Topic 3a - Part 2: Stratospheric ozone and CFCs – Detailed insights from satellite data and models

Chlorofluorocarbons are released at the Earth's surface by human activity, and they mix into the troposphere, is what we call it, the lower atmosphere. Tropos means well mixed. And it moves into the stratosphere by dynamical processes. And in the stratosphere, you have much stronger UV radiation, and also stronger, or larger concentrations of reactive free radicals. And chlorofluorocarbons are photolysed by this UV.

Which means that they're broken apart by light.

They're broken apart. And they also react with an excited oxygen atom. And they also release then, for example, chlorine monoxide. And chlorine and chlorine monoxide and bromine and bromine monoxide take part in catalytic cycles, which chew up ozones. So one chlorine atom released removes about 1,000 ozone molecules.

So the CFCs themselves don't stay intact.

No. CFCs are non reactive, but because they are destroyed by chemical processes and photolytic processes in the upper atmosphere, they release these killers of ozone, which are free radicals, which chew up the ozone in cycles. A single bromine takes out 10,000 ozones, and a chlorine, 1,000. And if we had used much more bromo carbon compounds, we probably would've had no ozone left by now.

So tell me about where you find ozone in our atmosphere.

So you find ozone mainly in the stratosphere. So in the stratosphere you will find around about 90% of the total ozone. And just a small amount of 10% is situated in the troposphere.

And that ozone in both places has implications for our health, doesn't it?

Yeah. So we are speaking from the stratosphere's ozone, we are speaking about the good ozone. Means the ozone layer is protecting us from the UV radiation. And the tropospheric ozone, the small part is toxic, that's why it's said bad ozone.

And that's down here at ground.

It's down here up to 10 kilometers in the mid latitude up to 80 kilometers in the tropics.

And why do we have ozone down here in the troposphere?

Because we have NOx, which is nitrogen oxide, stands for NO plus NO2. And we have a lot of hydrocarbons. These are the precursors for tropospheric ozone means in photochemical processes, tropospheric ozone is introduced.

Now, you're working on monitoring ozone from satellites. Tell me a little bit about what you can do with satellites and why ozone is sometimes difficult to measure from a satellite.

So when you are looking down from the satellites, so you see the total column. First, you have problems when you have clouds because then it's covered. And to get out the 10% the lowest amount of ozone, it's very difficult. So the main part is the stratospheric ozone. And you have to find a solution to eliminate the stratospheric part from the total amount to get out the tropospheric part.

So the problem is that you're looking down through the atmosphere and there's some ozone up here and some ozone down here. But if you just look straight through, you get everything.

Yeah.

So how do you separate those two?

So in the case, you have an instrument measuring both limb and nadir. So then you're looking for the upper layers and you're looking through the atmosphere, if possible up to the ground. Well, there's a difference of both gives you then the information of the lowest part.

And the benefit of satellites is that we can get a global view. And you've got a picture over here. Tell me about the diagram over there.

So here you can see the total anomaly ozone from 1997. It's an annual median value. And you can see, for example, the reference is 1998 up to 2010, so it's a 10 year average as a reference. And you see here what is more and what is less. So you see on the south pole that is coming up as a total amount of ozone, means it's increasing. Whereas over Europe, it's more or less the same. So what does it mean?

It means that in the southern part, beginning in the '80s and '90s the total amount of ozone was decreasing. After the '90s, because of the Montreal Protocol in 1987, it says stopping the CFCs, one, ozone was not destroyed any more or less, let's say, from the chemical side. Not from the dynamical side, just from the chemical side. So then you can see, OK, it's coming up.

It's not recovering totally. So means the values from 1997 and not reached up to now. It's the same for the northern hemisphere.

So the Montreal Protocol had an effect because the ozone levels are recovering, but they're not yet-- it will take a long time for them to get back to where they were.

Much, much longer than expected here.

And this is the total ozone in the atmosphere. So what patterns do we see for tropospheric ozone?

So we have more and more people living on the earth, so means we have more pollution, more fossil fuel burning. So during summer, so we need sunlight, photochemical reactions, we need sun light. So during summer we have more and more smog episodes, means more and more ozone, toxic ozone is produced. But that means-- so we have an increase of tropospheric ozone during special events, means that can increase the total amount too, but not that much.

And does the monitoring of tropospheric ozone, the ozone that's lower down, how is that being used by policymakers, for example, to write regulations and to monitor the effect of regulations?

So on the ground you have a lot of ground based measurements all over the world. And from there you can see, OK, there is a limit, which is reached during these pollution events. And then you have to close the windows and everything. So because it's a really huge toxic gas effecting the health mainly for children and old people. So the politics now is regulating the emissions. Tropospheric ozone is the secondary pollutant, means it's produced.

So the precursors are NOx, NO, NO2, and hydrocarbons. So once you're reducing the hydrocarbons and VOCs organic volatile compounds, if you're reducing both, finally, you reduce the production of tropospheric ozone.

So that's the type of pollution we don't think about. We think about the car exhaust, it produces some gases, and that's the pollutant. But actually these secondary pollutants, that's a different idea, isn't it? Because no one puts them in the atmosphere, but if you put the right ingredients, then they will form.

Yeah. So it means, if you are reducing the traffic, for example, by using more public transportation, it's helpful, finally.

Are you starting to see the measurements you're making with global satellite data, are you starting to see improvements in tropospheric ozone as well?

Yeah. It's very really difficult to figure it out, the right values. So what we are doing now, so we try to optimize the retrieval, we validate our retrieval with, for example, ground based measurement, ozone measurements to get, finally, the right numbers for the tropospheric ozone here.

And what do you see in the future? There's more and more satellites being put into space. What's your-- if someone was to give you a Christmas present for measurements of tropospheric ozone, what's the instrument or the technique? Or what would you like to see? Would you like to see people have ozone measurements on their phones? What would you like to see in 20 or 25 years time?

First of all, I would like to have a satellite with a really brilliant spatial resolution. Then, in addition, if it scales that scenario, so we can see all over Europe, for example, is one figure, which is excellent. And if we are able to produce measurements for the mobile phone in every hour in every minute, it's good, but that's future.

Far off in the future, 10 years, 30 years?

So you have ground based measurements for ozone, so they can provide these values every hour. So it's done. But from the satellite, to figure out really right numbers, so it's tricky. I don't want to say, it's 1 year, 10 years.

But you're working on it.

Yeah. Intensively.

So, Johannes, when we look at weather maps and satellite images in general of our planet, it almost looks like wallpaper. It's just a painted on pattern. And so it's easy to forget that the atmosphere has height as well. And things vary with height. Tell me a little bit about what happens at different heights in the atmosphere.

I mean, the lowest layer of the atmosphere is called the troposphere. And this means it's a well mixed layer. So this is basically where all the weather goes on. And then we have another layer on top of it, which is the stratosphere. And stratosphere means everything is more settled and stable. That's why it's called stratosphere. And then, if you go higher up, really the air gets really thin, but the chemistry, for instance, becomes very interesting because we have a lot of sunlight there, and there's sunlight in the UV, which trigger interesting reactions.

So we have a very three dimensional structure. And we've got some images here of the ozone hole. And we normally-- when we look at this quite often in the press, there's an image of the south pole of the planet, and it's just got a blue hole in the middle. But here we can see what an ozone hole means. So explain these images to me.

What we see here is a cross-section over Antarctica at different times. So this is in August, which is on the southern hemisphere, the winter. And what we see here in red, this is the ozone concentration. So the redder the color is, the more ozone is there. And we have here a feature which is called the polar vortex. This, because there is no sunshine in winter there, that's why the temperatures are very cold and the air is a little bit compressed, that's why it goes deeper here.

So this is height here. So this is ground level. And that's about 10 kilometers up there. So this is where our weather is. And then this is all in the stratosphere.

This part is-- this is the stratosphere.

So the ozone is sitting in a sort of disc shape almost over the South Pole. And this is quite high up, isn't it?

This is about sort of 20 to 30 kilometers here. This is sort of the height of the tropopause, what I referred to earlier. So this is the troposphere, and this is in the stratosphere. And the path here is what we call the mesosphere.

So the weather is all down here and the ozone is sitting up there. So that's in the winter. And what happens after that?

And then in springs, which is then September, sunlight comes in. And the process of the ozone hole formation is triggered by a chemical process. And the chemical process is started by chlorine atoms. And the chlorine atoms, they are stored at the surface of polar stratospheric clouds. In order to form these polar stratospheric clouds, it has to be very cold.

And this other condition is actually in the winter over Antarctica. And now spring comes and the first sunlight comes in and these chlorine atoms are released rapidly because the polar stratospheric clouds melt. And then they took out the ozone destruction. What we see here very nicely in this picture is that the lowest ozone values that they form directly on the edge of the vortex, because this is the area where sunlight comes in first and this part, maybe still have sort of ozone values, is still dark.

And then the ozone, the chemical processes basically eat in this ozone and remove it. And these are then the lower ozone values, which result in this hole which we see if we just look at at the maps. And this is here in September, 2017, to this year. This is sort of the time when the ozone hole in this year had the largest extent. We see, really, ozone values here are greatly reduced.

So we can see here that now it's not just a hole on a two dimensional picture, we can see that the ozone here sits in a kind of donut shape, and there's this gap in the middle. And the thing is that this is data, is it? These measurements, or is this from a model?

This is a combination of model and observations. Though the model is actually very good in giving us very detailed information about the vertical structure. Observations are very good to tell us the truth, but very often they only give us an idea of the total column. So the combination of the two, having a model, which represents the weather features very well, and then having observations, which constrain the values in the model, gives us this combined result. And we think this has the highest realism. And we can also show it with independent data that, really, we have a lot of-- a high amount of accuracy in these data here.

So this is really the data and the model working together so that you can see details in 3D. Even though you can't-- you're not flying through this in all these places, but together you can use that physical understanding to build up a three dimensional picture of what's going on.