Topic 2c (part 2) Finding detail in the snow-pack - radar and airborne measurements

In spring 2016, we made a profile from Swiss Camp Crawford, or actually the way back with measurements. Crawford is a point where two satellite orbits have been crossing. Crawford was a grad student of mine that was during the ERS-1 time period satellite from ESA. And when two satellites cross this crossover point is quite accurate for measurements. We use them, it was only 100 kilometres up from the Swiss camp, up in elevation. About 2000 metres elevation.

And along that line, since 1990, I've made a number of profile measurements with radar. What means radar? Radar is actually a device shown here. And you can see here behind the Ski-Doo. It looks through the snow, and depending on the antenna you have, you can look through 10 metres, 50 metres, or 1,000 metres. So you can look at the underside of the ice sheet. Or you can look within the layers of the snow.

We wanted to look when we did these profiles in 1995, 2000, 2005, and then again, 2016, how has the internal layer of the snow and ice changed over time? And as we know, that was the period when we had enormous warming, 2000 onwards. So some of these layers become icy layers, and we actually see them within the radar profile. And we look at these images. This actually is an example of processed data at Crawford Point in 19-- I think that was about 96, when we made these first measurements.

There was basically no melt there. You can see I had to put a red line through the profile. That was the summer 1996, 1997, 1998. So what is between the two colours, that's the annual accumulation, how much more snow we received over that year. Now if I were to have this profile continuing to 2016, these layers would have become smaller and more pronounced, because there was melting. The amount of water is still the same, but the snow is compressed because when it gets wet, or when it gets warm, the volume is still the same, but density increases.

And that's how we actually look at the variability of the accumulation, the snowfall, that occurs. And you can see here, I have nice examples how the accumulation varies with surface topography as well. Because depending on the surface, we actually see changes. It's quite enormous. This is 3.75 metres. This is 0. And you can see the accumulation does vary quite a lot, because the surface has surface undulation. And we are at Swiss Camp, we don't only make point measurements, sometimes we use some drones. In the old days we used kites.

You can see here there's a big kite. We are able to put the kite about 600 metres above the surface, and it stayed there. And along the kite we had this plane moving up and down. So we were able to monitor the atmosphere continuously by having a kite going up and down on the feather. These are the instruments. On the other hand, we have a collaboration with NASA.

And NASA is known to fly satellites, but also aircrafts. So every year, we have NASA plane, this time it was a P-3, that came by in 2016. And with that plane there is a high resolution

laser, and a radar. With the laser they measure the surface topography very accurately. With the radar, they measure the underside of the ice and all the layers. And along that profile, we usually have our own measurements, that I mentioned earlier, when we drive from Swiss Camp to Crawford, looking through the snow.

We actually are supported by aircraft measurements on an annual basis. So our measurements only fit in every few years, because annually, NASA provides us with the information of very accurate surface topography with their lasers, and the thickness of the ice, based on these aircraft measurements.

We use methods which can quantify larger structures. But still then we are at a quite small scale. We are at a square metre, maybe several square metres. But we would like to know, how is the snow pack? How variable is it over, let's say dozen of metres, hundreds of metres, kilometres? And that's where the radar comes in. Because the radar takes, let's say, every 30 centimetres a signal. And then we can make a big picture how this snow pack, be it in the Alps or in Greenland, how the snow pack varies?

The snow pack, or the firn in Greenland was investigated for a long time on traverses. Often the question was more how deep is the firn. So what's the accumulation? So what's the boundary between the ice and the more porous ice? But for some questions, it's more interesting to know how is this porous ice, which we call firn, and then the snow, what's the transitions? Is there a layering?

And that was the specific goal of our traverse, which we did from Crawford to summit. So we were mostly interested in this smaller scale variability. That's why we did every five kilometre a snow pit. So we have a lot of data we can look at.

This is an overview of the traverse, which we did with the ground penetrating radar sled. It took us nearly six day to walk this 100 kilometres from Crawford Point, which is here on the right side, to Swiss Camp, on the left side. And doing such a high resolution measurement was quite a challenge but also now we have a lot of good data which I try to analyze and process now. And during the traverse, we also did manual measurements, which you can see on the right site here, this is a picture from a snow pit where we did validation measurements.

For example, snow density, and also the SMP measurements, which Neige already explained. And at all these points we have now like a reference point to the GPR measured data. And it looks like this. If I have such a snow pit dataset, I can produce optimal radargram for this one trace, which at this point, the GPR should measure exactly what's shown up here. And this is what radargram measured actually for half a day. And for example, at this point here, we stopped.

We did the manual measurement, and here the wave should look like up here. So now I try to compare what we measured manually and what the radar gives us, what the data of the radar gives us, and try to find, for example, ice layers, or interesting layering which could refer to

melt events, for example from April 2016, melt event. So I try to compare what we saw in the field, what the GPR measured, and what we expected.

And sometimes there are also things we didn't expect. And we can see that, for example close to Crawford, the depth to the huge ice crust, which was built maybe in 2012, comes closer to the snow surface when we come nearer to Swiss Camp. So at Swiss Camp, the snow height is smaller. We saw this in the field, at a snow pit. But now we can also see it in the radargram. And we can make comparison between the two datasets.

And we can find the ice layer along the whole 100 kilometre. We have a very high resolution of the radar data. We measured every 30 centimetres. And so now we are able to have the data, for example, of this ice layers, or the whole layering of the snow pack, from Crawford Point towards Swiss Camp for very high resolution.