Topic 2b - Part 1: Air quality measurements - in situ instruments & validating satellite data

Andreas, we're standing on the roof here because this is where you're making measurements. Tell me about the instruments up here.

So we take measurements of air pollution here in Bremen, and we do that with scattered light. So basically, this is a light collection unit, a telescope where the sunlight, which is scattered in the atmosphere among clouds, is entering the instrument, and then is focused and follows a quartz fiber down to the lab where we have the real part of the instrument. And this telescope moves because we want to look at different parts of the sky in different directions to see different parts of, for example, the NO2 distribution here.

So it's looking out across the landscape, collecting all the light that's coming sideways, not directly down from the sun.

It's not directly from the sun, and that has two advantages. So first of all, there's not always sun in Bremen.

So we do like to measure year-round. And secondly, the light path is much longer if we take a very horizontal view through the atmosphere. And the long light path means a good signal.

And so the light that is coming in here, this is-- we look sideways all the time, but we don't see what this instrument is seeing. So what is this seeing?

Well, it's actually seeing in the same wavelength range or color range as we do, but it has much better resolution. So our eyes just can distinguish three different colors, and then the mixture of that. But our instrument can see thousands of different colors shades or wavelengths, and that gives us the opportunity to look at absorption from trace gases like NO2, for example, which is brownish if we see it at large concentration. But the instrument can see it also at very low concentrations.

So the light coming into this has been scattered off lots of things along the way.

Right.

And those things are changing the light. Tell me about the sort of light it's measuring and what it can see.

So we point to the sky. So the only thing that can scatter the light is molecules, and air, and particles-- aerosols, basically. And we are interested in the molecules, mainly. And the molecules either scatter the light-- that's just a change in direction of the photons-- or they do absorb light. And if they absorb, each molecule has its own characteristic absorption. The first thing, of course, is what we are interested in NO2 for example or SO2 formaldehyde. They all absorb in a UV-visible. And that's our target species, so we like them.

And then there is other things, which we maybe don't like so much, which is aerosols or clouds because they also have a very big impact on the light path. Imagine if there was a cloud. Then you cannot see the sun at all. So the light is all diffused, has been scattered many, many times. And that changes the light path. And that, of course, we need to take into account in our analysis.

And as we're talking, it's moving itself around. What's it doing?

Well, the idea is that, depending on where we are looking, we have a different flight path through the atmosphere. So you can imagine, if you look very close to the horizon, you have a very long light path at the lowest layer of the atmosphere. And at some point, then the light is scattered, goes to the sun. Whereas, if we look at the zenith as we do right now, then we have a very short light path through the lower layers. And you can imagine, if I now scan at different angles, this gradually changes. And from that, I can make an estimate of not only which absorber we have and how much, but also in which altitude.

And so these are--

--these are local measurements in this area, but they matter for a much bigger picture, don't they? What are these measurements used for?

So first of all, it's not a local measurement in the sense of just right here, but it averages over a light path which can actually be several kilometers. So the measurements are representative of the NO2 or ozone distribution in this direction. So we use this data for validation of satellite measurements. So when a satellite comes over, we also take a measurement. And then we try to do a one-to-one comparison, which sounds straightforward, but is not because the satellite pixels, even of the best instruments we have right now like S5-P they are still larger than the air volume that we are probing here. So that's the challenge of validation, to really compare like and like.

So you're matching up the things that you see from a very long way in the sky and things that are here. And what do you see? We're looking at landscape here. We can see some buildings, some trees. What is there in what we can see that is changing what it can see?

Well, if you look carefully, you will see the incineration plant there, the steel factory at the horizon, which is a very big source of NO2. And also, there's the city of Bremen, which has two coal-fired power plants, very big sources of NO2. And then there is a beautiful countryside over there, where there is no sources of NO2. And as we scan over this area, we see very different concentrations of NO2. And a satellite from top, it will see a mixture of all that, depending on its spatial resolution.

And how much does it vary with time of year, for example, or what day of the week it is?

imperative space

Oh, very much. Day of the week signals-- Sundays have quite lower signals on average than weekdays, which tells us that a lot of this is coming from road transport.

So you can see from space that it's Sunday.

Absolutely. You can also see, as you might know, the dominant religion of people living there because not everyone has their day off on Sunday. So you can see different patterns over the earth. And interestingly, 10 years ago, there was no weekly cycle over China because people were working all the time. But nowadays, you start seeing that, which tells you that they are more moving towards our lifestyle, with the weekend off.

So hidden within these invisible gases that we can't see, we are leaving fingerprints on the atmosphere. How is that changing over the long-term?

Well, over the long-term, luckily for Europe and for US-- also for Japan-- things have been improving very much. There is more and more filters built into cars like catalytic converters, filters into power plants. Also, the type of fuel we're using is changing. We use much more clean fuels like gas. And then, as you can see on the horizon, we're moving towards renewable energy. And that all helps to improve air quality here in Europe.

So NO_2 values have been decreasing for 20 years now, and they are about half as high as they used to be. And at the same time, of course, in places where industry has been built up like in Asia, air pollution gets worse and worse.

And tell me about the other measurements that you're making on the roof and, also, which satellites that data can be compared with.

So for this instrument, which uses UV-visible light, we compare it to instruments which work basically in the same way. That's instruments like GOME, SCIAMACHY, GOME-2, OMI, and now the latest one, Sentinel-5 Precursor-- S5-P instrument. That's the satellites that we're trying to validate. But you can also measure it in the infrared part of the spectrum. And that's about climate gases like CO_2, methane, CO also.

And that's done, actually, over under this dome. Because this instrument, it uses direct sunlight. So it needs to be closed when the weather is not so good. And they use the infrared part of the spectrum. And their measurements can then-- for example, the methane and CO measurements done here can be compared to SCIAMACHY data or to Sentinel-5 P data. CO_2 measurements can be compared to OCO satellite. So it's basically the same principle of absorption spectroscopy, but using direct sunlight and a different spectral range.

But there's a problem here, presumably. Because in the summer, you're more likely to have sunny days. And in the winter--

Absolutely.

--not so many sunny days. So how do you manage that difference?

Well, it's a problem for validation because you're not sampling evenly. It's also a problem for these measurements where you have the cloud issue, which was more severe in winter. On one hand, there's not much we can do about it because there's only so many measurements we can take. But one way to address this is to use models. Because the model may not be perfectly accurate, but it can very well simulate a seasonal variability, also a diurnal cycle.

And by using this information from the model and applying it to the measurements, you can make them more comparable and avoid this type of bias.

And let's go back to this instrument here. So we've got lots of things coming out of the back of it. Tell me what they are and where they're going.

Well, basically, the most important thing is the light, which goes through this quartz fiber bundle here. And all the other cables are mainly power and signal to operate the movements. And they all go down to the lab. Actually, if you follow the line--

--then we go downstairs, where the computer control is, and the spectrometer, and the detectors, and all the electronics we need.

So let's go down and have a look at what's going on down there.

OK. Please, come with me.

So what have we got in here?

So this instrument looks directly at the sun. And as we have seen from the outside-- and actually, here you can see the whole roof where the lights come in via a mirror.

That's used down here.

And then there's another here. Don't worry about the dust. That's no problem.

And then it enters this very big spectrometer, which is a Fourier transform spectrometer which provides a very high spectral resolution. The type of spectra that you measure, you can actually see on the screen here. So it has tons of structure. And each of these lines is an absorption line from the molecule. And there's very many molecules absorbing it.

So the clever thing about this setup is that the telescope on the roof takes care of the sun's

moving, but the light always comes down the same holes.

Exactly. So the spectrometer doesn't have to change at all. That's all done upstairs.

And then what's happening to the sunlight is it's being split by wavelength.

Yes. It's being split, actually, in two parts by a semi-transparent mirror. So one light path is short and the other one can be changed the length of light path. And then the two light beams are recombined and interfere. And this interference pattern can then be analyzed. And that's what we see on the screen.

So what you see here-- what we've got on the screen-- is it's almost like the rainbow's spread out on the bottom, but it's beyond the edge of the rainbow.

Very much so. So it's in infrared, so we cannot see that.

Right. [LAUGHS] But there's lots of information in there. And it's all those tiny-- to a human who doesn't recognize it, it looks just very messy. But actually, all those little zigzagging lines, that's information.

That's information. That's all the absorption lines from the different molecules.

So, Andreas, we're now one floor down. The light comes in up there somewhere. Tell me what happens to it.

Right. That's just the cables we saw upstairs. And we have the light fibers, which are fixed to the wall to protect them a little bit. And then all the electronics come in here. And that's the spectrometer, which separates the wavelengths with the CCD detector here. And basically, well, there's some readout-- electronics, computers. And in the end, what we see is the spectrum of light as it's being measured right now. So that's wavelength here and that's intensity. This is in the UV at 300 nanometers, roughly. And here, we are about at 400 nanometers.

So human vision is kind of like that.

Right. Yes.

So we're just on the edge of human vision and a little bit--

Right.

So that's from one instrument, and we have another one covering the more divisible part, which is down here.

And the camera here, this is showing what it's looking at--

Exactly.

--right now.

So that's what we saw when we were upstairs a minute ago.

And this is the spectrum right now.

That's the spectrum to fit. Yup. And all the lines you see here, that's actually unfortunately not the signal from the atmosphere. It's from other lines from the sun atmosphere. So they are stable. They don't change. That's not our signal. So the atmospheric signal is really very tiny. It's less than 1%. So we cannot see it here right away.

So it's a subtraction thing. You take what the light would be if nothing was happening to it, and then you look at what you measure.

Yes. More or less. So on the satellite, you can do that because you can look into the sun without atmosphere. Here on the ground, we cannot remove the atmosphere. So we take a measurement which has a shorter light path and a measurement with a longer light path, and then take the difference.

And hidden in all of the details here, that's where the signatures of these gases are. So even though it just looks like lots of lines, actually, when you really get into it, there's very detailed information in there.

There is. And it's ozone up here, and NO2 is more in this part of the spectrum. But you can't see it here.

Right

But the numbers will give you the answers afterwards.

Yes. They will.

This information is what you compare it with the satellites. So this is all part of that network.

That's all part of the network. So basically, each day, we create one comparison point for the satellite if there are no clouds because the satellite cannot look through the clouds. And there is more stations worldwide from our institute, and many, many other institutes. So it's kind of a network of DOAS instruments providing the validation that's needed for this species.