/2025), für 2024 vorläufige Daten (Stand 15.03.2025)

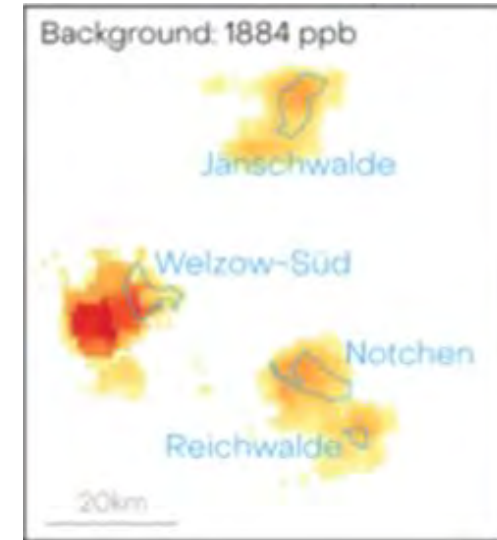
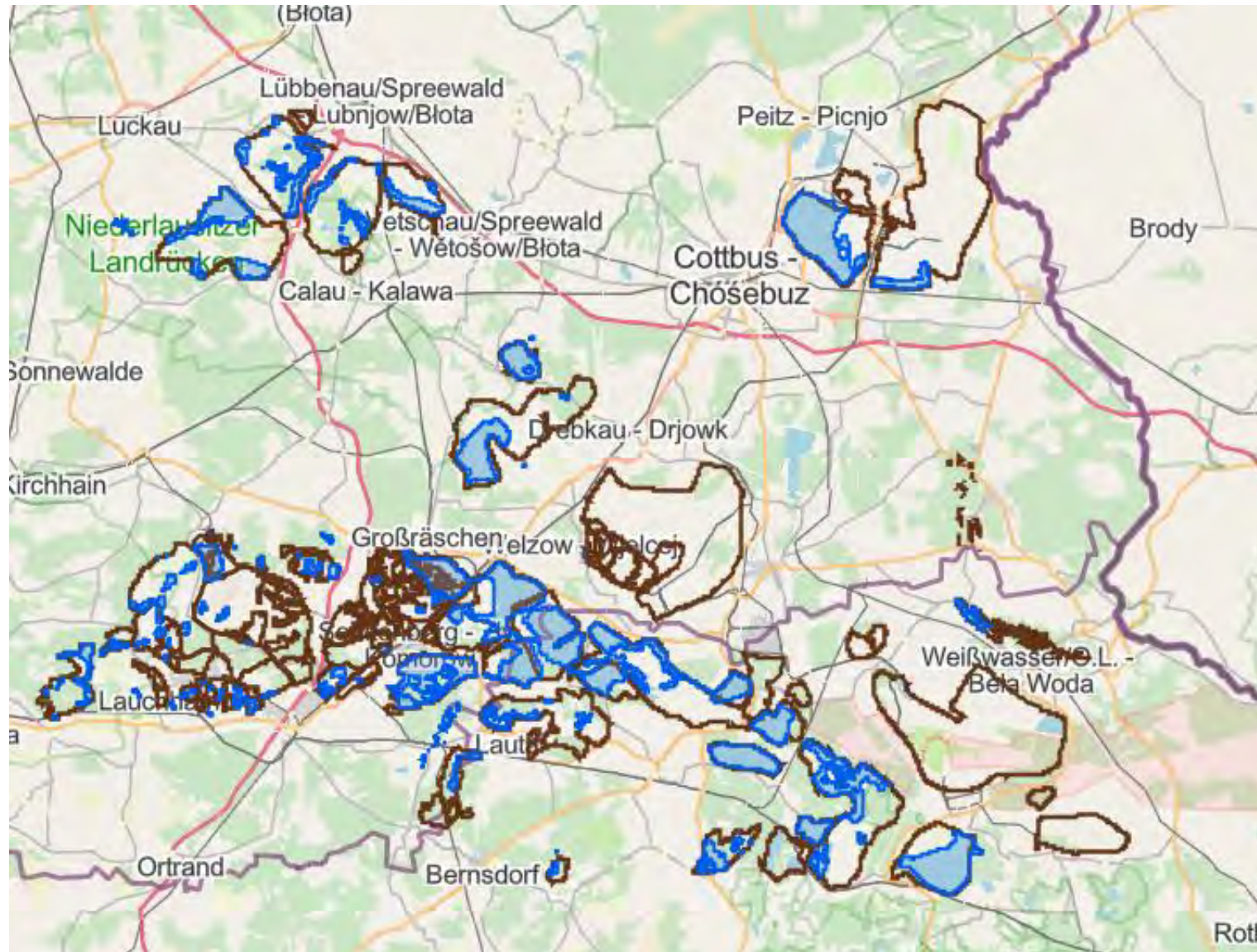
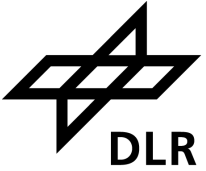
Countries	using GFEIv2 (UNFCCC)		using GFEIv1		using EDGARv6		Averaged posterior (Tg a ⁻¹)
	Prior (Tg a ⁻¹)	Posterior (Tg a ⁻¹)	Prior (Tg a ⁻¹)	Posterior (Tg a ⁻¹)	Prior (Tg a ⁻¹)	Posterior (Tg a ⁻¹)	
Germany	0.01	0.01	0.10	0.14	0.14	0.18	0.11

From Table 6 of the supplement to [Shen et al. \(2023\)](#)

Spectral bands of relevant remote-sensing instruments



Other complications in the Lausitz



The brown outlines show mining areas (past and present), the blue areas show mines that have been (and in some cases are actively being) flooded to create lakes.

Thus, the albedo *and* the elevation are changing dynamically, but the DEM is static.

Albedo timeseries in the Lausitz



3 km

2020-09-20



2022-09-25



2024-09-19



2020-09-20



2022-09-25



2024-09-19

