Topic 1g - Part 2: Satellite measurements - Example instruments and missions

[MUSIC PLAYING] I guess we don't think of it as a multidisciplinary exercise. But it really is. So people come up through the chemistry route, the physics route. These days you can study meteorology. You can study atmospheric dynamics. So that's the science drive.

But you actually need the engineers as well, the people who can build sophisticated instruments and get them to work. It's a real endeavor together.

The challenge of measuring the atmosphere is twofold. It's measuring the change with time across maybe the whole globe down to understanding that whole difference in chemistry and physics, really, across all the layers of the atmosphere.

And we can do it, really, through three different methods. We have what we call in situ measurements, measurements at a point in the atmosphere. Then we can use vertical profiling measurements, things like putting instruments on balloons or airplanes and flying them or floating them up through the atmosphere.

But the final method, especially one that you want to get the whole picture of the whole of the globe, is we can use satellites, which can pass over and produce that global picture every day.

We've used this word "instrument," which is a very broad word. And to a scientist, we know that means something that's making a measurement, usually something that does something. But there are specific instruments on satellites doing specific jobs. Tell me about some of those.

Yeah, we have, in Europe, we have a world-leading fleet of satellites that are flying over our head. And there are two groups in that. There are other meteorological satellites. But those meteorological satellites, these days, carry atmospheric composition instruments.

There's one that we particularly use in the air quality area that's called GOME-2. And that gives us a picture of the atmosphere, really, on a daily basis, on a twice daily basis, in fact, of the atmospheric composition. But actually going down to the urban scale now, as part of the Copernicus Sentinel missions, we have Sentinel-5P carrying an instrument called Tropomi.

Developed by the Dutch, it has UK technology in it as well. And that gives us information, really, about a fine detail and fine scale of air pollution in space. The great thing about these instruments is they can do many of these different things.

So Tropomi can measure things like ozone, NO2, but also give us measurements around aerosol optical depth and something information about the aerosol particles that are there as well.

And Sentinel-5P is in the sky now. But there's more coming down the line. What's coming next?

Yeah, the next quantum leap I think we'll find is with the flight of Sentinel-4 where we've moved to geostationary orbit. And for those familiar with geostationary orbit, that's the equivalent of a satellite that sits and moves with the Earth simultaneously.

And what that will give us is a 15-minute picture over Europe, of the air pollution in real-time. And that's really going to revolutionize our understanding of atmospheric composition over Europe.

So the idea is at the moment, satellites in low polar orbit paint stripes, effectively. It's like having a paint brush. And you paint around the planet. But this is a spotlight.

Yeah, absolutely. And you need both of these sort of things because you need to be able to cover the global coverage, the local coverage. But now we're going to have this exquisite picture in real-time of the Earth coupled to that global picture. Because one thing we know about air pollution-- it goes from the local to the global scale.

So this is a scale model, a two to one model of the SCIAMACHY instrument. The SCIAMACHY instrument is part of the SCIAMACHY project, which began in the early 1980s when myself and a group of collaborators decided that we should be able to passively remote sense key gaseous pollutants in the atmosphere.

And that's a big idea, isn't it? Because we're talking about gases that are present in tiny quantities among all the billions of molecules in the atmosphere. And you're talking about detecting those from a very long way away.

Absolutely. And that was, at the time, a problem to convince people because even relatively inexpensive satellites are relatively expensive compared to many things, Although probably per measurement point, they're very cheap because we get lots and lots of measurements.

But that was an issue. But I have to say that the interest-- the fact that Europe was, which is about 30% responsible for the ozone hole, did help and paid in large part for this instrument. It wasn't just SCIAMACHY There was a smaller instrument, which originally we called SCI-mini which became GOME, the global ozone monitoring experiment.

And the European Space Agency, at the time, was also very keen to initiate these projects. And so they managed to find space on an existing satellite, which is called ERS-2, the Earth Research Satellite 2 from ESA. And GOME flew and was successful. It flew before SCIAMACHY GOME only-- views the Earth in nadir geometry, whereas SCIAMACHY can view in limb, nadir, and occultation.

So these are, whether you're looking straight down or through the atmosphere. The dissonant information should get limb, and occultation we use for getting vertical profiles, particularly in the stratosphere, mesosphere, and above. And nadir is often, but not exclusively, dominated by the troposphere at the boundary layer because we look down. OK, and most of the molecules are in the lower part of the atmosphere.

And solar radiation very nicely goes through and strikes the surface and then comes back. And we look at that reflected, scattered radiation coming up from the Earth's surface at the bottom of the troposphere, bottom of the boundary layer, planetary boundary layer we call it.

And this is the information that we're then looking at. We're looking at the difference between extraterrestrial solar spectrum and that coming at the top of the atmosphere in different viewing geometries and the nadir viewing geometry.

Because of the nature of molecules and the way they interact with light, the same basic technique lets you get to a lot of different types of molecules.

Yes, well, we're fortunate in that we are getting, say, 10 key gaseous molecules this way, OK? And they are ozone. In the first case, ozone has a lot of important absorptions. Water vapour is a very important-- climate gas a very important part of the hydrological cycle.

But it's also part of a chemical transformations and tremical mechanisms of the atmosphere. Because, for example, the reaction of excited oxygen atoms produces OH, which is the vacuum cleaner of the atmosphere.

Water vapour's playing a role. And then oxides of nitrogen, in particular, NO2, we measure in-- and we also measure oxygenated volatile organic compounds, which are hydrocarbons, which are emitted either by man or the biosphere. And are converted to these oxygenated VOCs, we call them, which are things like formaldehyde and glyoxal.

We get lots of different molecules because we're using primarily absorption spectroscopy but also a bit of emission spectroscopy. Now in absorption spectroscopy, technically we're using electronic vibrational rotational spectroscopy. And we're also using vibrational rotational spectroscopy.

And this enables us to look at fingerprint spectra of the following molecules-- ozone-- and we see that in several different places in the spectra-- sulfur dioxide, nitrogen dioxide, bromine, and chlorine oxides, and also iodine oxide, actually. In addition, we are able to see carbon monoxide, carbon dioxide, and methane. They're produced in combustion.

And carbon monoxide is partially oxidized carbon. And carbon dioxide is fully oxidized. But carbon dioxide is, of course, the most important man-made greenhouse gas. And there are other species as well that we can see.

In the upper atmosphere, we're also looking at metals, which are produced by ablation in the upper atmosphere. And we actually, in the upper atmosphere, we also see the OH radical. There's a set, a selected set of absorptions which are rather useful. There are many more species in the atmosphere.

But we're fortunate that this spectroscopy gives us a key set. It's a subset of all the molecules. But they happen to be particularly important ones in the atmosphere.

If you think about making a measurement from above the Earth, you're often looking down through the atmosphere. And you're looking at a column. And then if you're looking at a column, you're trying to say, where is the gas in that column? It's a bit like focusing a camera in some senses.

You can only get a certain degree of focus when you're a long way away. And that means you've got to put that big picture together with a small picture from the in situ measurements to get the level of detail that you need in order to do, for instance, an air quality forecast at the surface.

You still have things that different layers. And if the satellite-- it knows there's this much gas. But whether it's up there or down there, it's harder. You can do it, but it's harder, right?

Yeah, there's lots of properties of the atmosphere that you can use to separate which layer that it's in. But actually, once you get into, let's say the bottom one kilometer, you could say it's in the bottom one kilometer. It's very difficult to say it's in the bottom 10 meters, you know?

So I think that's the scale where you need to couple the measurements from different angles in order to be able to get that sort of level of detail.

So satellites are very useful. But they're not the magic ones all by themselves.

No, they're not a panacea for all ills. But absolutely, they're a critical part of our understanding of the atmosphere. That global picture, that often repeating picture on a global level, or even on the European level is absolutely what's required to drive our understanding of the atmosphere.

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