The images are murky at first. Sediment sweeps past the camera as Icefin, a bright yellow remotely operated robot submarine, moves tentatively forward under the ice. Then the waters begin to clear.

Icefin is under almost half a mile (600m) of ice, at the front of one the fastest-changing large glaciers in the world.

Suddenly a shadow looms above, an overhanging cliff of dirt-encrusted ice. It doesn’t look like much, but this is a unique image - the first ever pictures from a frontier that is changing our world.

Icefin has reached the point at which the warm ocean water meets the wall of ice at the front of the mighty Thwaites glacier - the point where this vast body of ice begins to melt.
The ‘doomsday' glacier

Glaciologists have described Thwaites as the “most important” glacier in the world, the “riskiest” glacier, even the “doomsday” glacier. It is massive - roughly the size of Britain. It already accounts for 4% of world sea level rise each year - a huge figure for a single glacier - and satellite data show that it is melting increasingly rapidly. There is enough water locked up in it to raise world sea level by more than half a metre.

Ice sheets in West Antarctica have thinned the most
You may be surprised that so little is known about such an important glacier - I certainly was when I was invited to cover the work of the team. I quickly discover why as I try to get there myself. Snow on the ice runway delays my flight from New Zealand to McMurdo, the main US research station in Antarctica. This is the first of a whole catalogue of delays and disruptions. It takes the science teams weeks just to get to their field camps. At one stage, the entire season’s research is on the point of being cancelled because storms stop all flights to West Antarctica from McMurdo for 17 consecutive days.

Why is Thwaites important?
West Antarctica is the stormiest part of the world’s stormiest continent. And Thwaites is remote even by Antarctic standards, more than 1,000 miles (1,600km) from the nearest research station. Only four people have ever been on the front of the glacier before and they were the advance party for this year’s work. But understanding what is happening here is essential for scientists to be able to predict future sea level rise accurately. The ice in Antarctica holds 90% of the world’s fresh water, and 80% of that ice is in the eastern part of the continent.
The ice in East Antarctica is thick - more than a mile thick on average - but it rests on high ground and only creeps sluggishly to the sea.

Some of it has been around for millions of years.

Western Antarctica, however, is very different. It is smaller but still huge, and is much more vulnerable to change.

Unlike the east it doesn’t rest on high ground. In fact, virtually the whole bed is way below sea level. If it wasn’t for the ice, it would be deep ocean with a few islands.

I’ve been in Antarctica five weeks before I finally board the red British Antarctic Survey Twin Otter that takes me to the front of the glacier.

I will be camping with the team at what is known as the grounding zone.

They are camped on the ice above the point where the glacier meets the ocean water, and have the most ambitious task of all.

They want to drill down through almost half a mile of ice right at the point where the glacier goes afloat.

No-one has ever done that on a glacier this big and dynamic.

They will use the hole to get access to the sea water that is melting the glacier to find out where it is from and why it is attacking the glacier so vigorously.

What lies beneath the ice of Antarctica?

Metres below/above sea level

-1500 -750 0 750 >1500

Source: Nasa/National Snow & Ice Data Center
They do not have long. All the delays mean there are just a few weeks of the Antarctic summer left before the weather starts to get really bad. As the members of the drilling team set up their equipment, I help out with a seismic survey of the bed beneath the glacier.

Dr Kiya Riverman, a glaciologist at the University of Oregon, drills down with an ice auger - a large spiral stainless-steel drill bit - and sets small explosive charges. The rest of us dig holes in the ice for the "georods" and "geophones" - the electronic ears that listen to the echo of the blast that bounces back from the bedrock through the layers of water and ice.

The reason the scientists are so worried about Thwaites is because of that downward sloping submarine bed. It means the glacier gets thicker and thicker as you go inland.
At its deepest point, the base of the glacier is more than a mile below sea level and there is another mile of ice on top of that. What appears to be happening is that deep warm ocean water is flowing to the coast and down to the ice front, melting the glacier. As the glacier retreats back, yet more ice is exposed.

**How Thwaites glacier is melting**

Changing winds and currents mean warmer water is getting under the ice

- New grounding line
- Warm water flow
- Glacier retreats more rapidly after losing grip on sea floor
- Ice becomes less stable as more is exposed
- Chunks of ice break off

**Drawing not to scale**

Source: International Thwaites Glacier Collaboration

It is a bit like cutting slices from the sharp end of a wedge of cheese. The surface area of each one gets bigger and bigger - providing ever more ice for the water to melt.

And that is not the only effect. Gravity means ice wants to be flat. As the front of the glacier melts, the weight of the vast reservoir of ice behind it pushes forward. It wants to "smoosh out," explains Dr Riverman. The higher the ice cliff, she says, the more "smooshing" the glacier wants to do.

So, the more the glacier melts, the more quickly the ice in it is likely to flow.

"The fear is these processes will just accelerate," she says. "It is a feedback loop, a vicious cycle."

Doing science of this scale in such an extreme environment is not just about flying a few scientists to a remote location. They need tonnes of specialist equipment and tens of thousands of litres of fuel, as well as tents and other camping supplies and food.

I camped on the ice for a month, some of the scientists will be out there for far longer, two months or more.

It took more than a dozen flights by the US Antarctic programme's fleet of huge ski-equipped Hercules cargo planes just to get the scientists and some of their cargo to the
The distances are so great they needed to set up another camp halfway down the glacier so the planes could refuel.

The British Antarctic Survey's contribution was an epic overland journey that brought in hundreds of tonnes of fuel and cargo.

Two ice-hardened ships docked alongside an ice cliff at the foot of the Antarctic Peninsula during the last Antarctic summer.

A team of drivers in specialist snow vehicles then dragged it more than a thousand miles across the ice sheet through some of the most inhospitable terrain and weather on earth.

It was tough going, the top speed was just 10mph.

Drilling through the ice

The scientists at the grounding zone camp plan to use hot water to drill their hole through the ice.

They need 10,000 litres of water, which means melting 10 tonnes of snow.

Everyone sets to work with spades, hefting snow into the “flubber” - a rubber container the size of a small swimming pool.

“If I’m the most southerly Jacuzzi in the world,” jokes Paul Anker, a British Antarctic Survey drilling engineer.

The principle is simple - you heat the water with a bank of boilers to just below boiling point and then spray it onto the ice, melting your way down.
But drilling a 30cm hole through almost half a mile of ice at the front of the most remote glacier in the world is not easy. The ice is about -25C (-13F) so the hole is liable to freeze over and the whole process is dependent on the vagaries of the weather. By early January, the flubber is full and all the equipment is ready but then we get a warning that yet another storm is on its way. Antarctic storms can be very intense. It is not unusual to have hurricane force winds as well as very low temperatures. This one is relatively mild for Antarctica but still involves three days of wind gusting up to 60mph. It blows huge drifts of snow into the camp, swamping the equipment, and all the work stops.

Scientists are studying why the Thwaites Glacier is retreating. We sit in the mess tent playing cards and drinking tea and the scientists discuss why the glacier is retreating so rapidly. They say what is happening here is down to the complex interplay of climate, weather and ocean currents. The key is the warm seawater, which originates on the other side of the world. As the Gulf Stream cools between Greenland and Iceland, the water sinks. This water is salty, which makes it relatively heavy, but is still a degree or two above freezing. This heavy salty water is carried by a deep ocean current called the Atlantic conveyor all the way down to the south Atlantic. Here it becomes part of the Antarctic Circumpolar Current, flowing deep - a third of a mile (530m) - below a layer of much colder water. The deep warm circumpolar water travels all the way around the continent but has been increasingly encroaching on the icy edge of West Antarctica.
This is where our changing climate comes in. The scientists say the Pacific Ocean is warming up and that is shifting wind patterns off the coast of West Antarctica, allowing the warm deep water to well up over the continental shelf.

“The deep Antarctic circumpolar water is only a handful of degrees warmer than the water above it - a degree or two above 0C - but that’s warm enough to light this glacier up,” says David Holland, an oceanographer with New York University and one of the lead scientists at the grounding zone camp.

I was supposed to leave Antarctica at the end of December but all the delays mean the drilling only begins on 7 January. That is when the satellite phone call comes from the United States Antarctic Program HQ in McMurdo. We are told we cannot delay our flights off the continent any longer and must leave on the supply plane that is due to arrive at the camp in an hour or so. It is very frustrating to be forced to leave before the hole is finished and the instruments have been deployed, especially given how long it took to get here.

We say our goodbyes and board the plane. I look back and see the wheel at the top of the drill turning, the black hose spooling out steadily. The plane flies up over the camp and directly north, out towards the ocean. The scientists had told me that we had been camped on what is basically a small bay of ice protected by a horseshoe of raised ground. As we fly out over the front of the glacier, I realise with a shock just how fragile a fingerhold it is.
There is no mistaking the epic forces at work here, slowly tearing, ripping and shattering the ice. In some places the great sheet of ice has broken up completely, collapsing into a jumble of massive icebergs which float in drunken chaos. Elsewhere, there are cliffs of ice, some of which rise up almost a mile from the sea bed. The front of the glacier is almost 100 miles wide (160km) and is collapsing into the sea at up to two miles (3km) a year. The scale is staggering and explains why Thwaites is already such an important component of world sea level rise, but I am shocked to discover there is another process that could accelerate its retreat even more.

Footage was captured by Icefin, a remotely operated robot submarine.

Melt rates are increasing

Most glaciers that flow into the sea have what is known as an “ice pump”. Sea water is salty and dense which makes it heavy. Melt water is fresh and therefore relatively light. As the glacier melts, the fresh water therefore tends to flow upwards, drawing up the heavier warmer sea water behind it.

When the sea water is cold, this process is very slow, the ice pump usually just melts a few dozen centimetres a year - easily balanced by the new ice created by falling snow. But warm water transforms the process, according to the scientists.

Evidence from other glaciers shows that if you increase the amount of warm water that is reaching the glacier the ice pump works much faster. “It can set glaciers on fire,” says Prof Holland, “increasing melt rates by as much as a hundred-fold.”

The small plane takes us to the camp in the middle of the West Antarctic Ice Sheet but more bad weather means more delays and it is nine days before a Hercules comes to take us back to McMurdo.

By then we have been joined by some of the scientists. It has been a very successful season.

They have confirmed that the deep circumpolar warm water is getting under the glacier and have collected huge amounts of data. Icefin, the robot submarine, has managed to make five missions, taking a host of measurements in the water beneath the glacier and recording some extraordinary images.

It will take years to process all the information the team has gathered and incorporate the findings into the models that are used to project future sea level rise.

Rising sea levels

Thwaites is not going to vanish overnight - the scientists say it will take decades, possibly more than a century. But that should not make us complacent. A metre of sea level rise may not sound much, particularly when you consider that in some places the tide can rise and fall by three or four metres every day. But sea level has a huge effect on the severity of storm surges, says Prof David Vaughan, the director of science at the British Antarctic Survey.

Take London.
An increase in sea level of 50cm would mean the storm that used to come every thousand years will now come every 100 years.

If you increase that to a metre then that millennial storm is likely to come once a decade.

“When you think about it, we shouldn’t be surprised by any of this,” says Prof Vaughan as we are preparing to board the plane that will take us back to New Zealand and then home.

Ever-increasing carbon dioxide levels are putting a lot more heat into the atmosphere and the oceans.

Heat is energy, and energy drives the weather and ocean currents.

Increase the amount of energy in the system, he says, and inevitably big global processes are going to change.

“They already have in the Arctic,” says Prof Vaughan with a sigh. “What we are seeing here in the Antarctic is just another huge system responding in its own way.”