Larscience – Episode 8 – Cloud microphysics over Larsen C

Well, hello. It's been a while, hasn't it? I've been focussing mainly on making videos, so I haven't had as much time to record podcasts, but I figured it was about time for another one. If you're interested in watching some of those videos, you can check them out on my YouTube channel, which is linked on the website. There's loads of absolutely amazing footage from my trip to Antarctica, which you just can't really do justice to in a podcast, so make sure you check it out.

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Since I got back, I've been doing a lot of work modelling clouds, to understand the effect they have on the amount of energy that reaches the surface of the Larsen C ice shelf.

I spoke about clouds in episode 4, but I've managed to do quite a bit more of my own work since then. I recently presented some of my results at the Polar 2018 conference in the Swiss Alps, which was awesome. You can even read my blog post about it on the website if that tickles your fancy. Anyway, I thought I'd give you a quick summary of the work that I showed there, but in plain English, obviously.

So, as I'm sure you've figured out by now, the aim of my research is to figure out what's making Larsen C melt, and the physical mechanisms in the atmosphere that drive change there. Clouds are one element of that. Clouds influence the amount of energy that reaches the surface of the ice shelf because essentially, they get in the way of energy coming in from the sun, and of energy leaving the Earth. Plus, they also emit energy themselves, which affects the temperature at the surface. Adding clouds into the equation instantly makes everything a bit more complicated.

There's a lot we don't know about clouds, not least the effect of their composition on the micro-scale. These teeny-tiny scale properties are called microphysics, very aptly, and include things like the shape, size and number of particles that make up the cloud, and the amount of ice vs. liquid water they contain.

You might think that those microphysical properties don't sound like they should have much influence, but they actually have a huge bearing on the way the cloud interacts with radiation (aka energy) coming into and going out of the Earth's surface. If you've got a lot of energy hitting the surface of an ice shelf, that can raise its temperature, which in summer especially, can cause melting, so that's why we care about it.

It's pretty hard to measure those properties, because like I was saying in episode 6, you need a plane with a whole bunch of shiny science equipment to fly through the clouds and see what they're made of, which is hard at the best of times, let alone in Antarctica.

Having said that, we do have some idea of how the mechanisms of cloud microphysics work, and also of the effect they have on the amount of energy that reaches the surface. It's just that the relative magnitude of each effect is quite uncertain – mostly because they all compete, so act in different directions (some cool the surface, others warm it) and can also interact to produce completely different effects. All of that can make the influence of any specific property quite hard to dissect.

But anyway, here's a run-down of the basics, as I understand them, but this is by no means a complete picture.

First off, we've got phase partitioning. This is just a fancy way of saying how much liquid water there is in a cloud compared to ice. During summer over much of the Antarctic Peninsula, including Larsen C, most clouds are composed of ice and liquid, so we call them 'mixed phase'. The 'phase' part of that term describes what form the water is in – either water vapour, liquid or ice. This property isn't striiiictly microphysical because it describes the composition of a cloud as a whole, but it's important because liquid and ice particles behave differently when they are hit with solar radiation.

Clouds made of ice particles tend to let more sunlight through (so we say they are more 'transparent' to solar radiation), mostly because they are larger, so there are more gaps between individual ice crystals. That means more solar radiation reaches the ground than it would if the cloud were made of liquid. On the other hand, liquid tends to absorb and emit radiation that comes upwards from the Earth's surface. Liquid clouds are much warmer, and they emit much more energy back downwards that can warm the surface. That type of energy is different to the energy that comes from the sun, just to complicate things a bit more. Solar energy is called 'shortwave' and the energy emitted by the Earth, and absorbed/re-emitted by clouds is 'longwave'. If you can remember learning about the energy spectrum at school, these terms just mean that the sun and Earth emit energy in a different part of that spectrum (because the sun's way hotter than the Earth, thankfully), so they have a different wavelength.

So, related to this phase partitioning is the number of particles that make up the cloud, and the size and shape of those particles. Let's start with the number bit. Liquid clouds are made up of lots of small, round droplets, and the more droplets they contain, the brighter the cloud is. If it's brighter, it reflects more incoming solar radiation, which has a cooling effect on the surface because less reaches the ground. However, as we just learned, water emits more longwave radiation back to the surface, so the two effects compete. Generally, liquid clouds have an overall warming effect on the surface because they tend to be closer to the ground, and so warmer, which means they radiate more strongly. For comparison, imagine a radiator – if you really crank it, you can stand the same distance away from it, but feel warmer. It's the same with clouds, but rather than a toasty 60 we're talking about a few degrees below zero, which would be a pretty rubbish temperature for a radiator.

The size of particles also makes a difference. The bigger the particle, the more radiation it absorbs (and then re-emits). This happens regardless of whether it's ice or liquid. As I mentioned earlier, ice clouds tend to contain fewer, larger particles. Larger particles behave differently to smaller ones when they are hit with solar radiation. Particles may also scatter light - so send it flying off in different directions basically - depending on their size. The shape of particles also affects this – so large, weirdly shaped, lumpy ice crystals (which we call irregular so we don't hurt their feelings) scatter and reflect more light than more symmetrical, round crystals.

For instance, the base of rain clouds appears dark because of these properties, which is helpful because it means you have a bit of time to grab your brolly before the cloud dumps a load of water on you. All the big, heavy, raindrops collect at the bottom they are bigger and heavier (gravity, dude) they are usually (although not always) more likely to be liquid - both of which make them absorb more radiation - and they are usually more spherical, so they scatter less radiation. All of that combined means less light is reflected or scattered, and we see it as darker. Cool eh?

Now, all of that was quite complicated, what with all the different effects acting in different directions. That's just a taster of the complexity of microphysical processes. There's so much going on in clouds that it's hard to say what the effect of one specific microphysical characteristic is for all clouds.

Now, imagine being a climate model. Climate models are simple beasts – they can't handle the subtleties of the real world so well, not least because scientists don't understand them completely yet either. They need simplified rules of what happens in all (in inverted commas) cases. As I say, it's hard to do that with microphysics. Climate models really struggle to get clouds right as a result. So much so, that they are the number one source of uncertainty in our estimates of future climate change.

Part of the reason for this is that they mostly only calculate the amount of liquid or ice in the cloud, and not the number, shape or size of particles. This is known as 'single moment' cloud modelling, because it only calculates a single property. (By the way, I know I've only defined the 'single' bit of that term – but don't please ask me to define a moment: I've spent nearly two years trying to decipher that one and I'm still in the dark. All I know is that it's comes from mechanics in maths – that's the bit I missed at school, and that each one is a physically measurable property.) Anyway, scientists who use models are now trying to increase the number of things models can calculate, using 'double moment' schemes that also tell you how <u>many</u> particles a cloud contains, but these types of model are much more expensive to work with because they take up so much more computing time on the giant supercomputers that are needed to run climate models.

Now! (hand rub) We've gotten to the juicy bit of what I've found in my work. I've been focussing until now on the phase partitioning in summertime clouds over Larsen C, so how much ice and liquid there is. I've chosen 2011 because there was a big measurement campaign, called OFCAP, so we have lots of data to compare the model to, and that means we can get an idea of how well it is doing (or let's be honest, how badly). I've got some data collected from the British Antarctic Survey aircraft as it flew through clouds, and some data collected at the surface from two weather stations, which tells me how much energy is going up and coming down. I'm using that data to see if the UK Met Office's weather prediction model can tell me anything about how cloud microphysical composition affects the amount of energy at the surface.

What I've found so far is that the model is getting it pretty wrong. The errors in the microphysics are quite large, and while we can't be sure there aren't other things causing the problems, it seems likely that these are causing the issues. There are inconsistencies between how much energy the model thinks there is available at the surface of the ice shelf to cause melting, and how much melting we actually see. But I'm guessing that probably won't be particularly surprising to you, given what I've told you already.

The model predicts way too much ice, and way too little liquid. That's because too much liquid is getting turned into ice by two microphysical processes called vapour deposition and riming. Vapour deposition is when you have an ice crystal or a lump of ice made of lots of crystals, and some water vapour sticks - or gets deposited – onto it and freezes. Riming is quite similar, except that rather than having water vapour sticking to the ice, the water is already in the liquid phase, so you get liquid water sticking to the ice crystal and freezing. Both of those processes take liquid away and add to the amount of ice present in the cloud.

The effect of that is to make clouds that are too icy, which like I said earlier, means they let too much incoming shortwave solar radiation through. That means that there's more shortwave energy reaching the surface in the model than there is in the real-life observations. At the same time though, remember, ice clouds are nowhere near as thick and warm as liquid clouds, and they don't emit as much longwave radiation back down to the surface. So, the fact that the model thinks there's less liquid in the clouds causes there to be less longwave energy coming back down towards the surface too.

So again, we've got competing effects: there's more solar shortwave energy reaching the surface, but less longwave energy coming down from the clouds.

Bear in mind that this is only one case study, so I'm going to be a typical cautious scientist and say that my results only apply to this particular example, and that I need to do more testing of different cases, BUT this makes the model completely over-estimate how much melting is going on over Larsen. Like, a lot a lot.

Thankfully, my results are pretty consistent with what we expect from the UM, which is the weather prediction model I've been using, and from what other people have found. It just goes to show how much work we need to do to sort the clouds out in models.

And that's what the UK Met Office have been doing! Wheeeyyy. They've developed a new 'double moment' package that I've been trying out. Until now, all of what I've been doing has used this 'single moment' version of the UM model. At the moment, I'm trying to run the double moment version, which should hopefully produce more comparable results. IF the darn thing would work. So far, and it's early days, it seems like a bit of a mixed bag. Some of the problems with the simpler experiments have been fixed, but there's a bunch of new problems now, which I won't bore you with, so it might be a while before I can accurately simulate the clouds over Larsen.

I'll keep you posted.

Thanks for listening, I'll try not to leave it so long before the next one. Don't forget to share/like/subscribe to the podcast and do all the usual social media things, you can check out my videos on YouTube by searching Dr Gilbz (yes that is with a 'z'), and follow me on Twitter @Dr_Gilbz, again… with a 'z'. See ya next time!