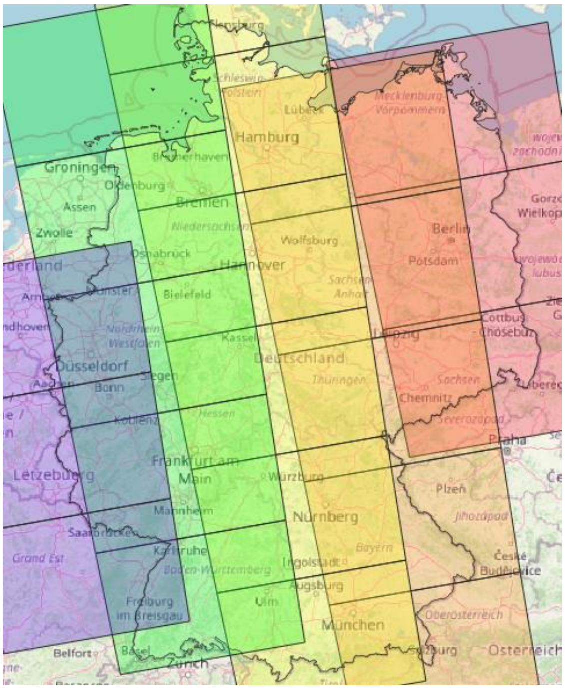
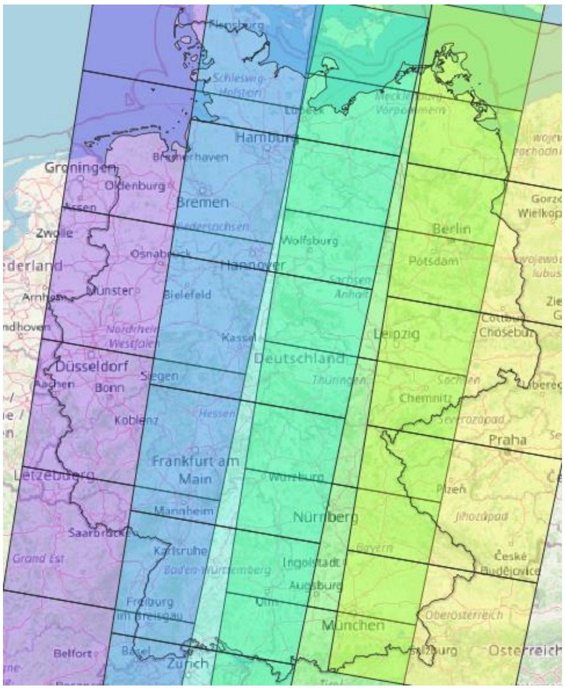
Flood monitoring with Sentinel-1 radar data in northern Germany

Prolonged rainfall over Christmas and New Year 2024 led to flooding in large parts of Germany. The flooding, which is still continuing in some areas, has been putting pressure on the dikes for a longer period of time as they are gradually starting to leak. This increases the local risk of dam failures. The persistent rainfall had spread over a large area and extended over the Harz and Rhön areas as well as the catchment areas of the rivers Aller, Weser and Leine. When the water masses of these rivers reached the North German plain, the flow rate slowed and the water expanded in width, as it had already rained persistently in these areas.

With radar data from the Sentinel-1 satellite you can see through the clouds. In addition, the satellite is independent of daylight because it uses its own energy. During the precipitation phase it was almost entirely cloudy and there was no other way to map the extent and duration of the floods on a large scale.

Radar satellites send a microwave with a wavelength of about 5.5 cm that easily penetrates the clouds. The microwaves are refracted on the surface and the reflection (backscatter) is in turn measured by the satellite. Sentinel-1 satellites orbit the Earth in a polar orbit at an altitude of 700 km. Each circumnavigation takes approximately 90 minutes.
We have an ascending and a descending capture mode. The repetition rate for each orbit is 12 days.
Data is recorded in strips approximately 240 km wide. Each individual footprint has a size of 200x240 km. The overlap of the footprints increases towards the poles.



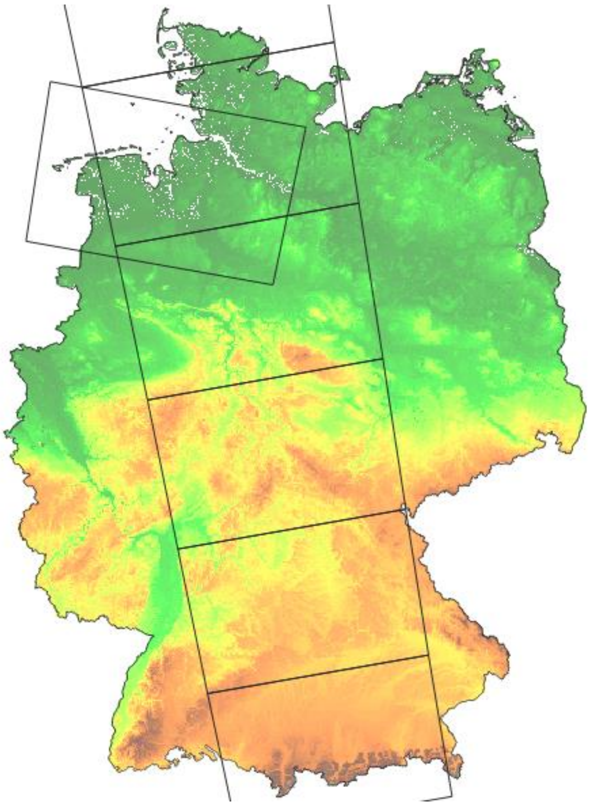


For flood monitoring, sections from different overlapping footprints can be used for defined areas. This results in shorter time intervals.

The Ascending 117 orbit was used for this monitoring. It covers Germany to a large extent.

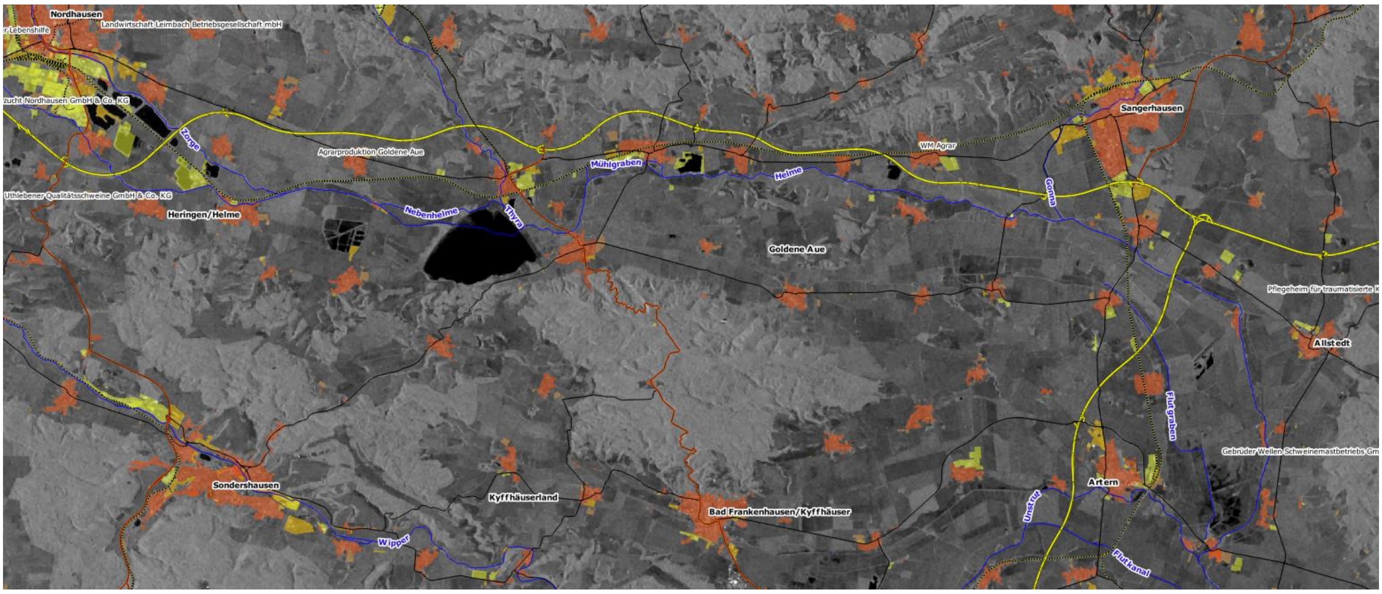
The overflight time is approximately 2 minutes. This will cover an area of approximately 200,000 sqkm captured in its entirety.

In addition, a footprint of the orbit Descending 139 was used to analyze another recording time in the overlap area.



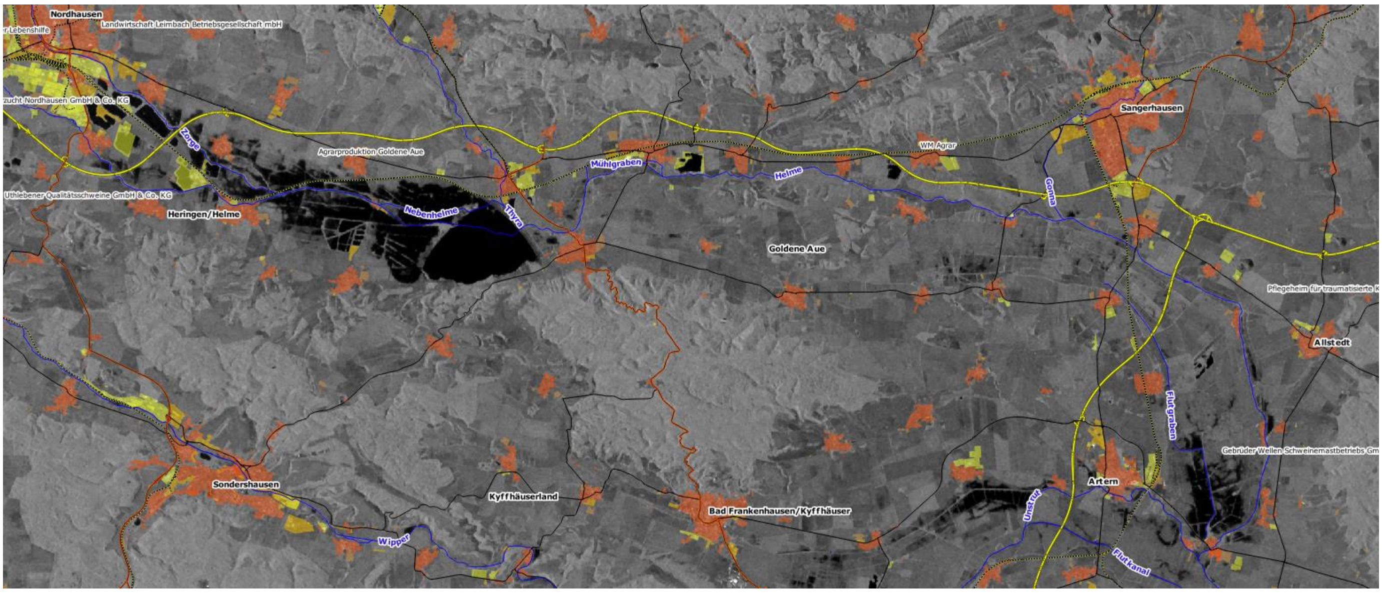
Let us first look at an area near Nordhausen on the border between Thuringia and Saxony-Anhalt.

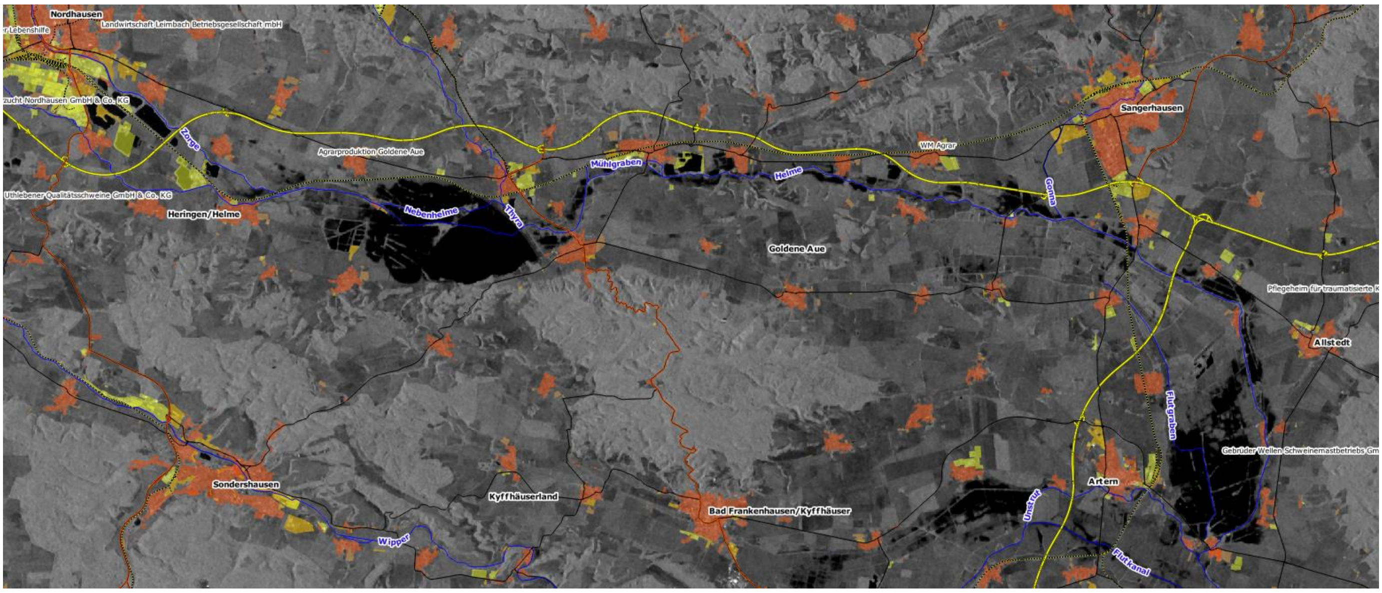
The image below is from December 13th before the flooding and shows water in black in a monochrome satellite image.
The microwave that hits a water surface is not scattered, but completely deflected. Due to that reason the backscatter there is low. Water surfaces therefore appear black.



Bright areas represent forests, as their vegetation causes high backscattering.
The image is overlaid with colored open street map data. They show roads, railways, rivers and settlement areas, which are differentiated by color into residential, industrial and commercial areas. Some agricultural businesses are shown in brown.
If you zoom in on the map you can see more details.

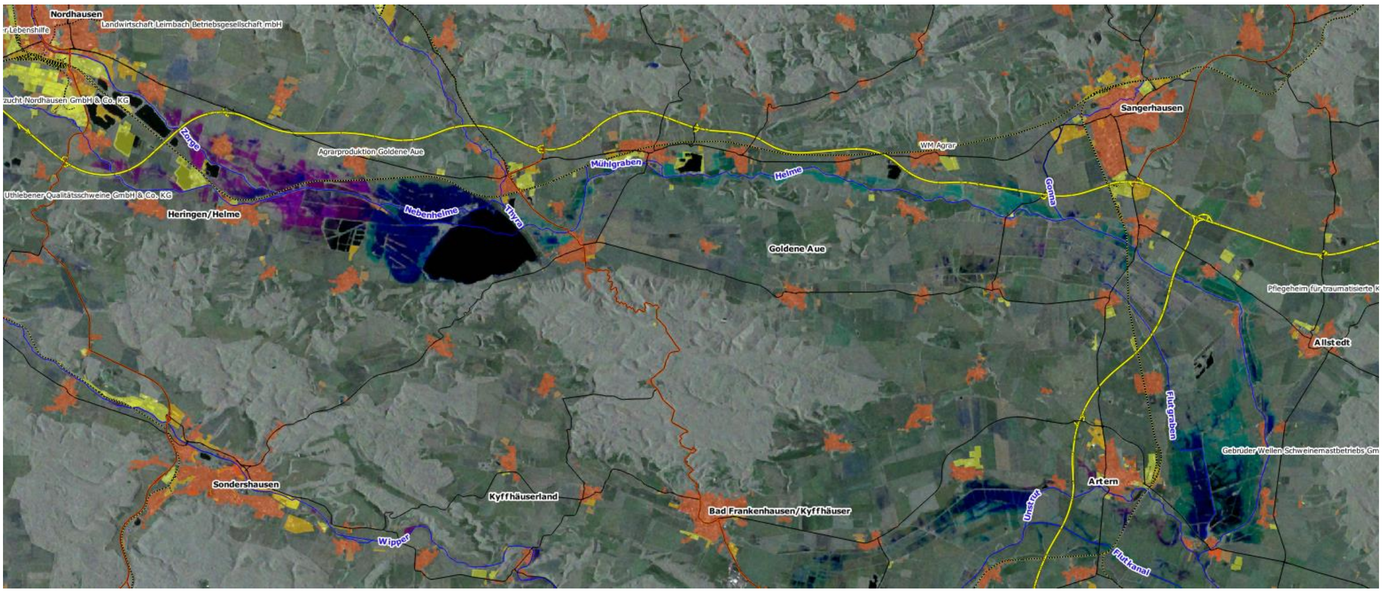
The second recording is from December 25th. You can see the flooded areas especially east of Nordhausen. The water comes from the Kelbra dam.





The lower image is from January 6, 2024. While the water has partially drained away east of Nordhausen, new flood areas have expanded in the upper reaches of the Hamme as more precipitation has occurred in the meantime.
You can clearly see the flooded areas to the left and right of the river.

The image below now combines the three consecutive shots into one color image. The recording from December 13th was placed on the blue channel, the recording from December 25th was placed on the green channel and the recording from January 6th was placed on the red channel.
As a result, those areas that have a high blue value and low red and green values appear in blue on the map. The values are low where the area is flooded. Because the blue areas were flooded on December 25th and January 6th, and were not flooded only on December 13th, they appear in blue color.



Accordingly, what was flooded on December 25th appears in pink, but was no longer flooded on January 6th and not yet on December 13th. The color there is a mixture of blue and red.
The areas that were not flooded on December 13th and December 25th, but on January 6th appear in turquoise. The color there is a mix of blue and green.

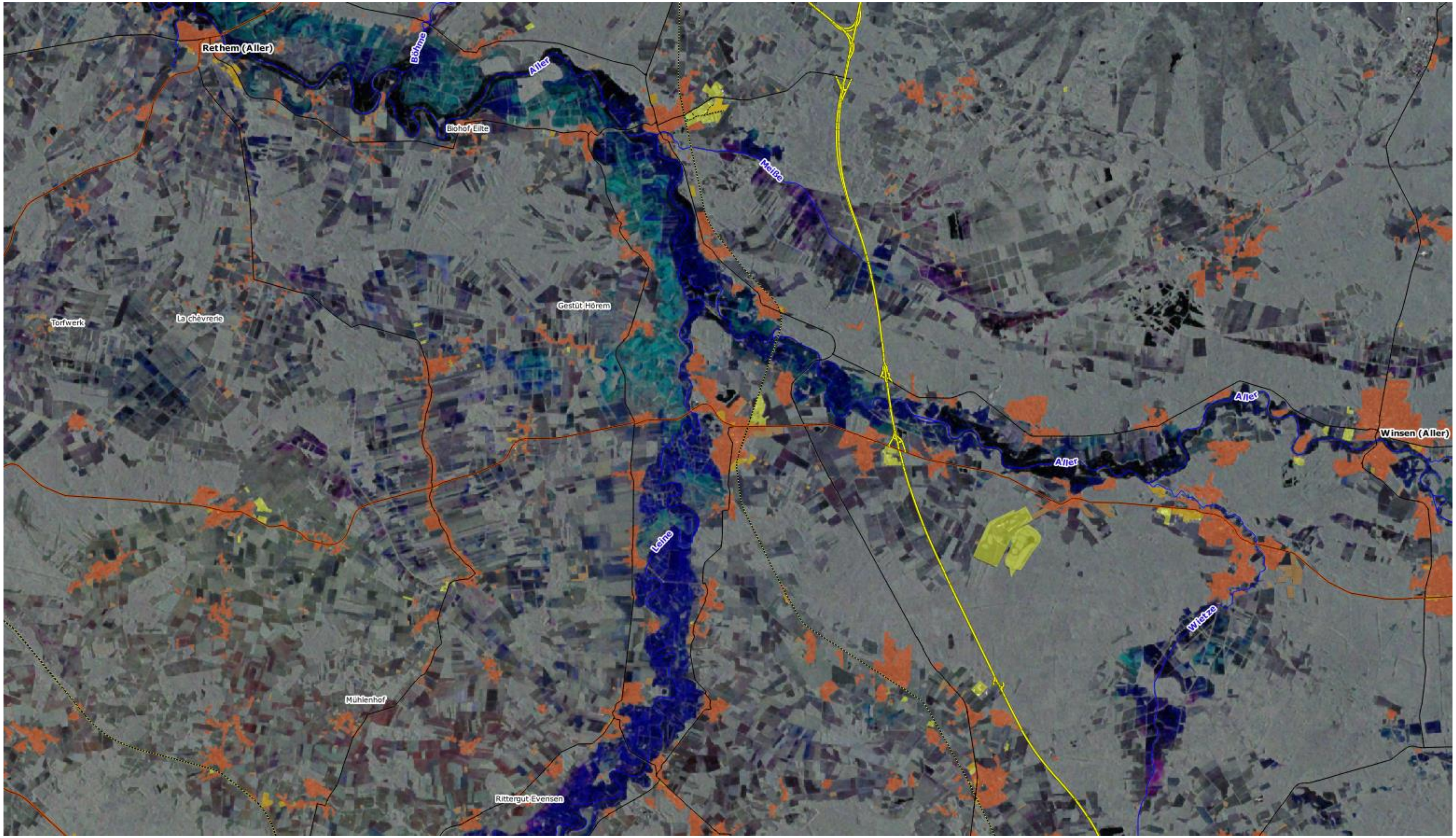
You could also explain it like this: The first image is before the flooding. What appears in **blue** was flooded on **both** subsequent dates. Pink shows what was flooded at first and then no longer, turquoise what was not flooded at first but was on the last date.

It is important to mention at this point that radar satellite data is particularly suitable for time series studies because the data is collected from the same angle with the same energy for each overflight. The signal penetrates the atmosphere unhindered and the lighting situation also has no influence on the recording quality.

In that way we see the changes on the surface and can use data acquisition by data acquisition for our evaluations. Observing changes is the basic approach in remote sensing.

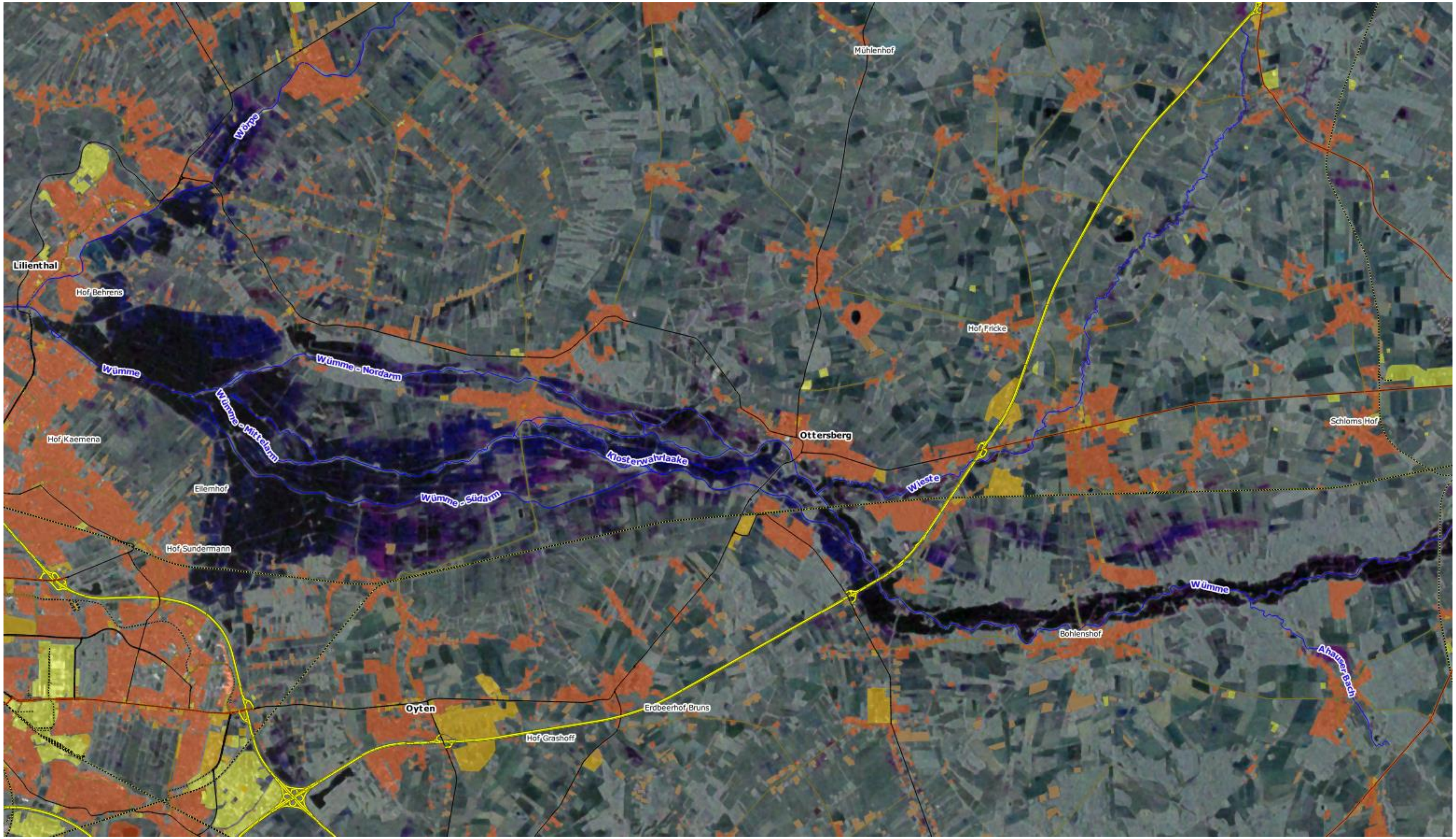
Before we can begin to quantify measurements, we must be able to represent and interpret the relative spatial and temporal changes.

The following image shows the area near the confluence of the rivers Leine and Aller. The color scheme is the same again, with areas appearing in black that were already flooded on December 13th and are still flooded on January 6th. This refers to areas in the immediate vicinity of the river that are not flooded at normal water levels.

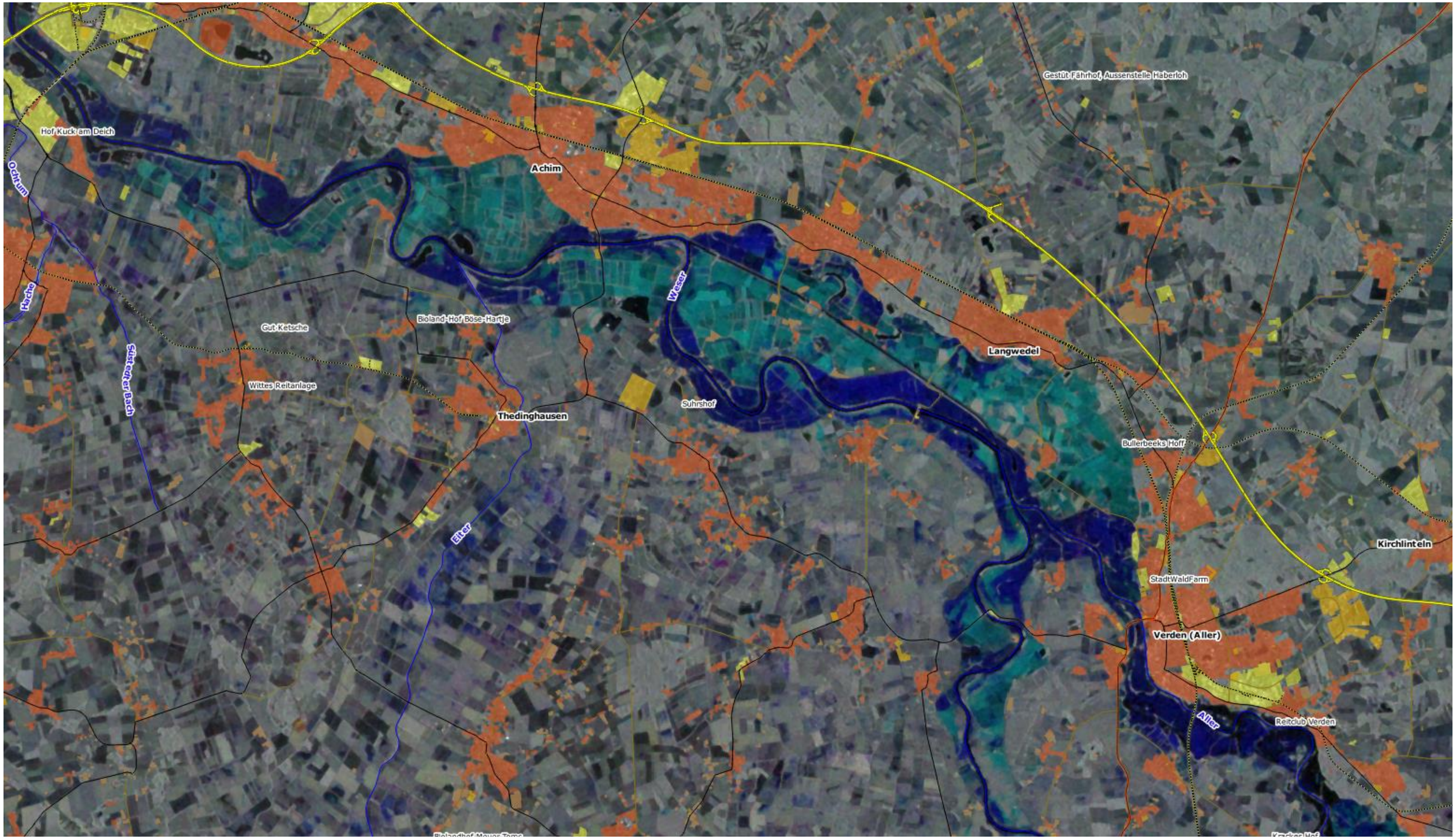


The image below comes from the area east of Bremen with the suburb Lilienthal. There you can see large areas that were flooded across all three images as they are shown in black. Here too, dark blue was flooded at Christmas and after New Year's, but not yet on December 13th.

In pink we see areas that were not yet flooded on December 13th and where the water had already drained away again after the New Year.



Another example shows the area at the confluence of the Aller and Weser. We see widespread flooding after December 13th with increasing extent after Christmas.



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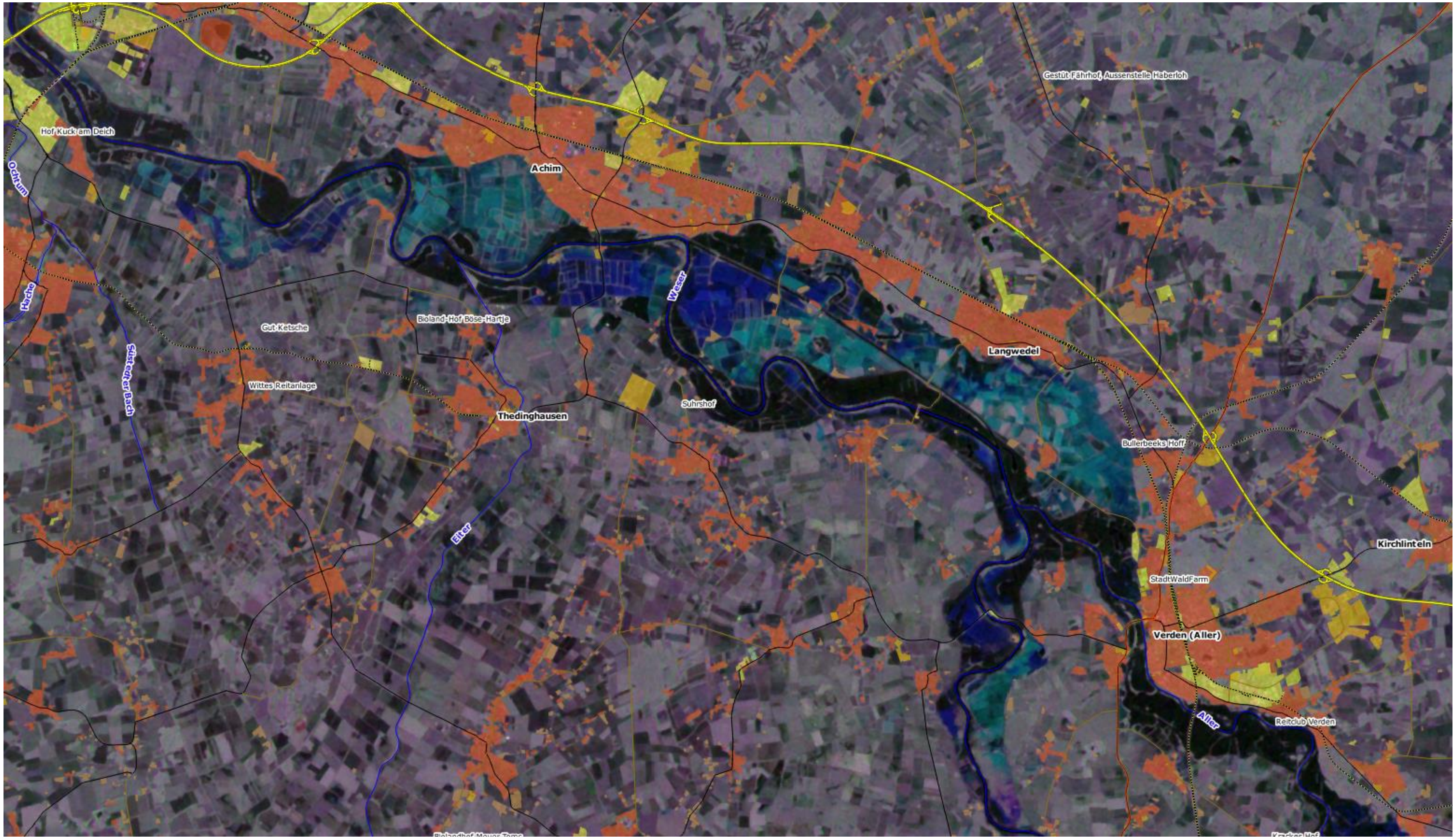
The following recording now shows the same region as the previous recording. However, here three other shots were combined into one image. The image represents the recordings from December 25th, December 27th and January 6th.
Everything that was already flooded on December 25th and is still flooded on January 6th appears black. Blue was not flooded on December 25th but was flooded on December 27th. In turquoise we see what else was flooded between December 27th and January 6th.



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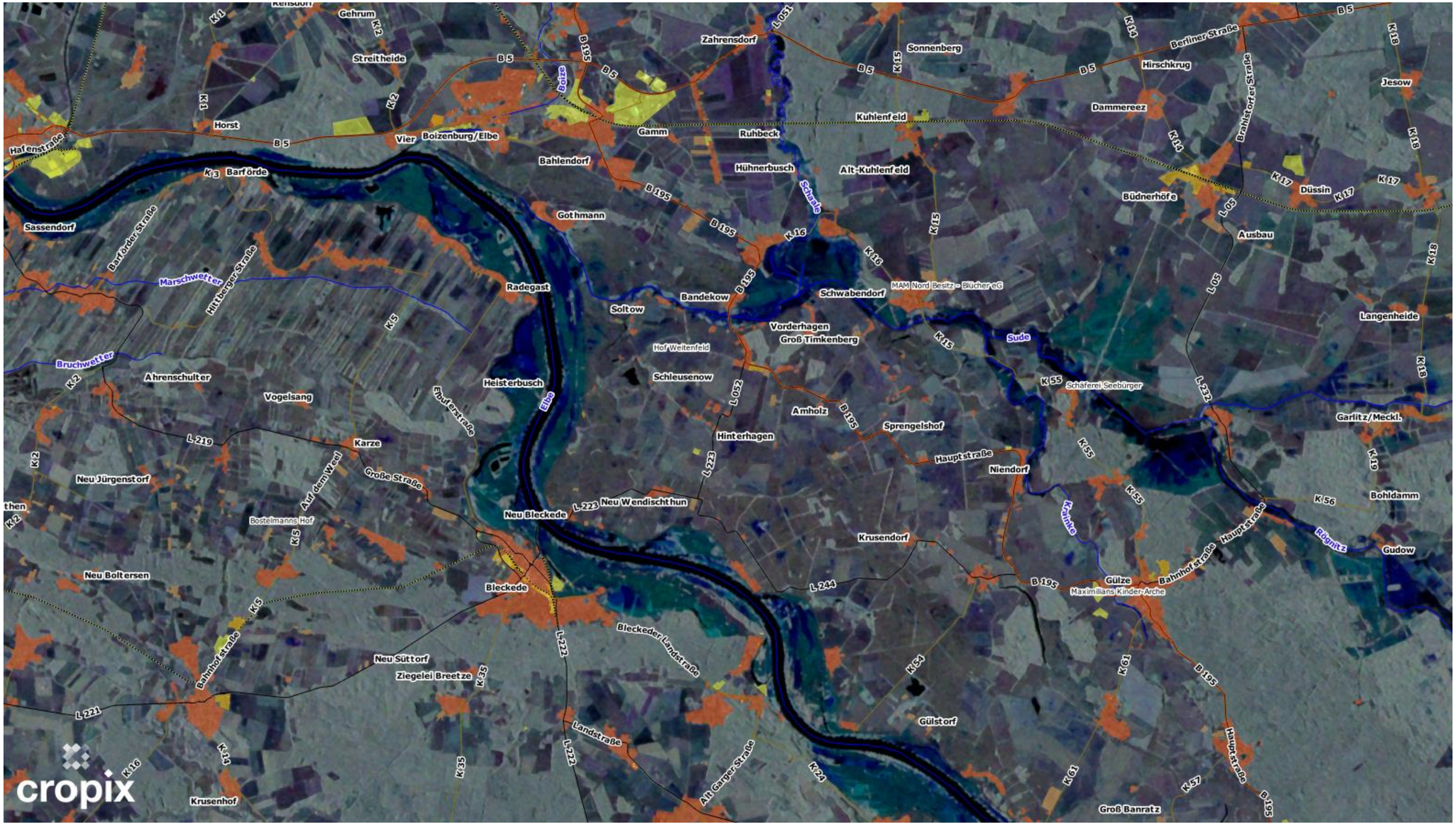
Finally, a shot east of Lauenburg on the Elbe. Here too, the course of the flood is clearly visible in color.



The evaluations show that Sentinel-1 radar data represent an opportunity to carry out flood monitoring over a large area and in a timely manner with consistent quality. It is not just a possibility, but actually the only way to document the course of the flood and the duration of the water, to estimate any damage and to develop avoidance strategies.