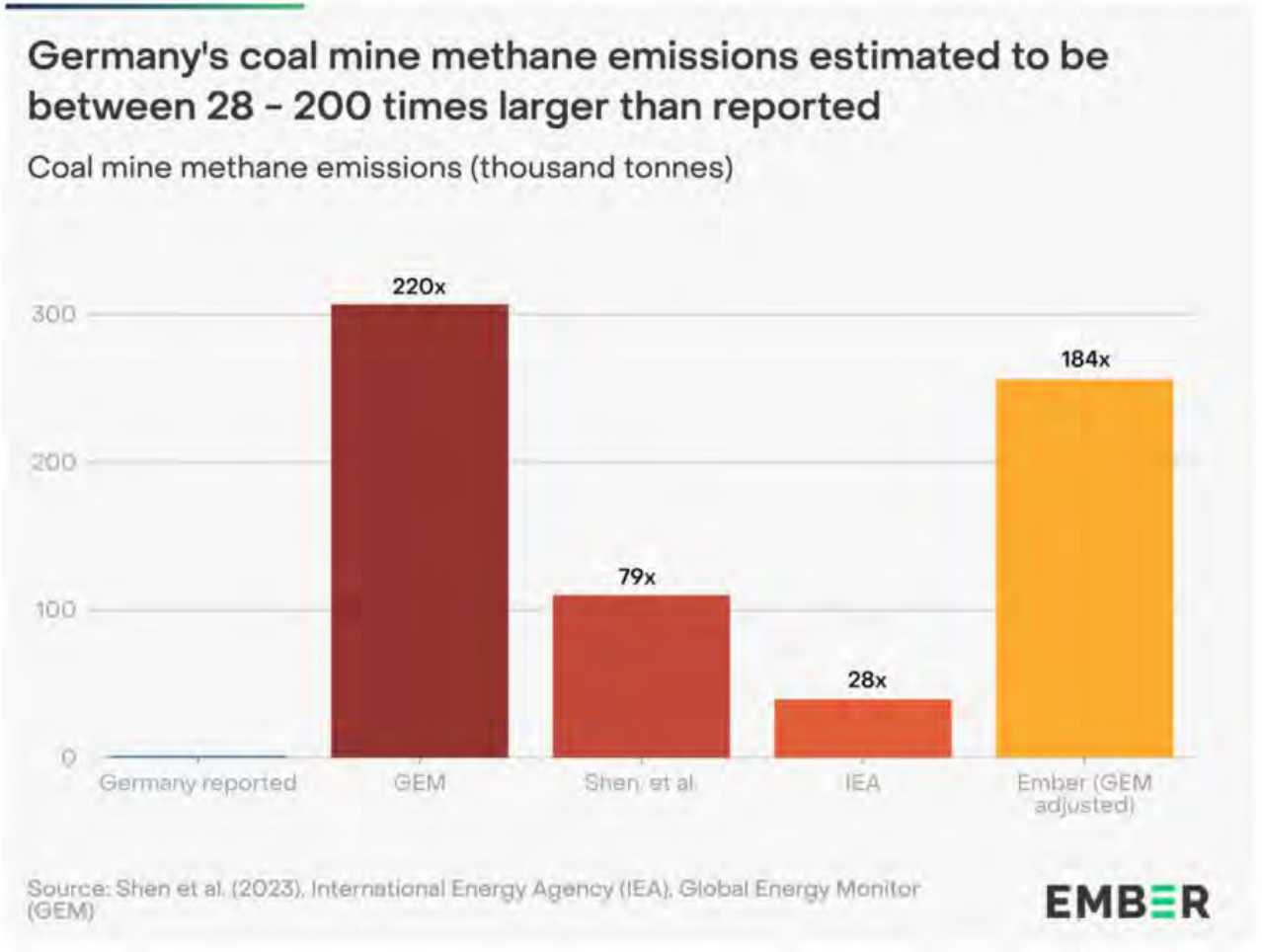
CORRELATED ALBEDO AND ELEVATION VARIABILITY LEADING TO RETRIEVAL ARTEFACTS

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

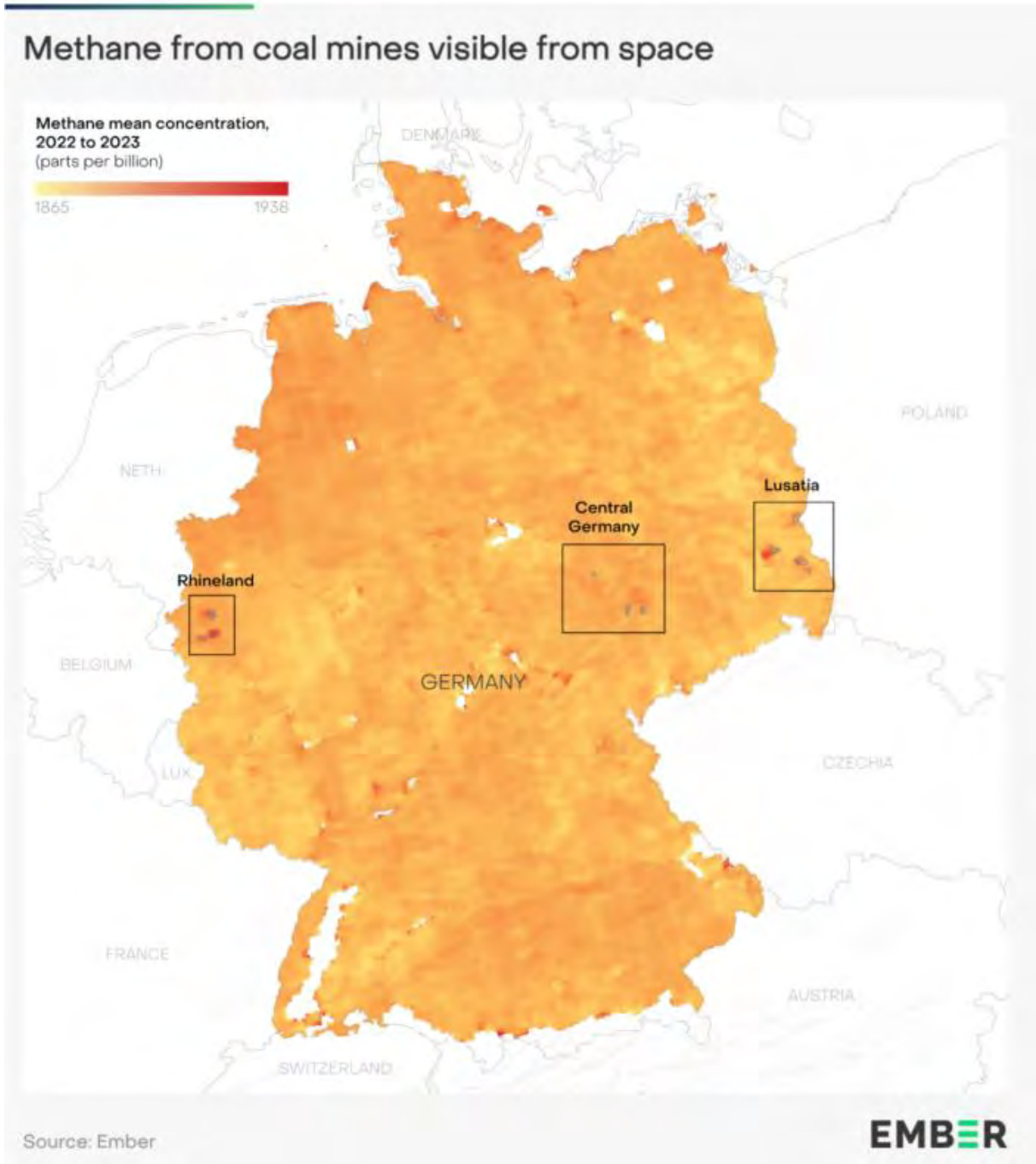
- Commissioned by a non-profit environmental group, the report was released the same week as the national emissions reporting
- The emission factor used for the open-pit lignite mines is 75 times lower than the IPCC default value
- Satellite measurements – also through an inversion study – were used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



Urgency to update Germany's coal mine methane emission factor | Ember

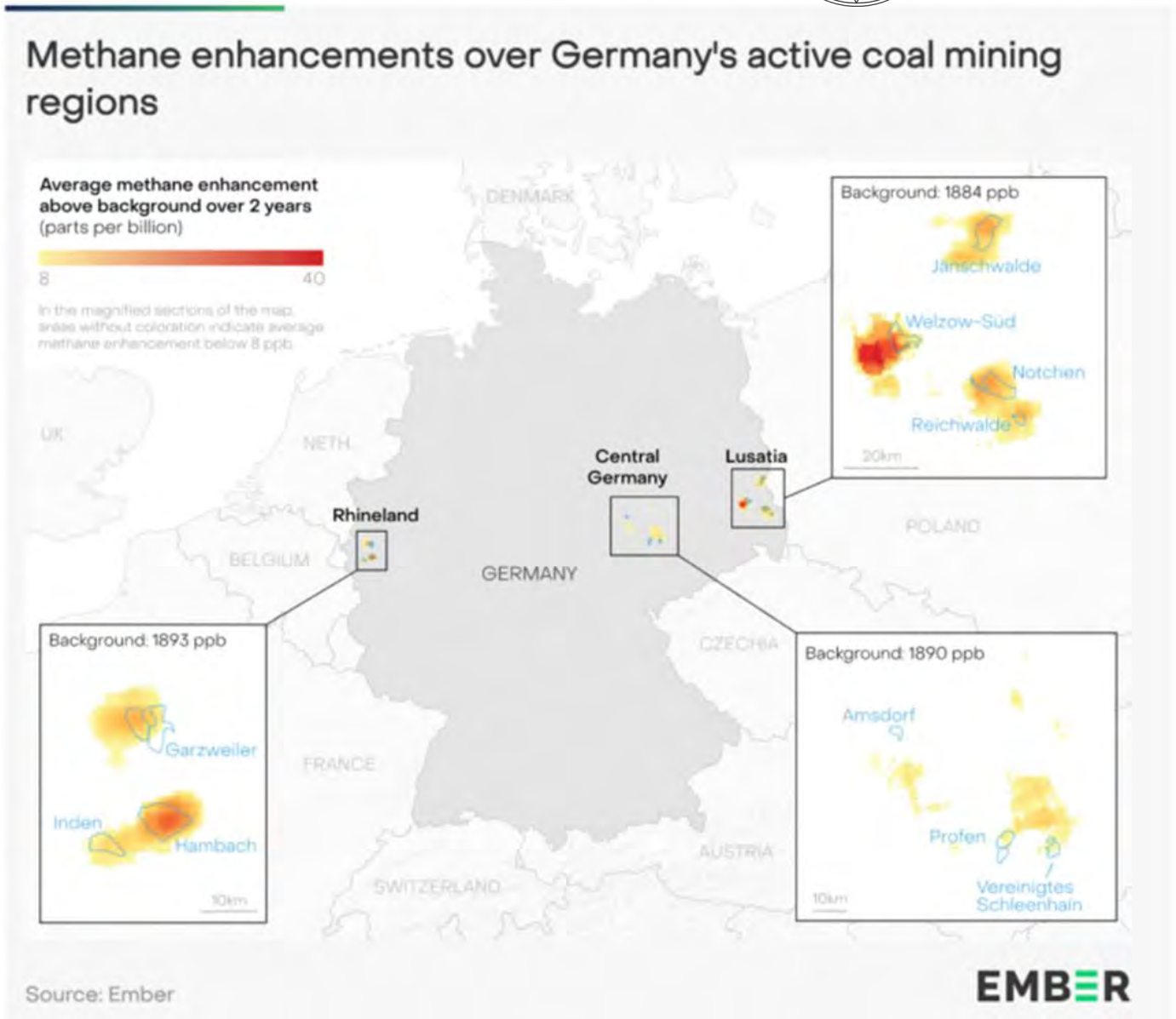
Seen by TROPOMI?

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



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](#))



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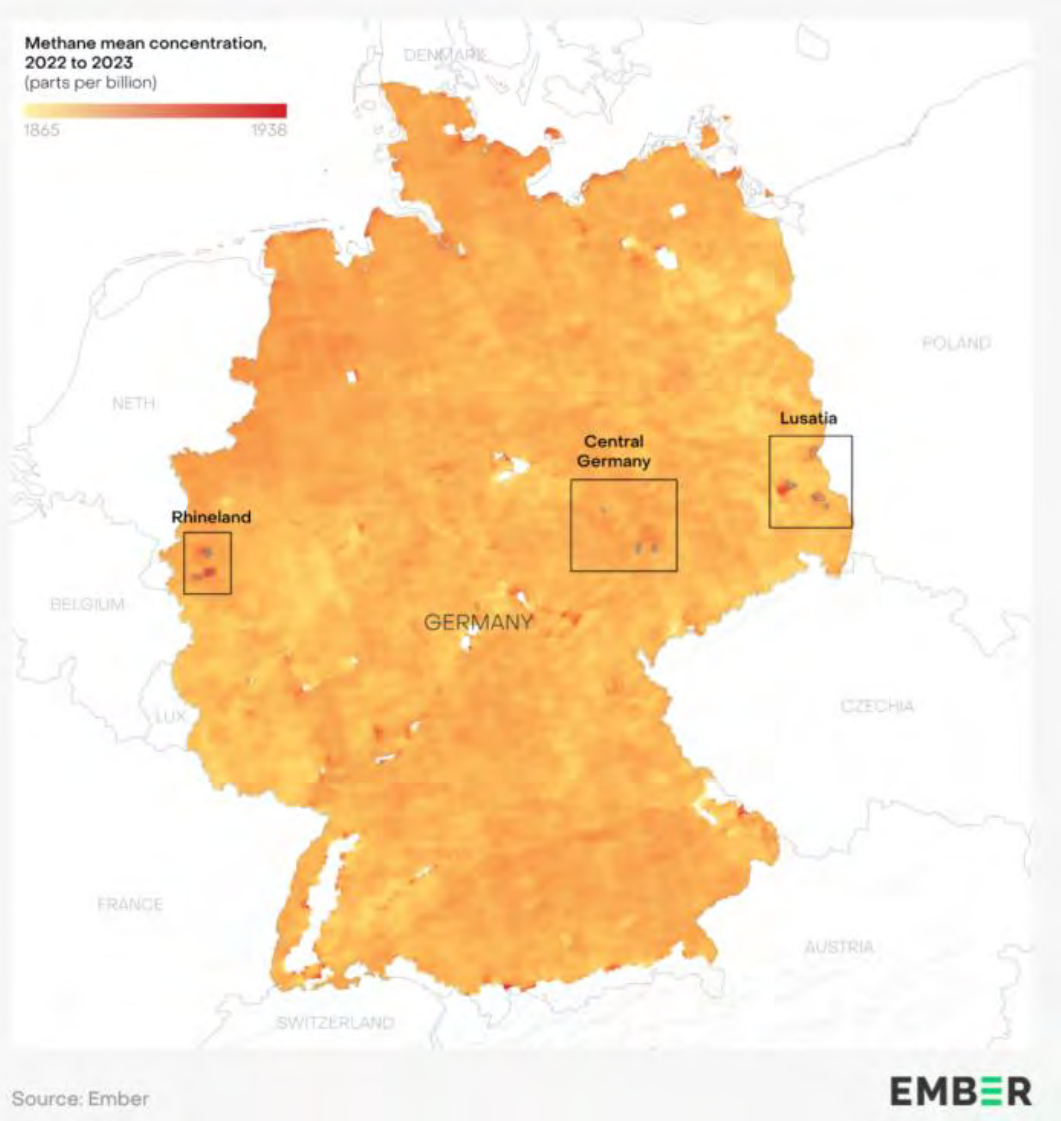

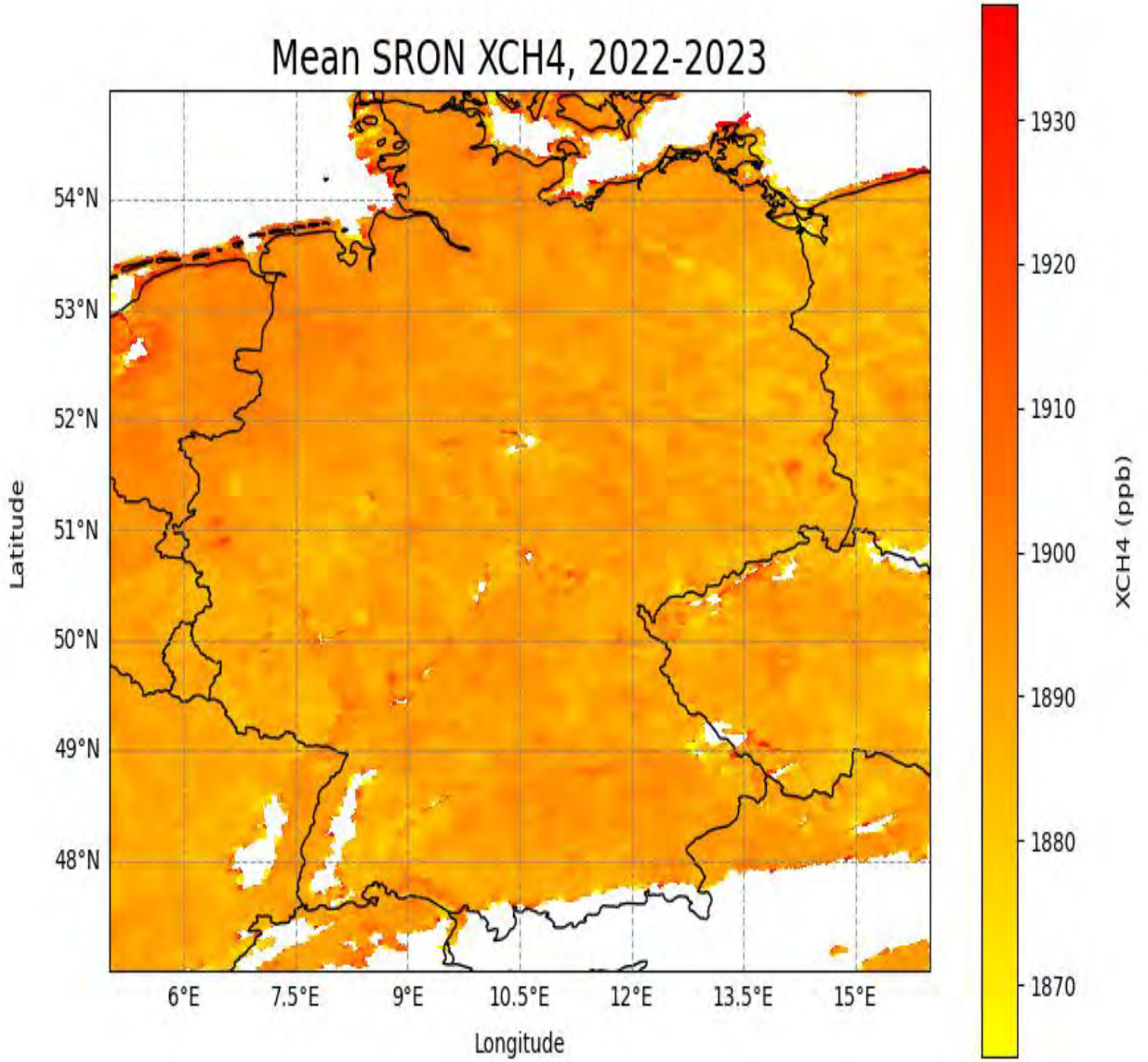

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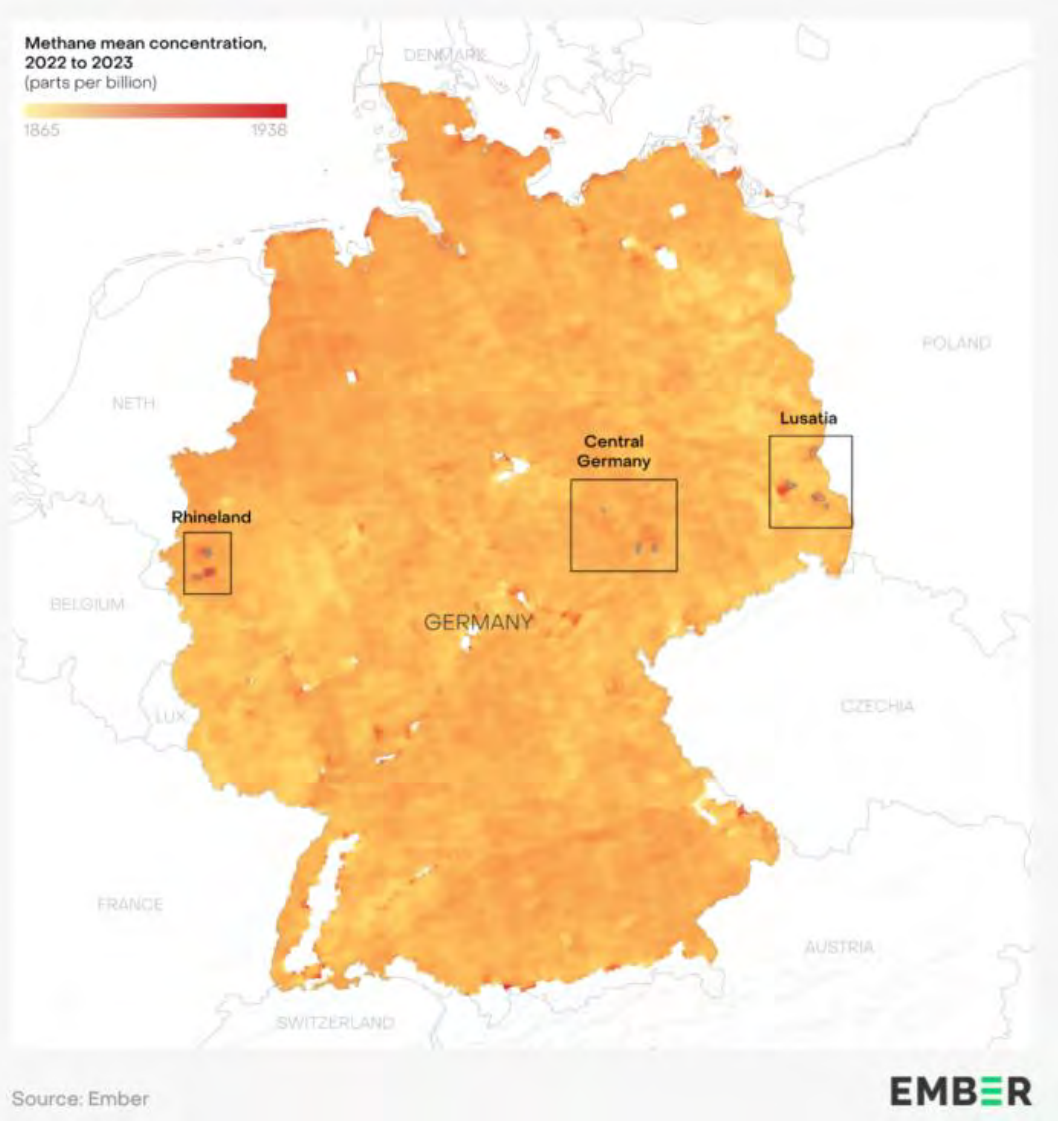
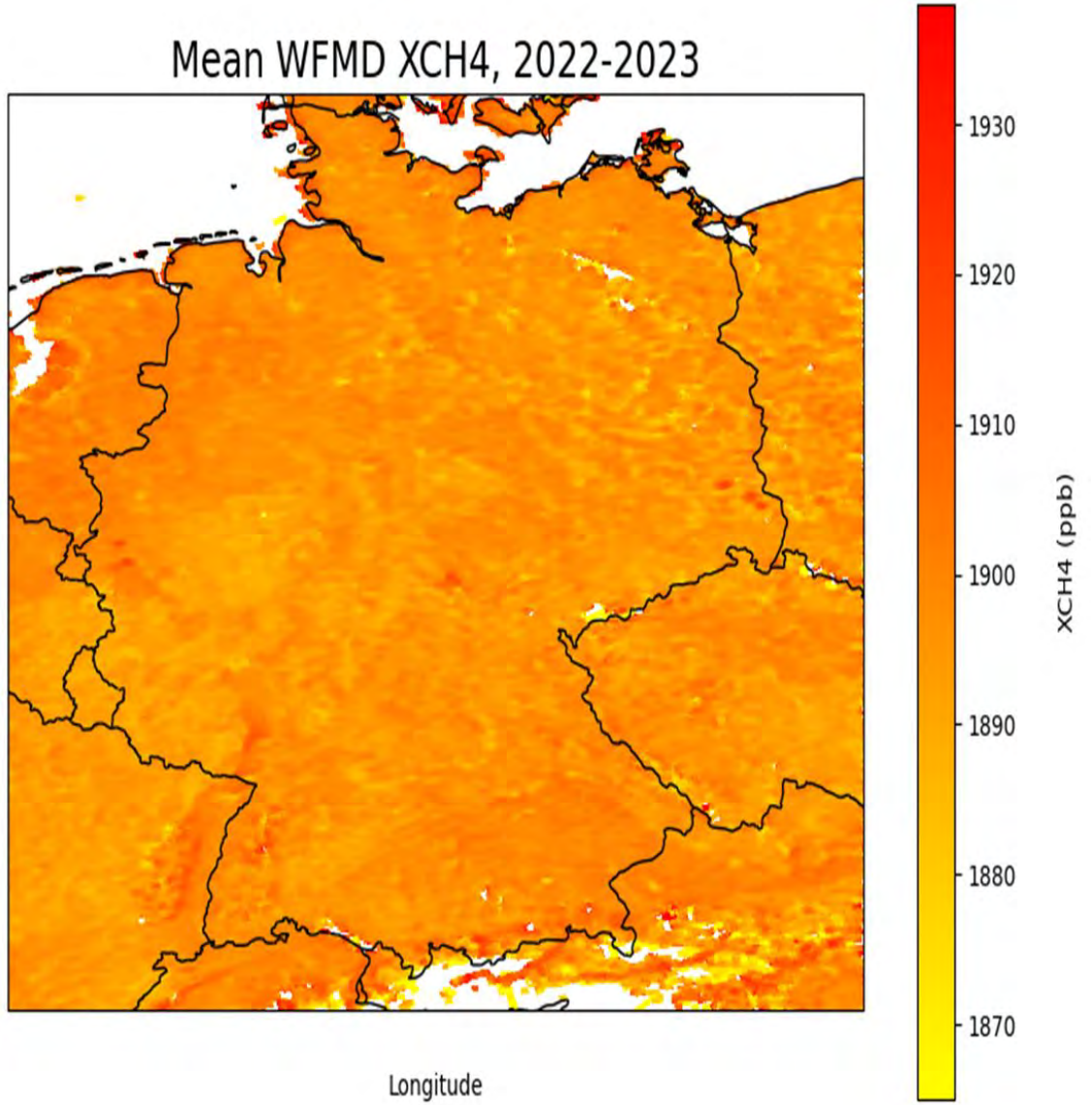
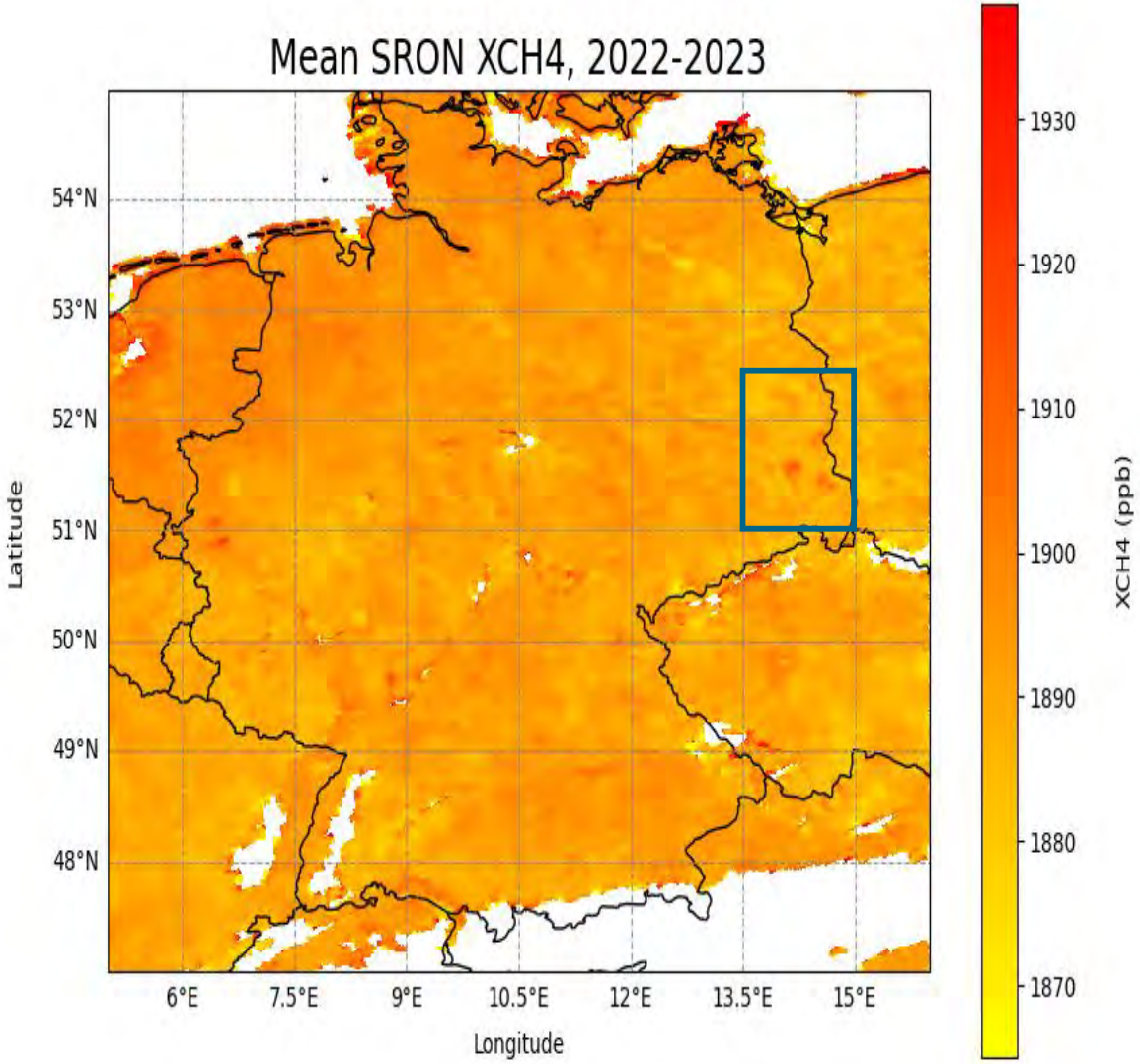
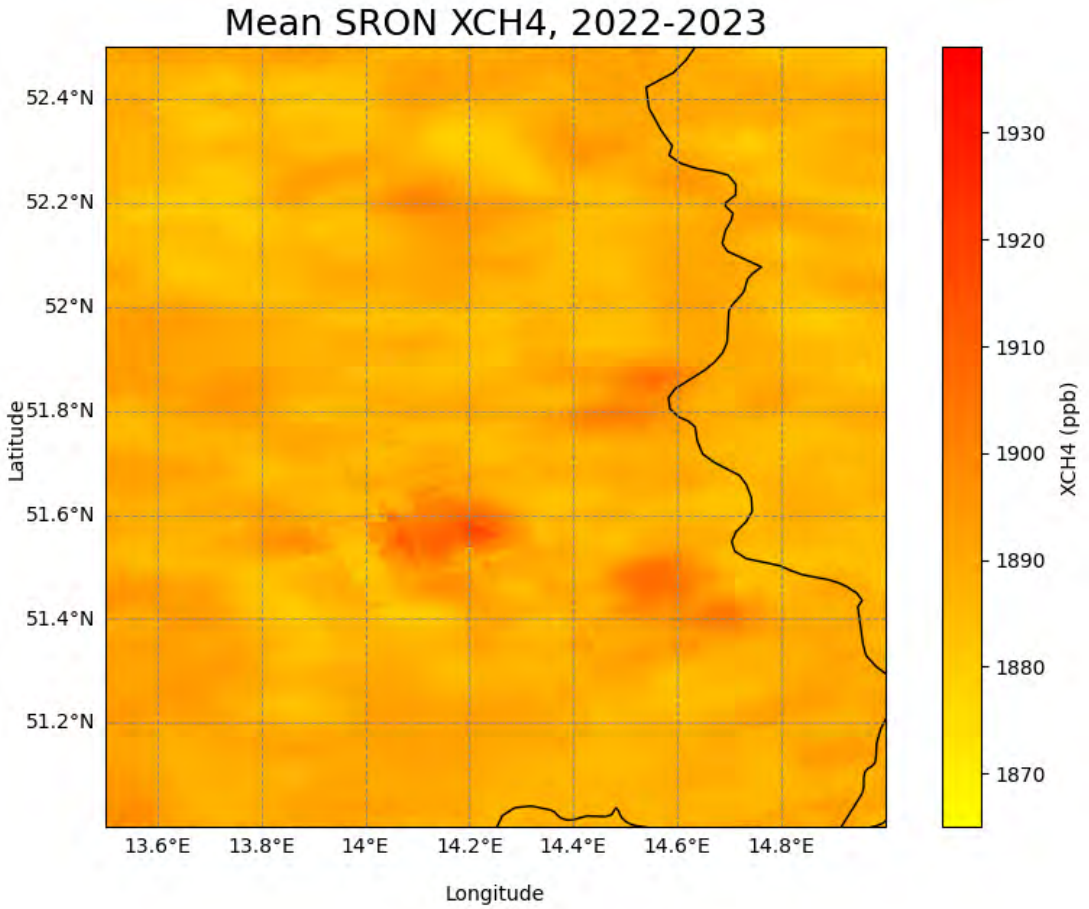




Do we see a plume?





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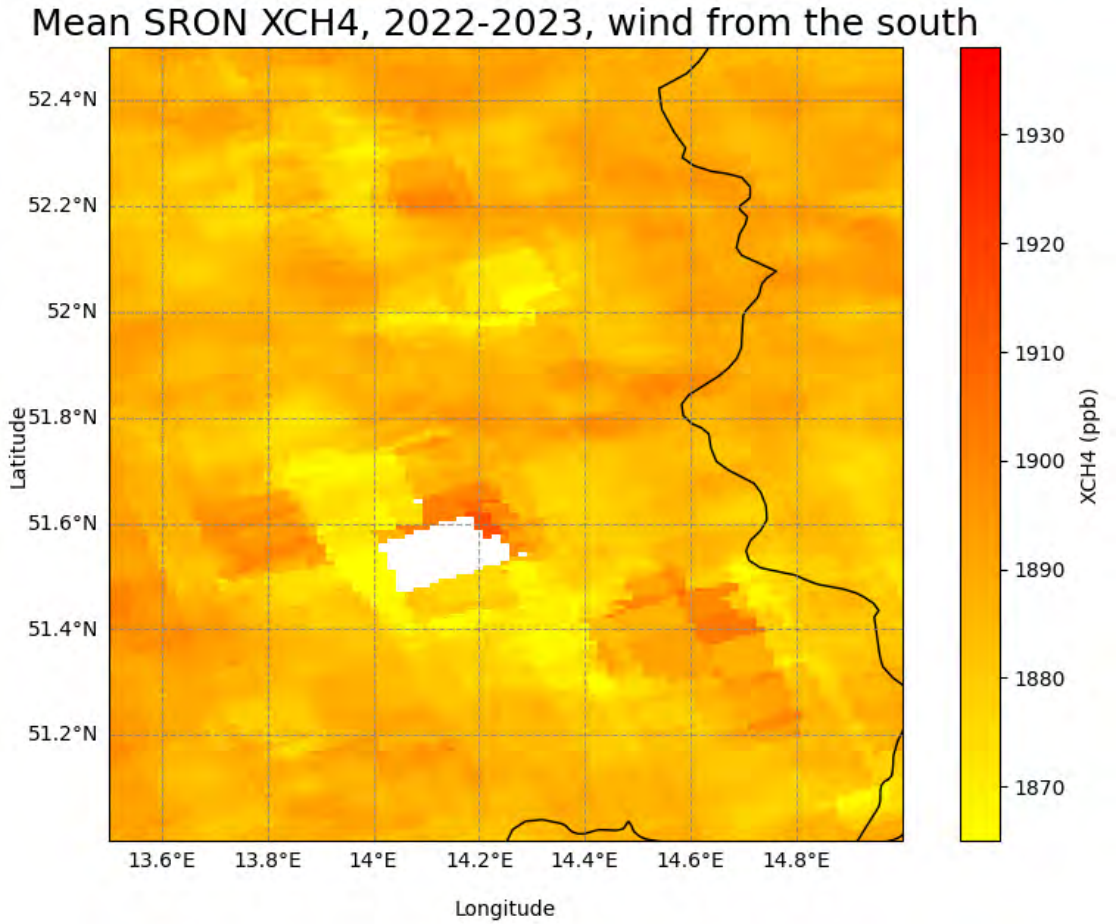

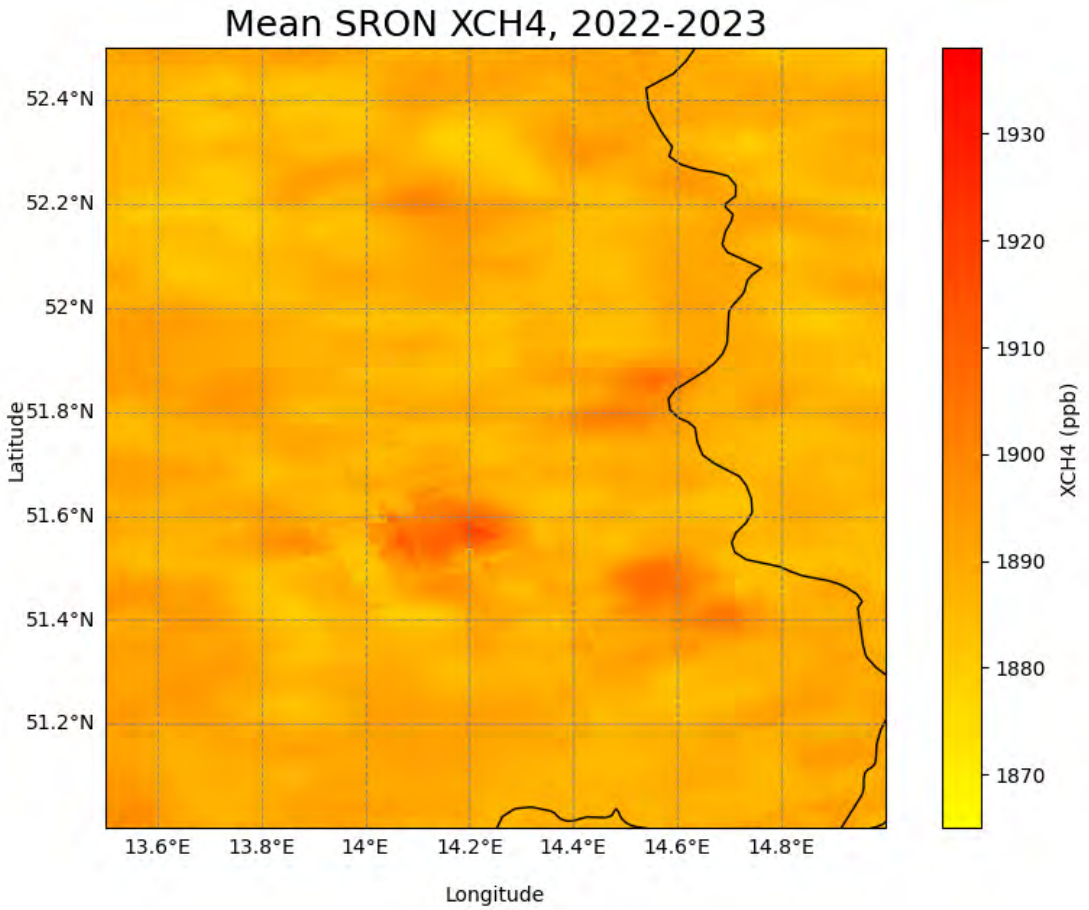

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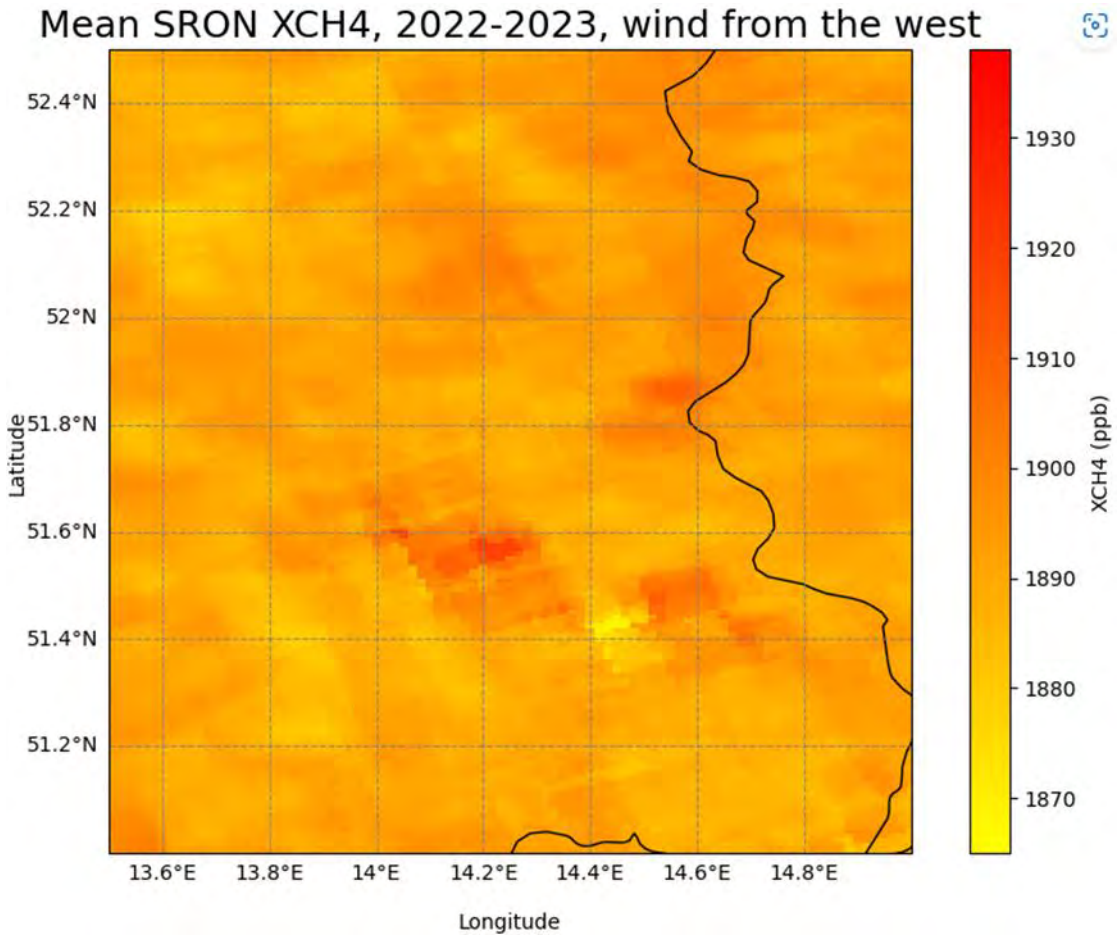
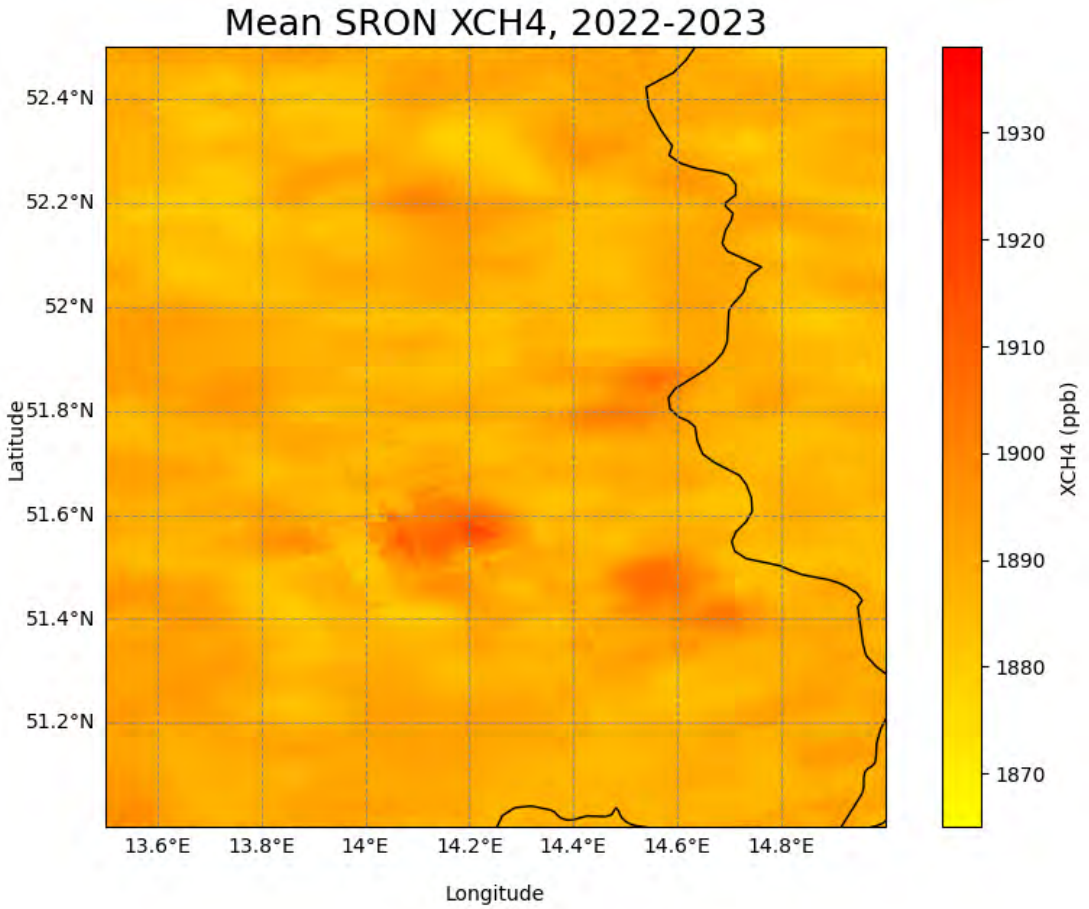




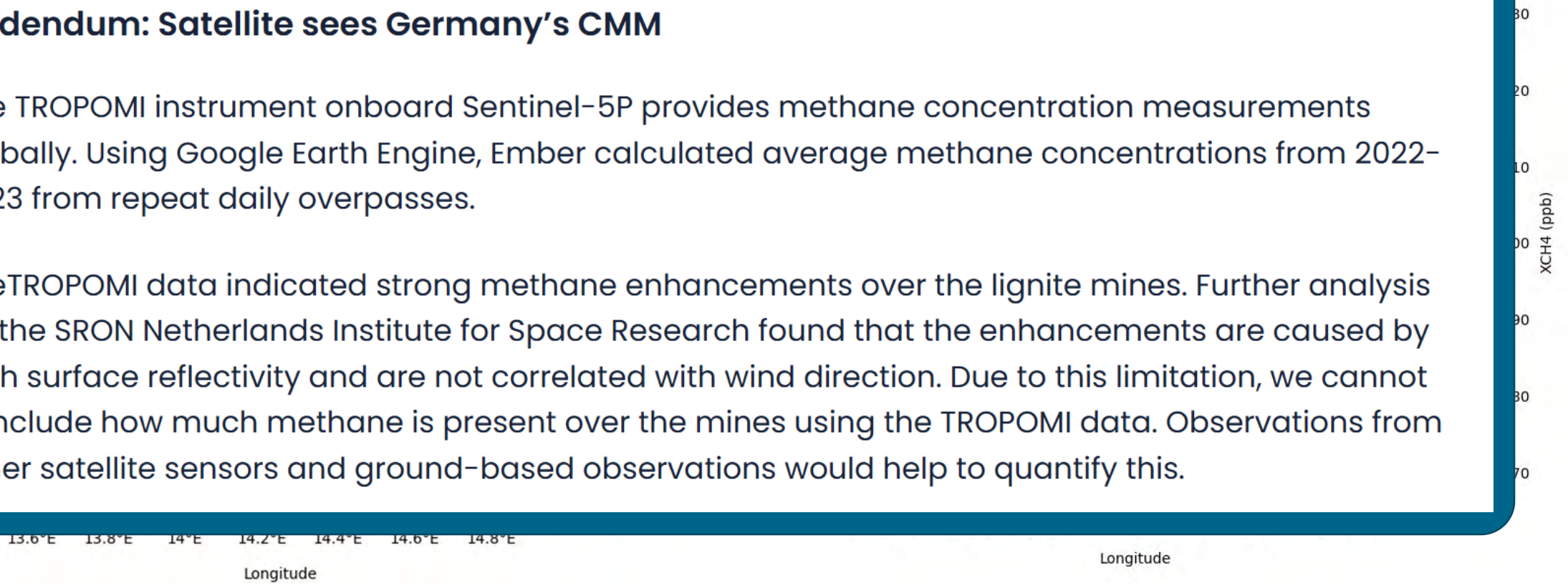
Do we see a plume?

EMBER

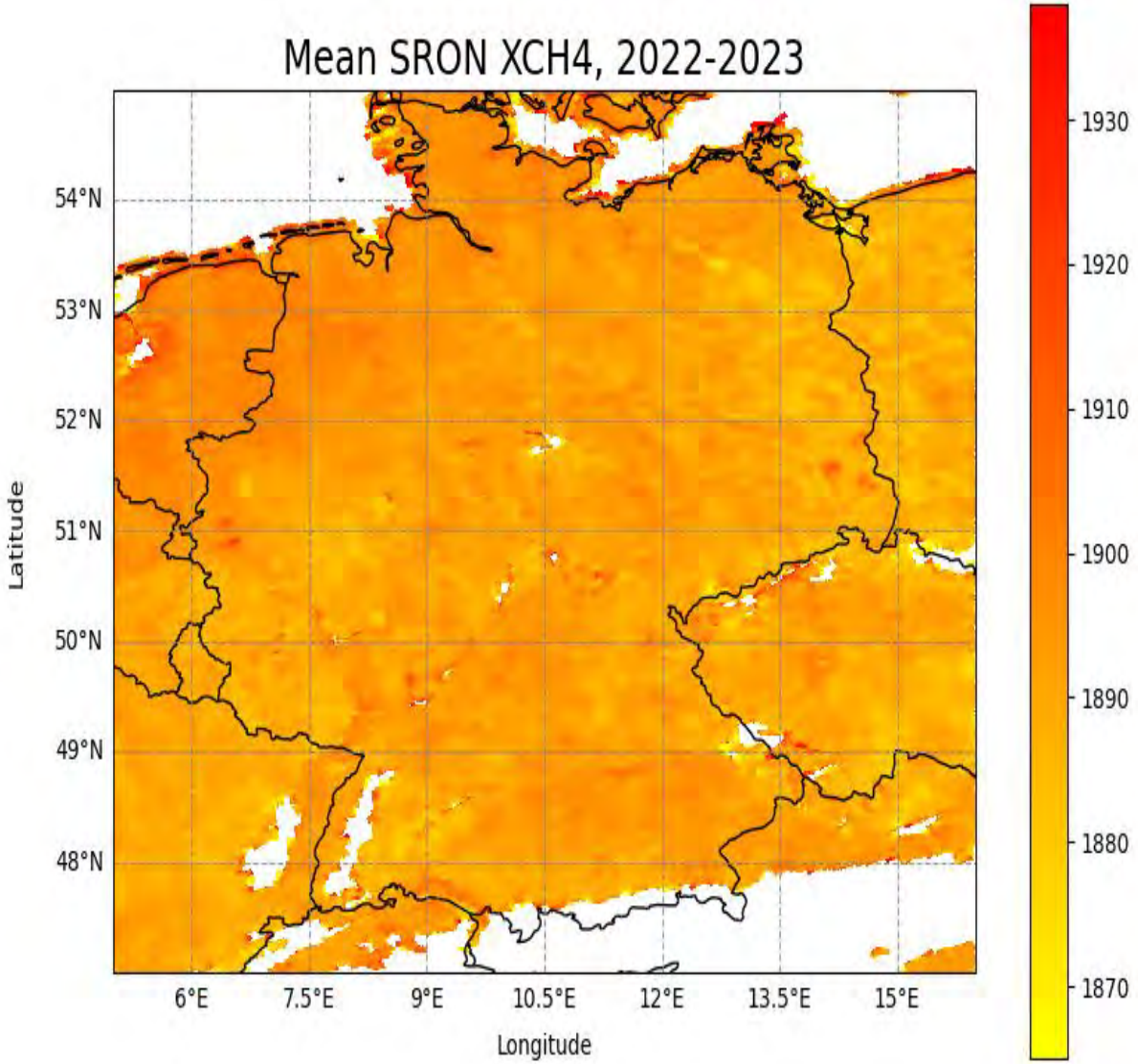
Addendum: Satellite sees Germany's CMM

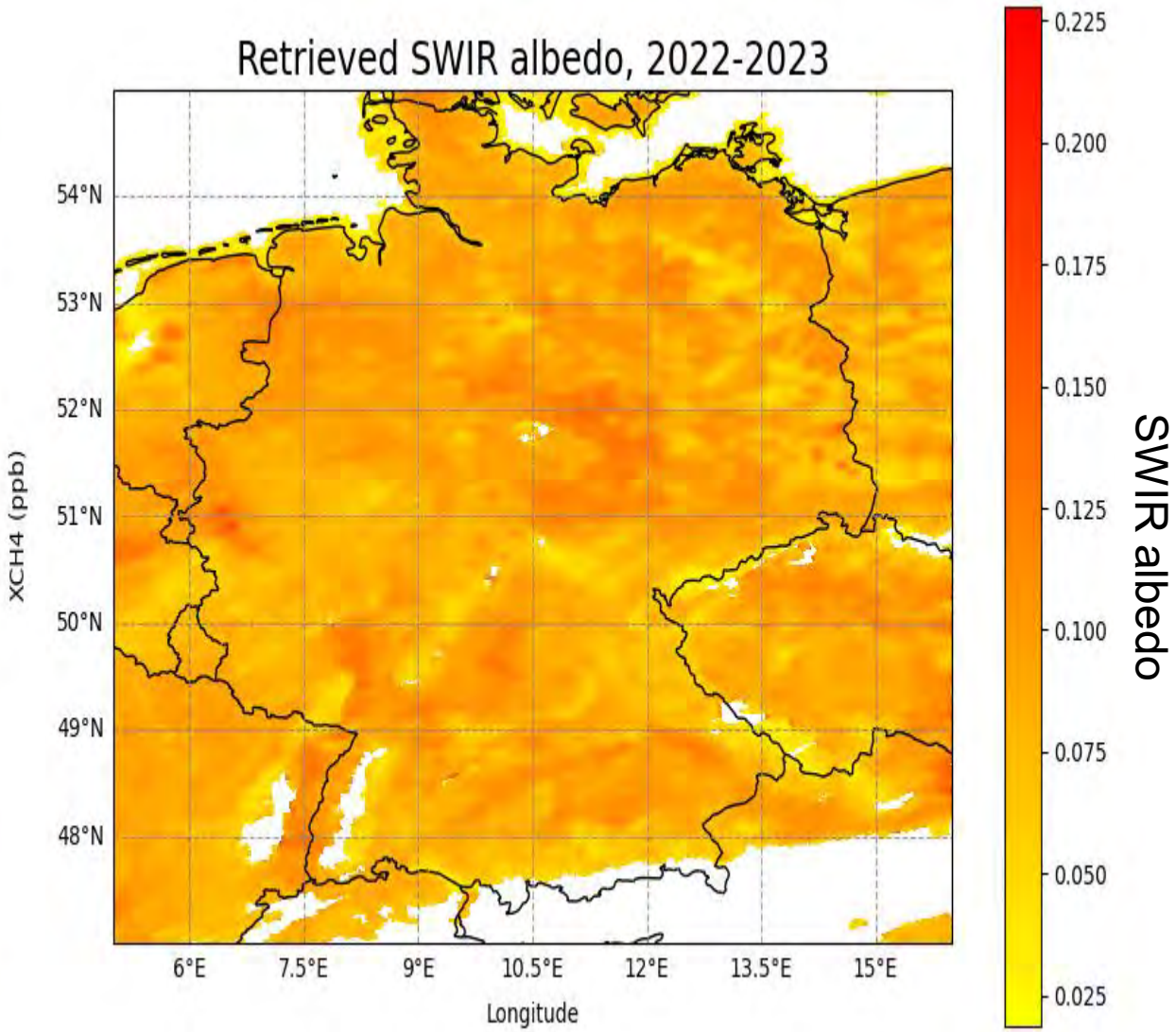
The TROPOMI instrument onboard Sentinel-5P provides methane concentration measurements globally. Using Google Earth Engine, Ember calculated average methane concentrations from 2022-2023 from repeat daily overpasses.

TheTROPOMI 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.



No plume – could it be albedo?





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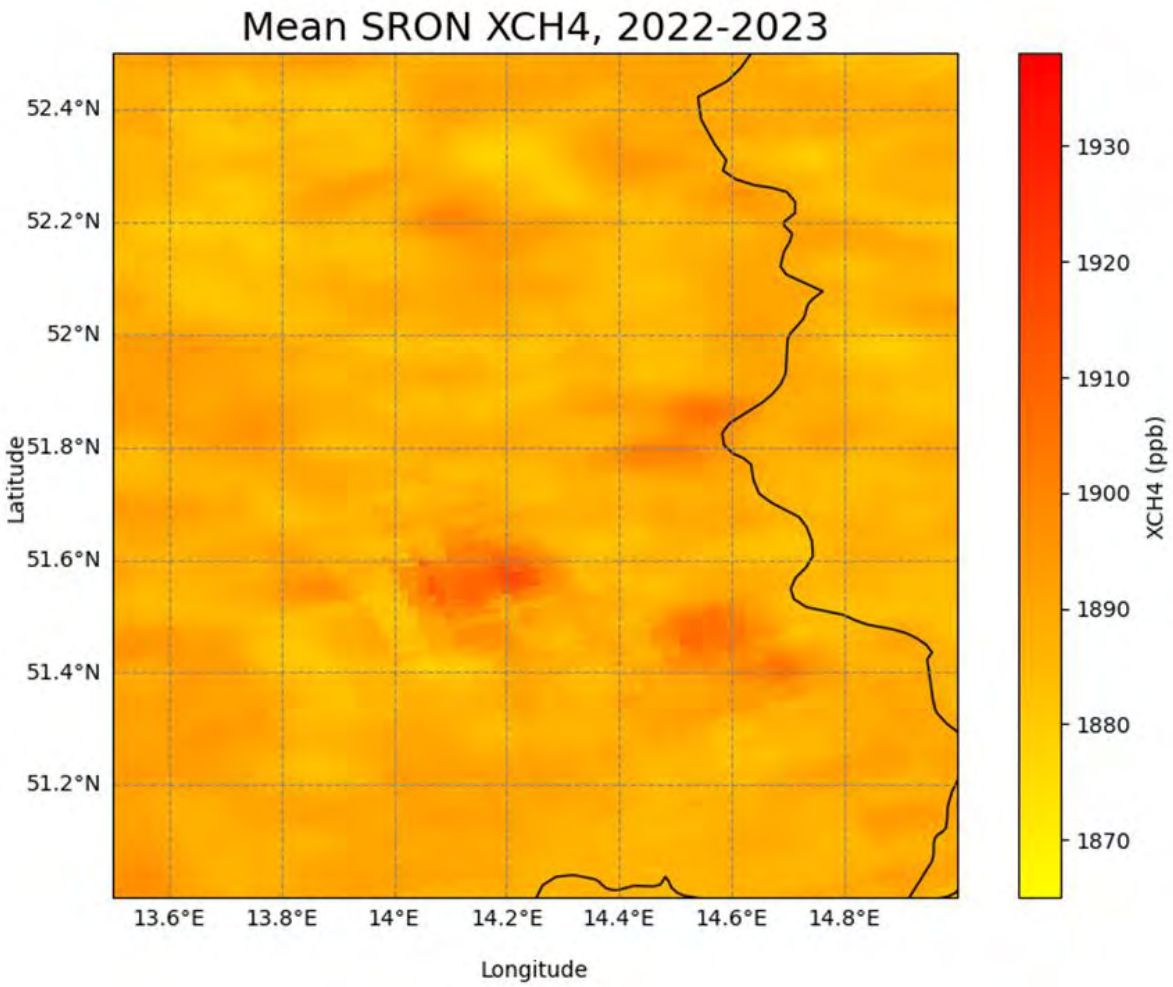
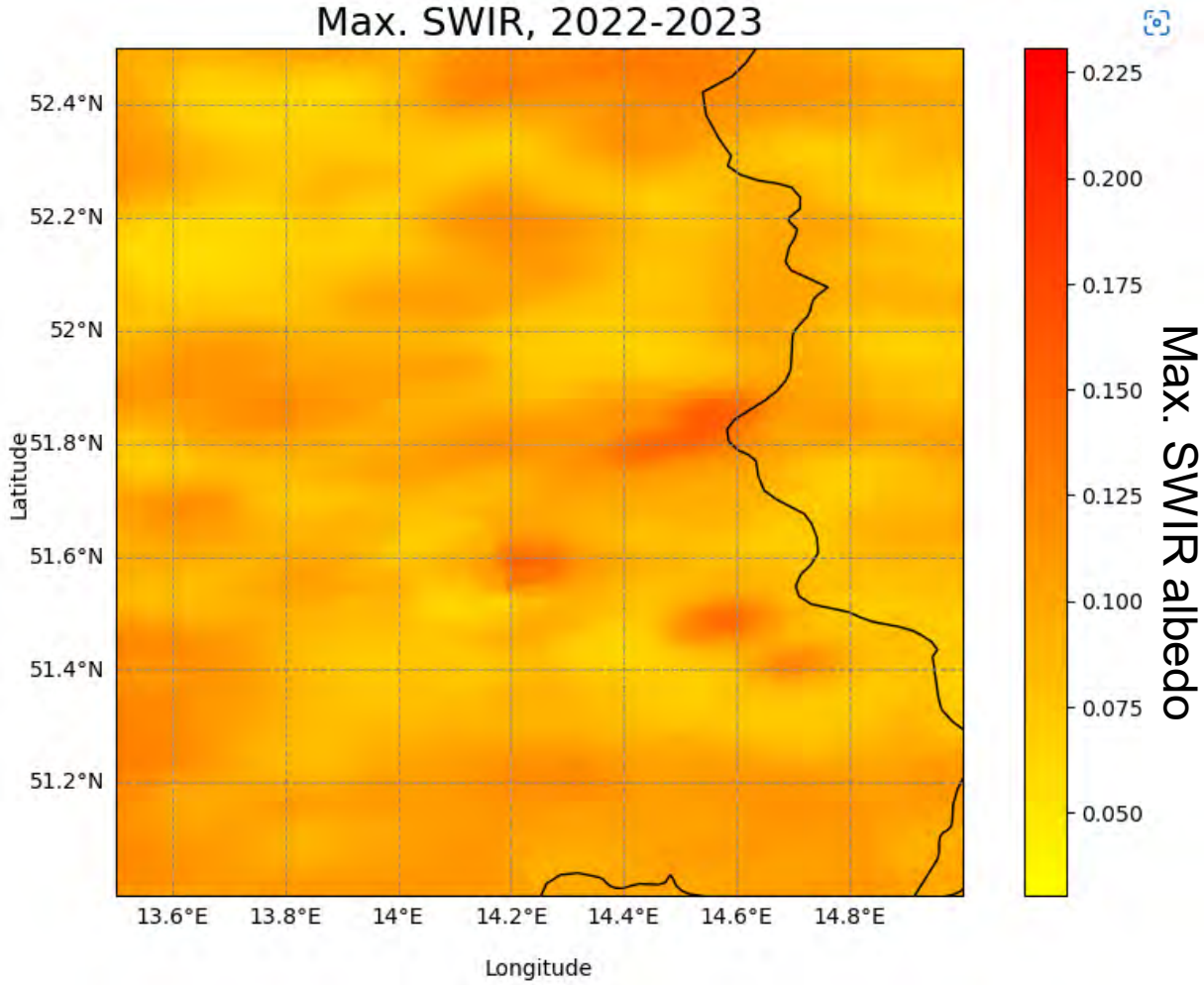
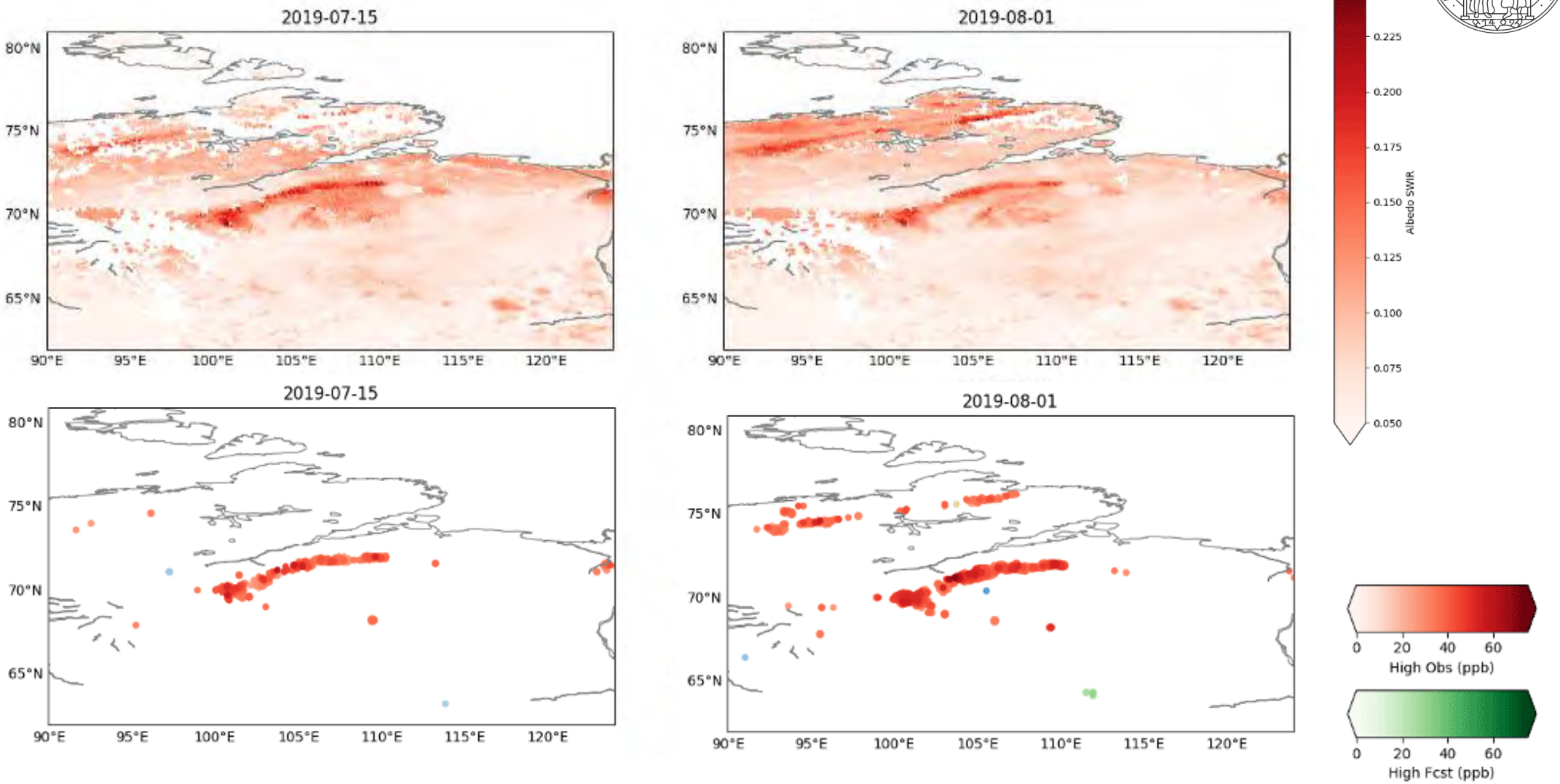
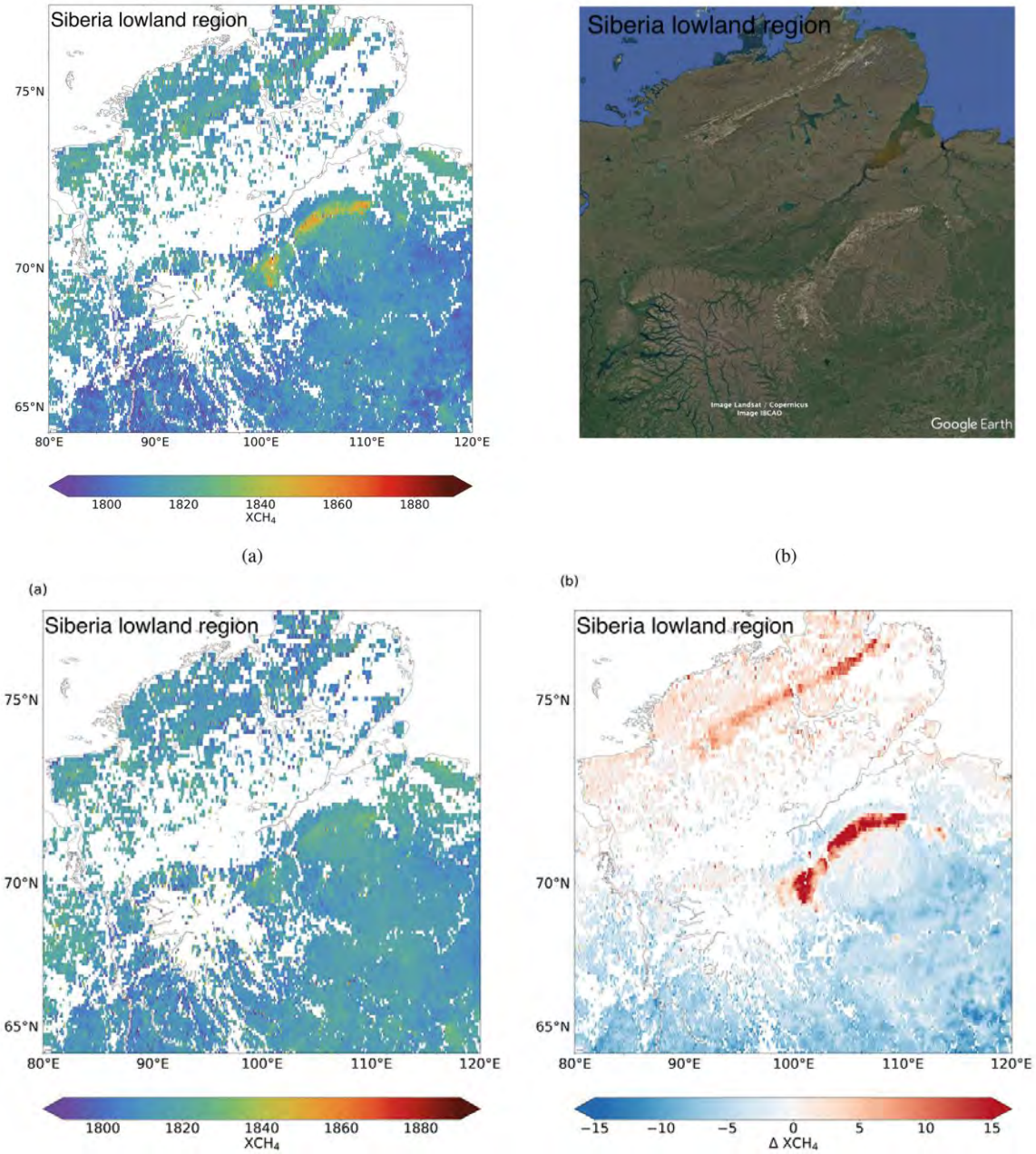




But wasn't the albedo problem (mostly) solved?

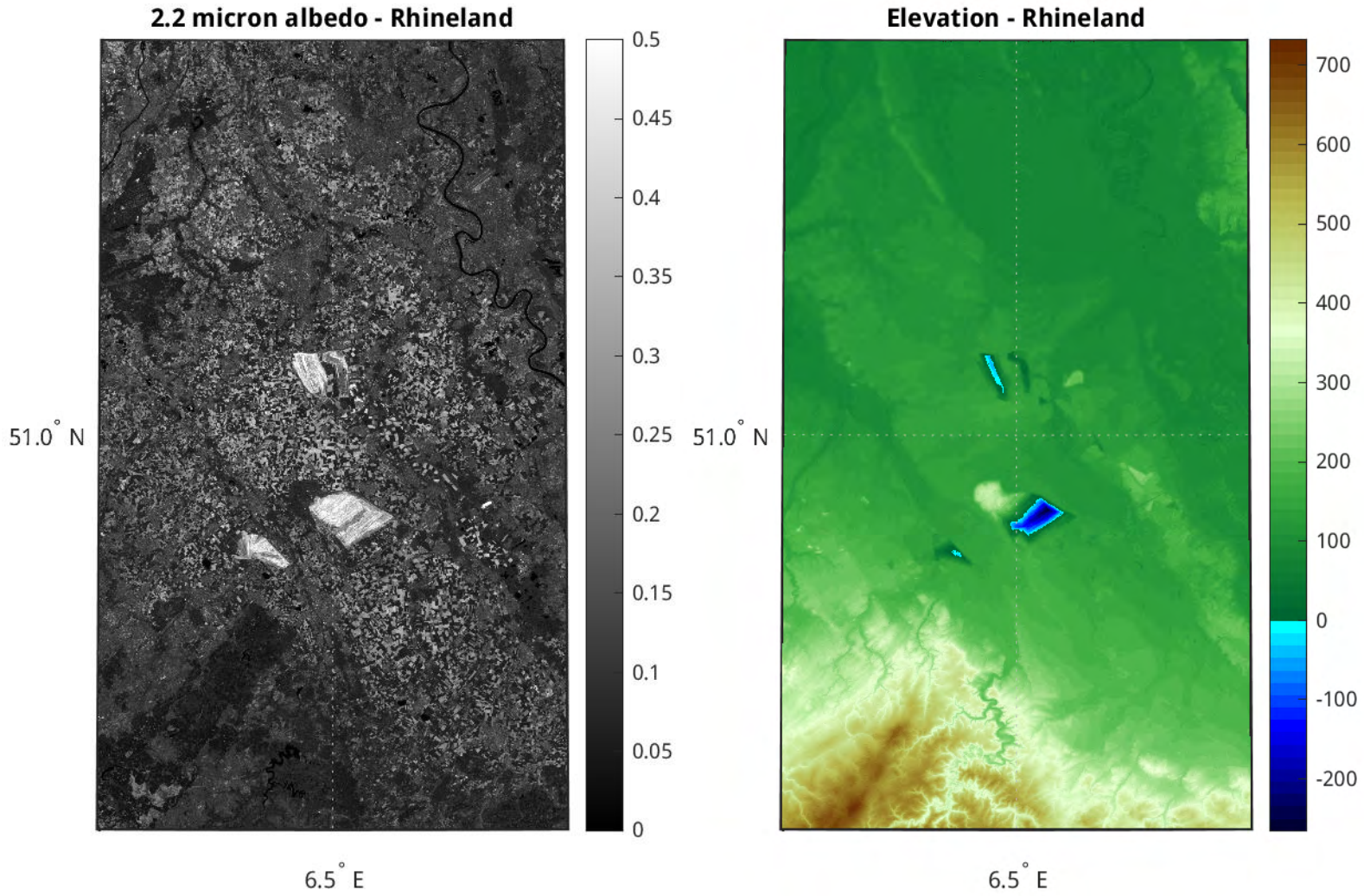


From [Barré et al., 2021]



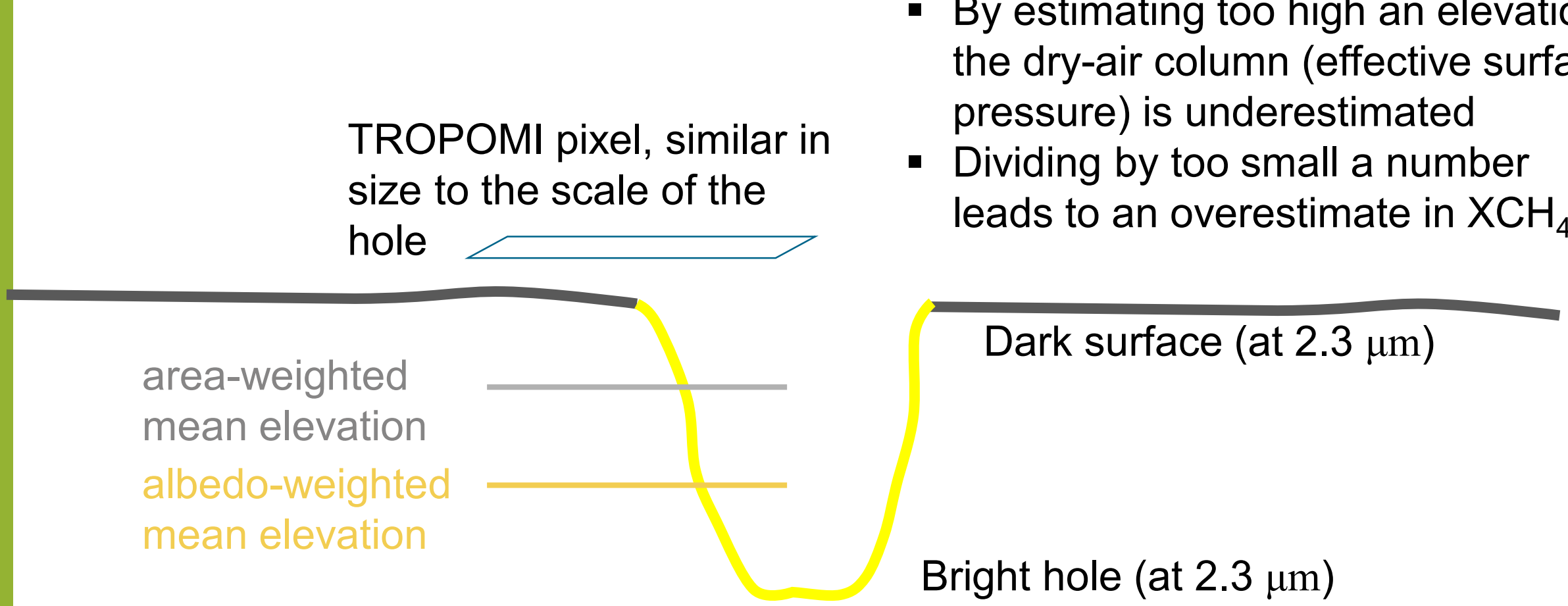
Accounting for surface reflectance features in spectral reflectance (e.g. Lorente et al., 2023) mostly made this go away

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



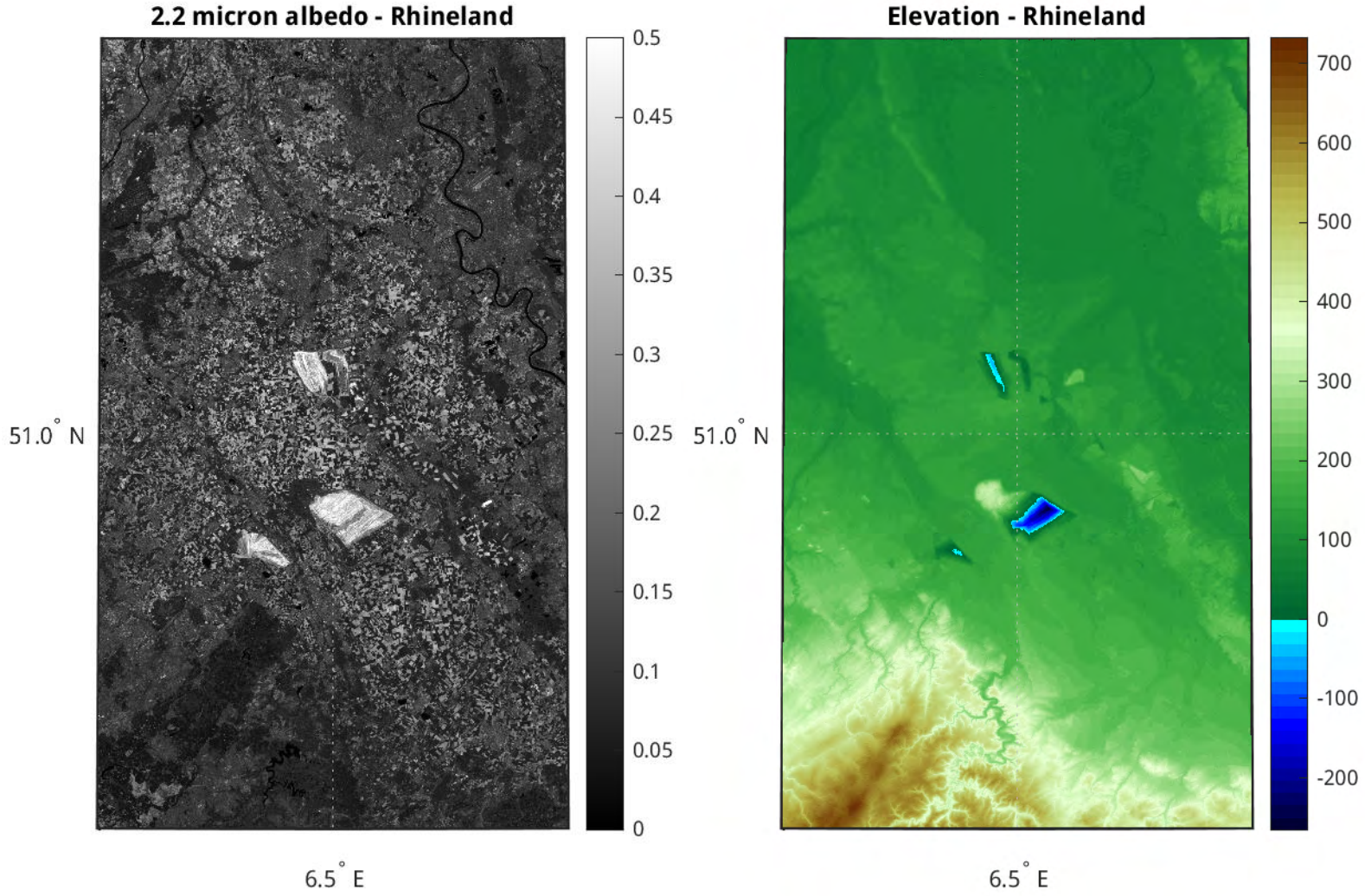
SWIR albedo and elevation are negatively correlated here

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



- 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

Albedo and elevation are negatively correlated here



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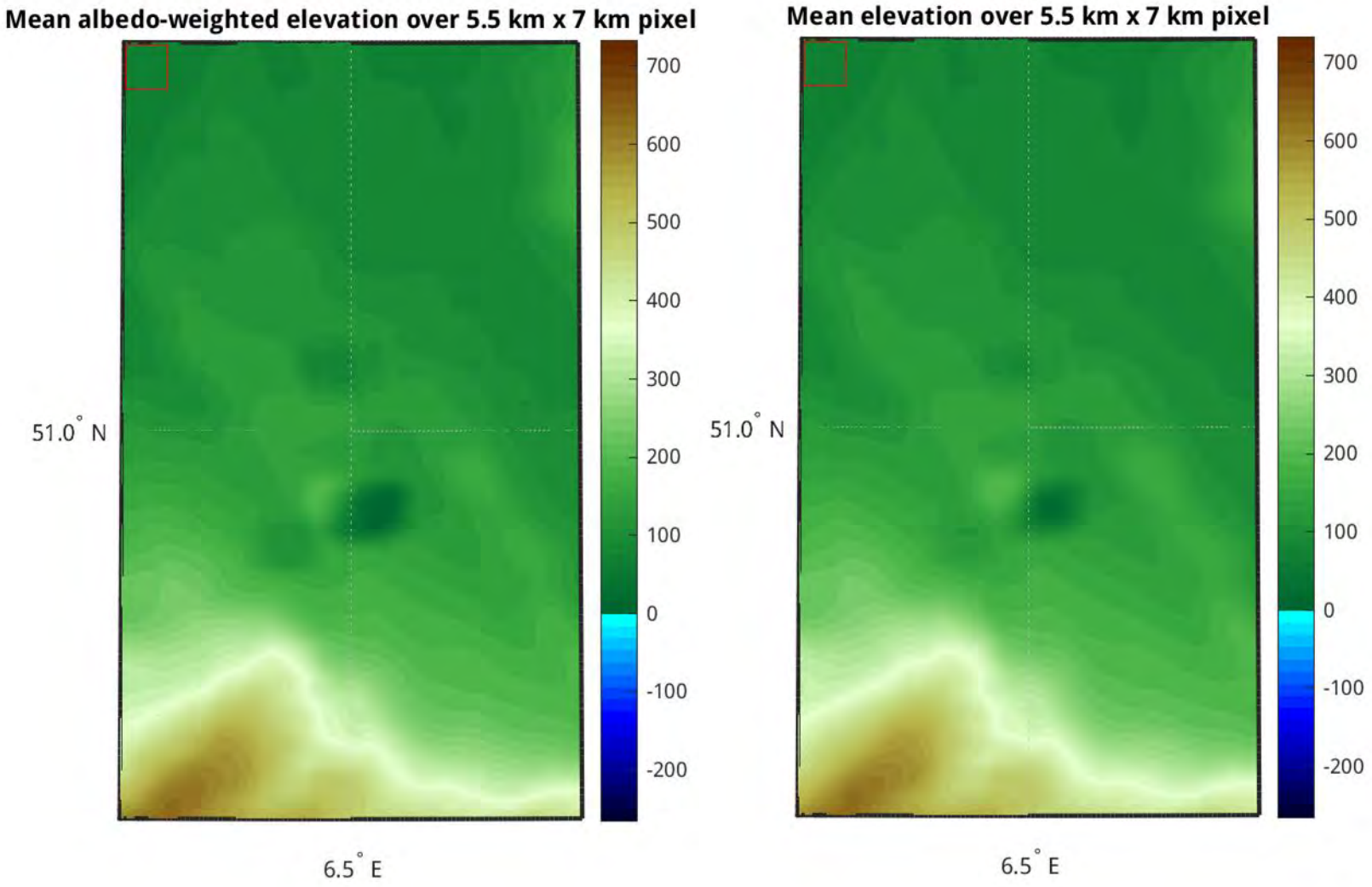
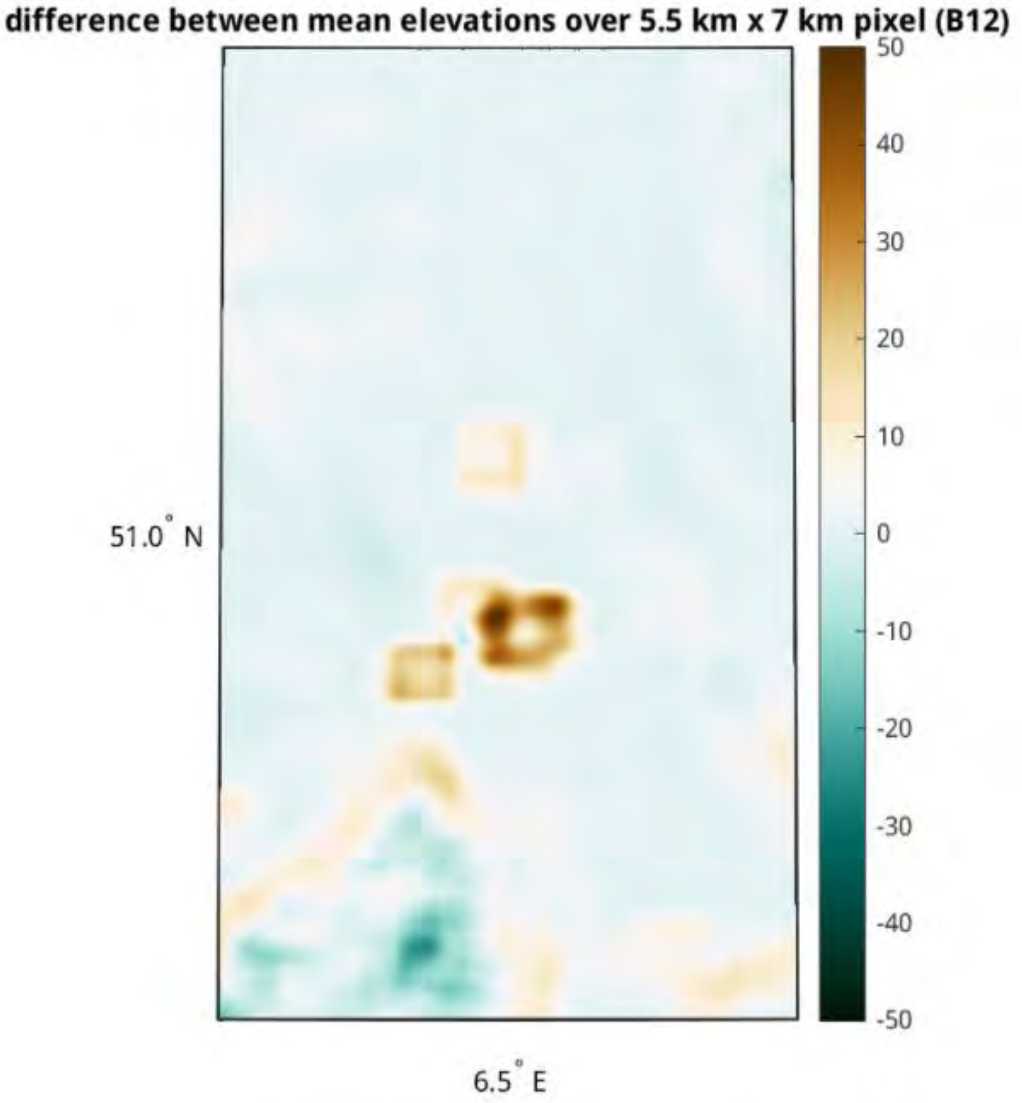
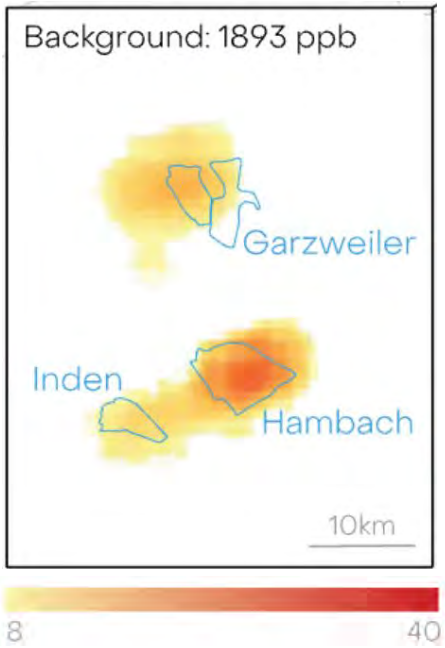


And the difference:

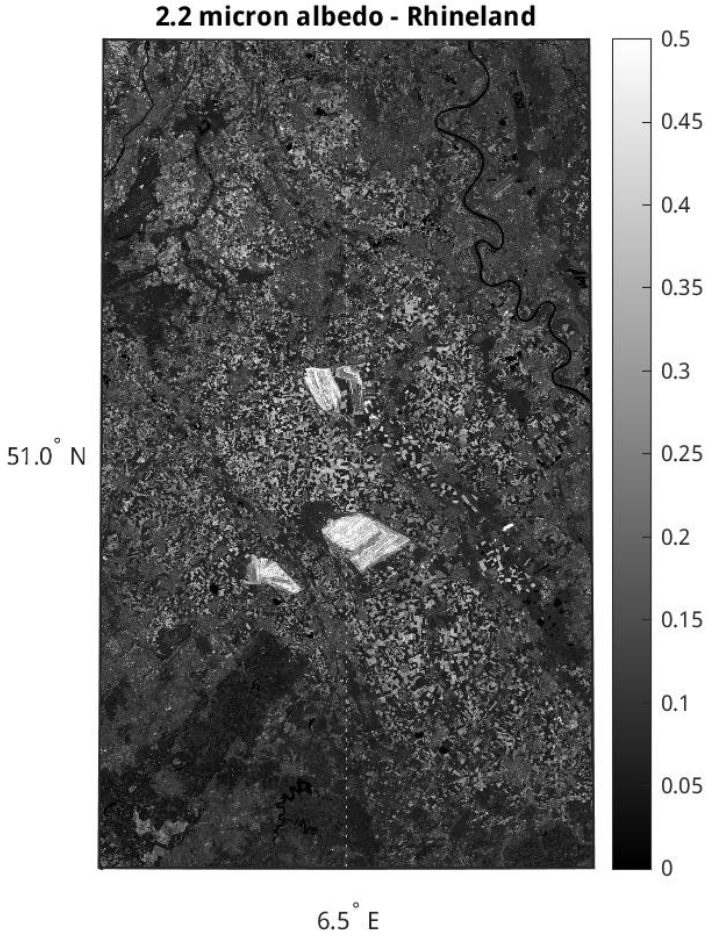


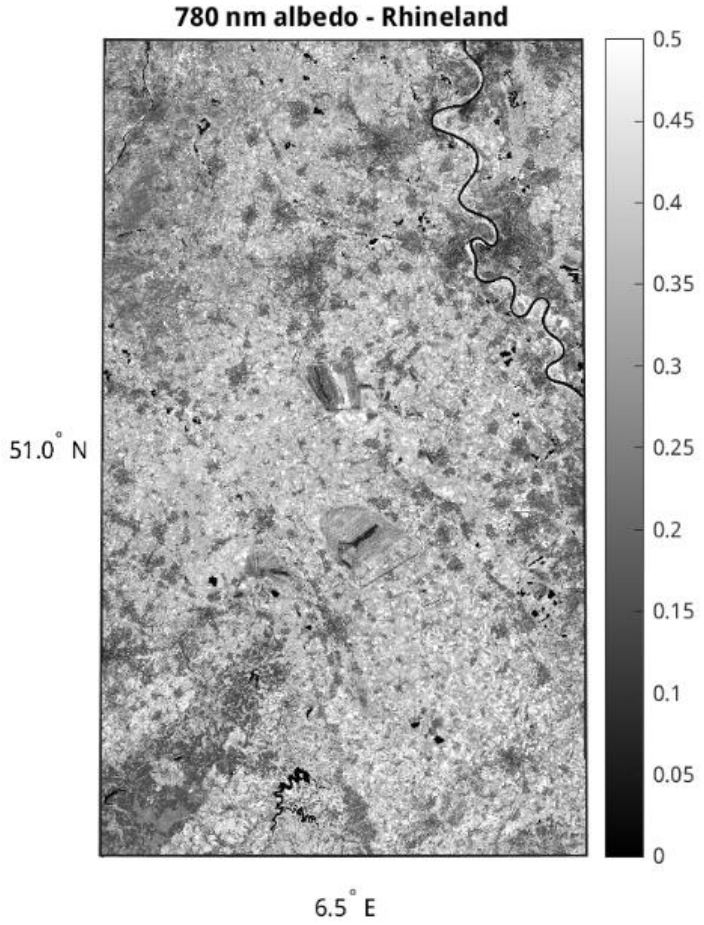
- Maximum differences of around 50 m for this scene
- Using the hypsometric equation, this results in a difference of around 0.6% in the surface pressure estimate, or about 12 ppb
- Maybe not the full story (neglecting complex scattering effects), but it explains the spatial pattern well



Note that the albedo in the O_2 A band is not always correlated with that of the SWIR 2 band…

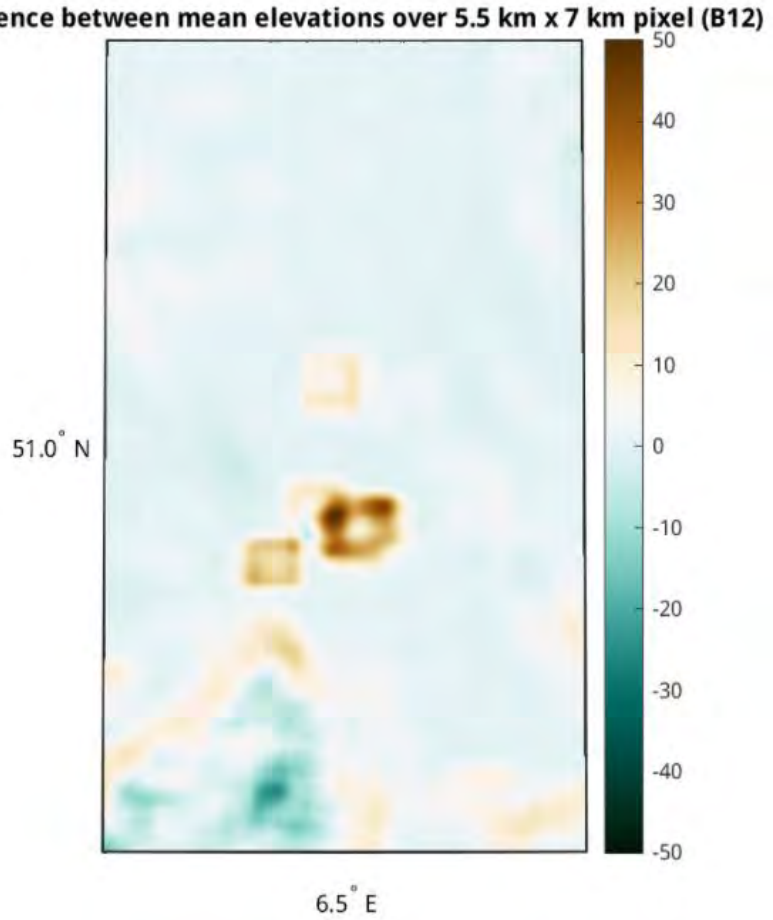
SWIR2 band

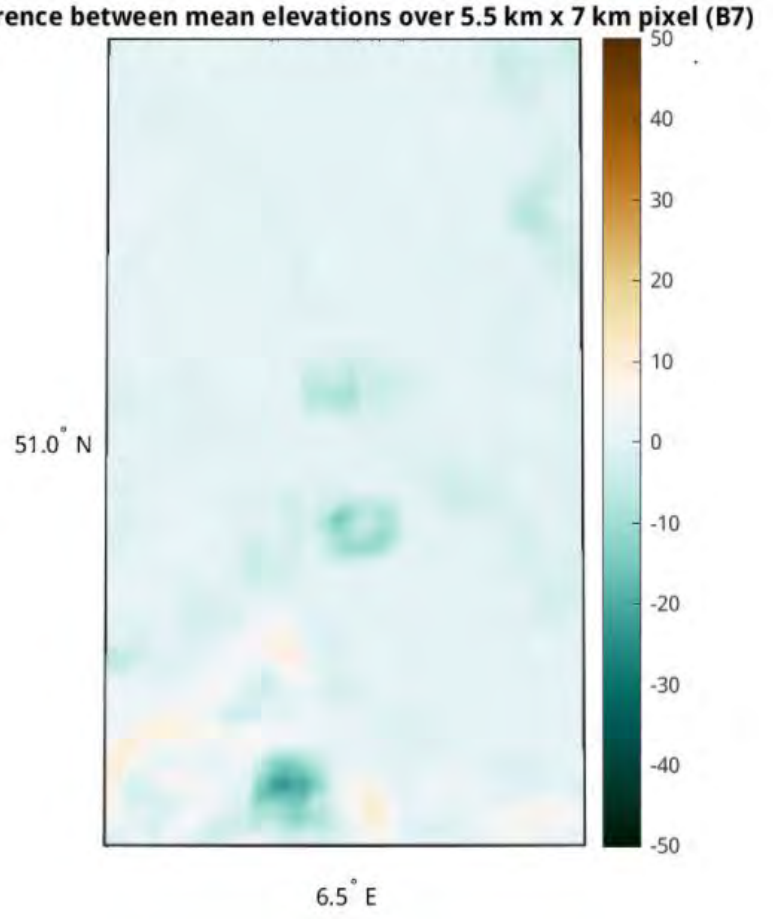




O_2 A band

Note that the albedo in the O_2 A band is not always correlated with that of the SWIR 2 band…





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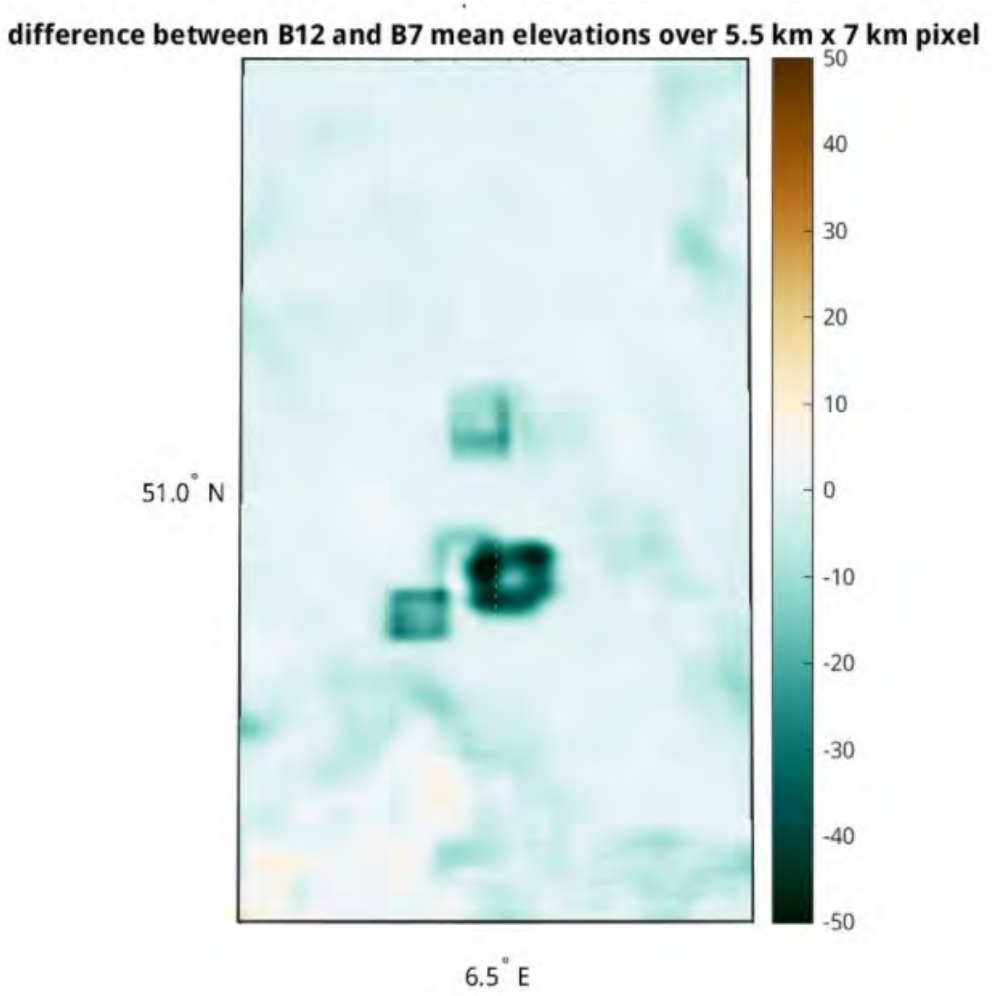
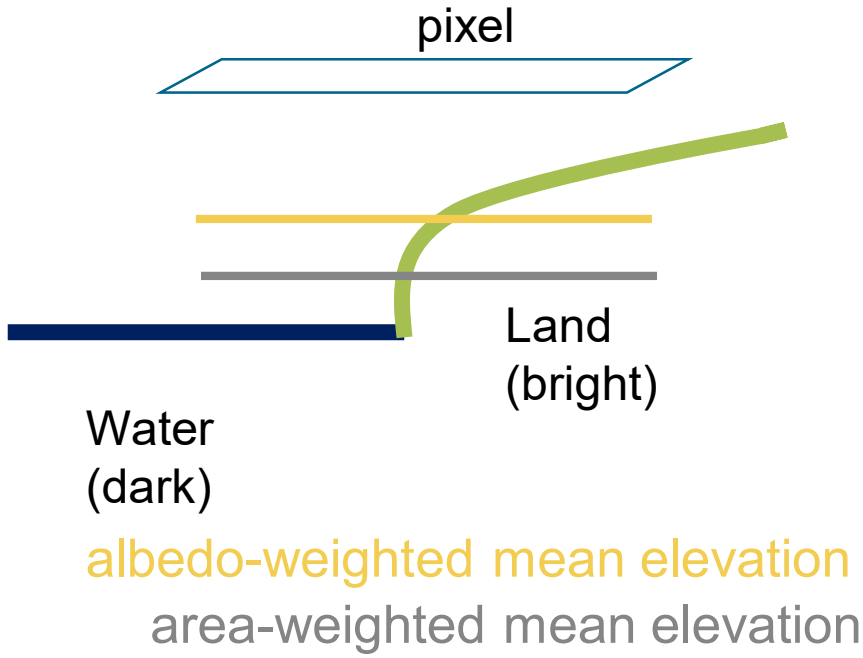


The O_2 A band cannot fix this problem, even with perfect spectroscopy!

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:

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DKRZ

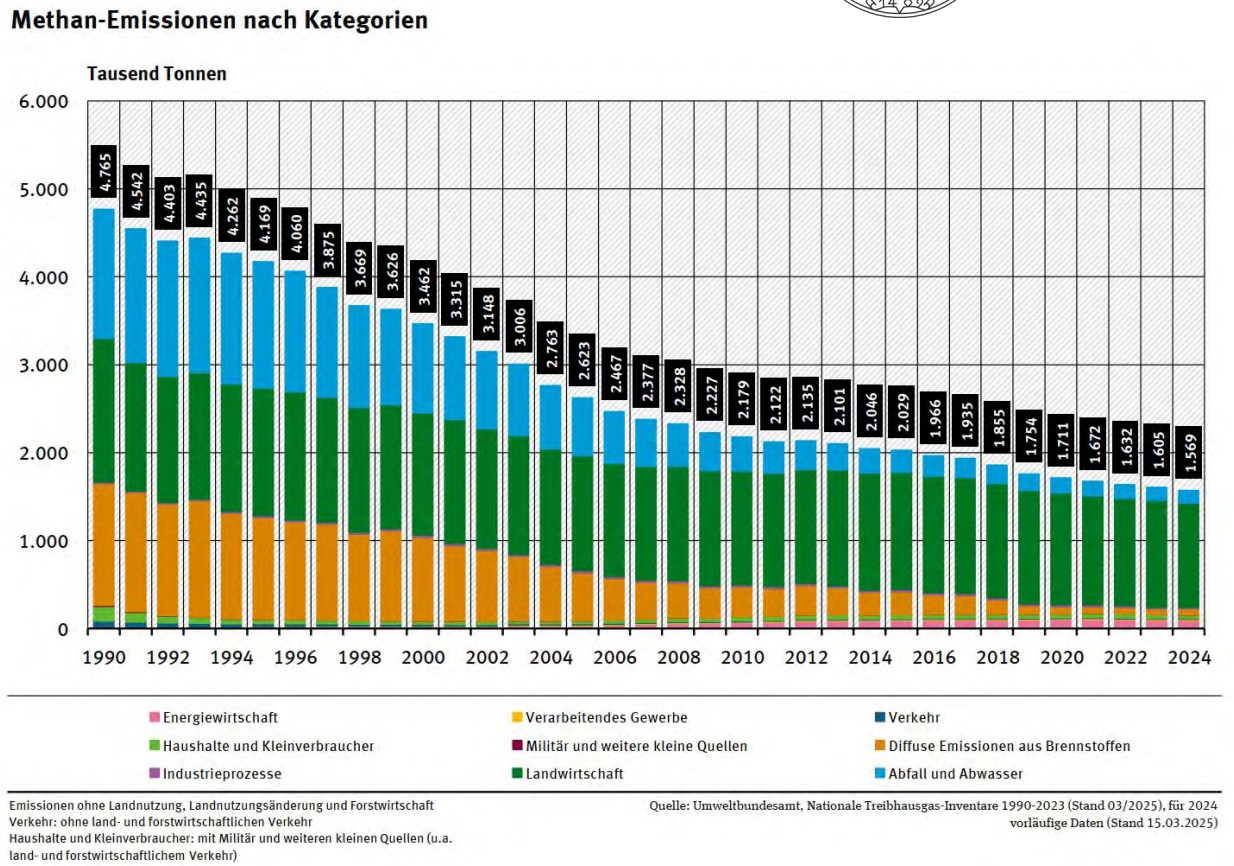
EXTRA SLIDES

In case someone asks the right question ;-)

DLR

About the Shen et al. (2023) inversion

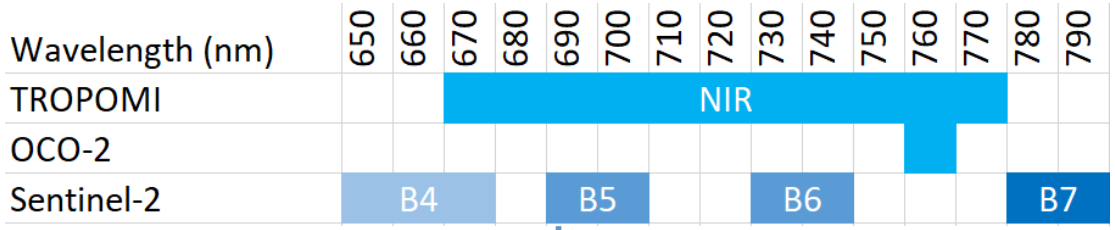
- Number given for coal emissions is 110 kt/yr, with a range of 6-280
- Very sensitive to the prior!
- 50-km resolution (transport and fluxes) for Germany
- No category-specific information on non-fossil posterior or prior emissions on the country scale
- ~75% of Germany's emissions are from agriculture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

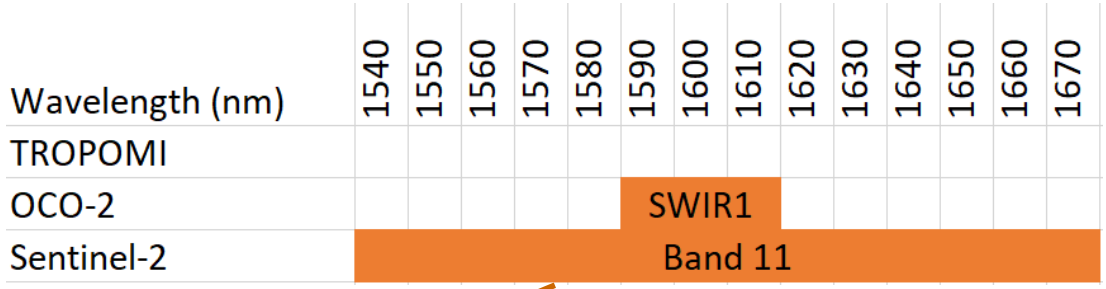


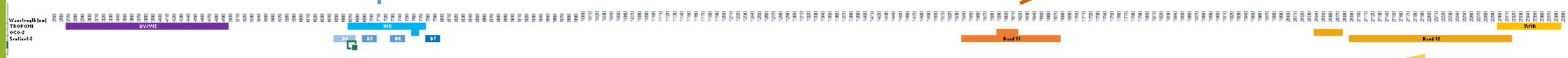
Countries	using GFEIv2 (UNFCCC)		using GFEIv1		using EDGARv6		Averaged posterior ($Tg\ a^{-1}$)
	Prior ($Tg\ a^{-1}$)	Posterior ($Tg\ a^{-1}$)	Prior ($Tg\ a^{-1}$)	Posterior ($Tg\ a^{-1}$)	Prior ($Tg\ a^{-1}$)	Posterior ($Tg\ a^{-1}$)	
Germany	0.01	0.01	0.10	0.14	0.14	0.18	0.11

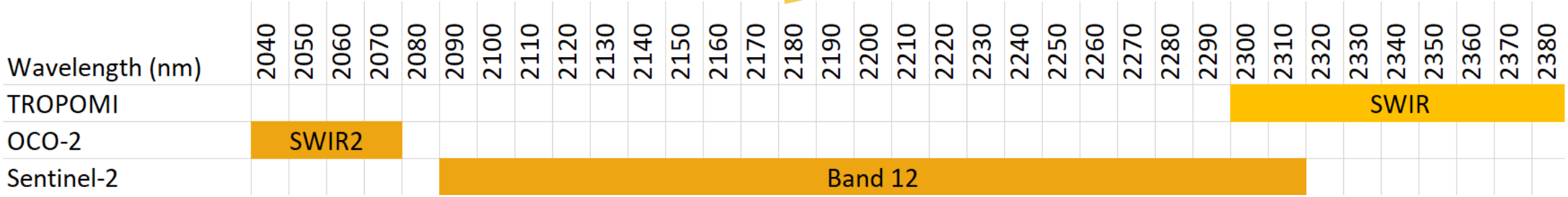
From Table 6 of the supplement to Shen et al. (2023)

Spectral bands of relevant remote-sensing instruments

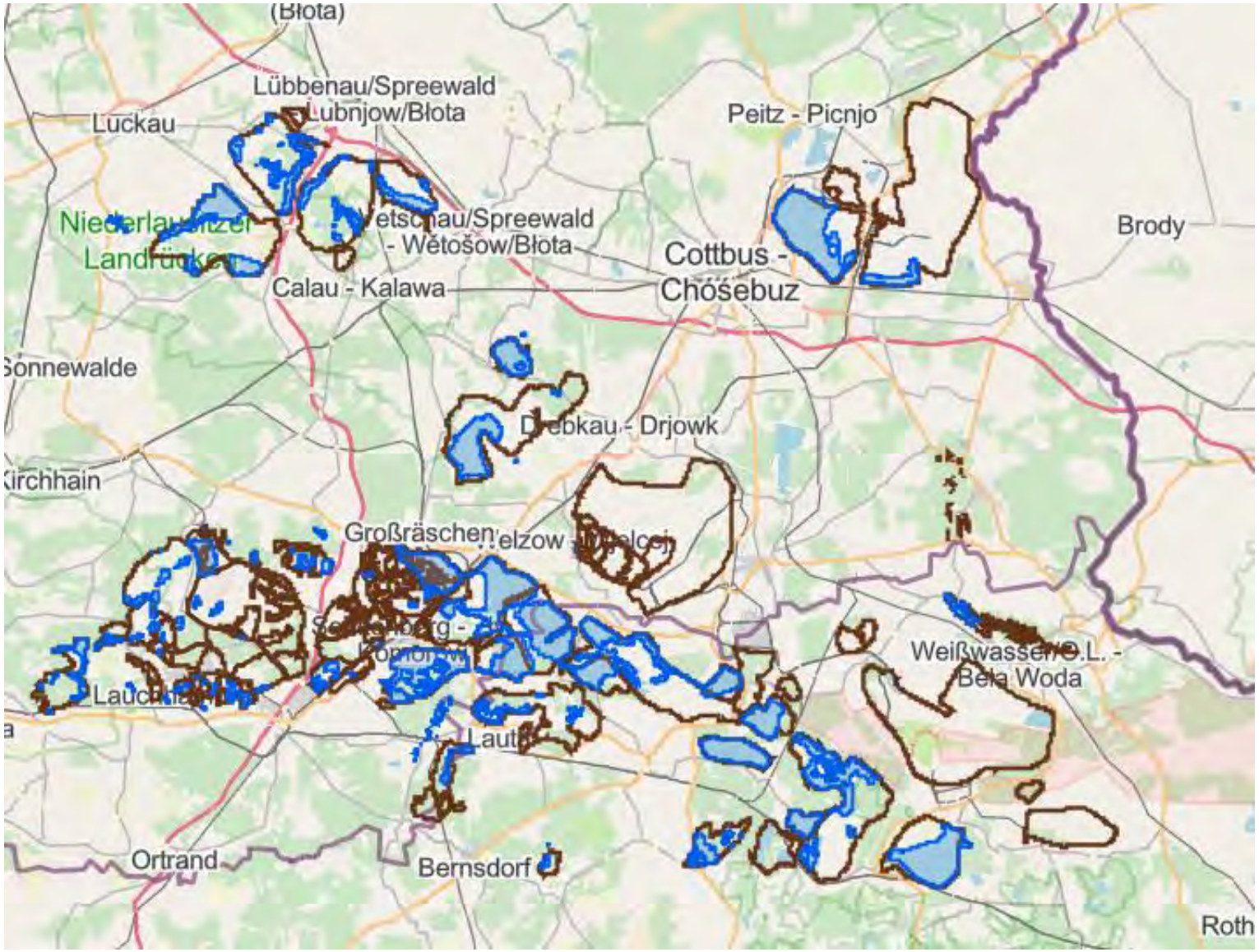


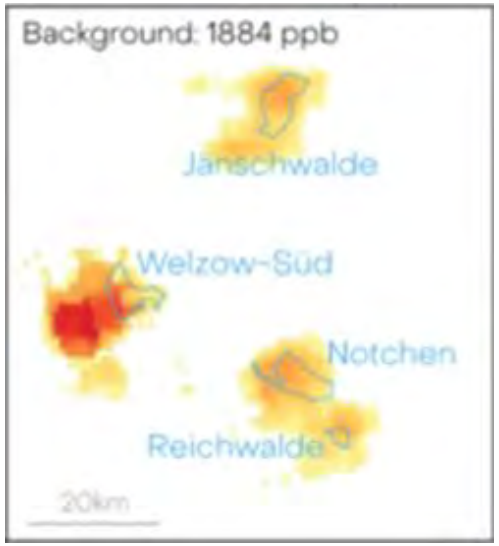






Other complications in the Lausitz





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.

Flutungsstand - LMBV

Albedo timeseries in the Lausitz

2020-09-20

2022-09-25

2024-09-19

2020-09-20

2022-09-25

2024-09-19