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Welcome to IFL Science The Big Questions, the podcast where we invite the experts to explore the biggest mysteries of science, with your host, Dr Alfredo Carpineti.

I: The Earth often seems like it is a nice little closed system. Sure, we get the energy from the Sun, but everything affecting it is within the atmosphere. That is not exactly true. The Sun is also spewing a constant stream of charged particles that slam into the magnetic field of our planet, altering its shape. This is just part of what we call Space Weather. For the big question of this episode, we're going to be asking Dr. Nigel Meredith from the British Antarctic Survey, what is space weather and how does it affect us? Would you mind starting by introducing yourself and telling us what you do?

R: My name is Nigel Meredith. I'm a space weather research scientist at the British Antarctic Survey. I develop models, global models of plasma waves in space, which are ultimately fed into our radiation belt models, which are also used for forecasting the space weather environment in the area of space and I'm also interested in calculating worse case scenarios. For example, I've worked out one in 10, one in 50, and one in 100-year space weather event for various orbits around the Earth.

I: That is very interesting. Shall we start by discussing, what do we mean by space weather?

R: Well, the term "space weather" refers to variable conditions on the Sun that can basically influence the performance of technology, both in space and on Earth. The main source of space weather is the Sun. We have explosions on the surface of the Sun, they send out bursts of charged particles and magnetic field into space and when they reach the Earth, they can tear open the geomagnetic field, giving rise to a geomagnetic storm and this can cause disruption to satellites, to communication and navigation signals, to aviation, and also to power supplies. The nature of this risk is such that severe space weather was added to the UK national risk register back in 2012.

I: Cool. So, it's something that can be extremely dangerous. How do you monitor that, both in general, if you monitor in space but also specifically, where do you get the data to keep an eye on the Sun and how the magnetic field around the Earth is changing?

R: There are various monitors. There are monitors at the so-called L1 point, which is outside of the Earth's magnetosphere towards the Sun and that measures conditions in the solar wind. Then of course, we have data from satellites themselves *in-situ* in the Earth's magnetosphere where satellites orbit. Then we can also make measurements on the ground as well. So, we make measurements of the waves in space on the ground and also electrical currents that are caused by the aurora. We can detect these on the ground as well and that's where the Antarctic comes in. So, for example, one of the main threats to satellites are so-called killer electrons. These electrons have energies of the order of a mega-electron volt, which means they're travelling at a very high fraction of the speed of light. These relativistic electrons, they can penetrate satellite surfaces and embed themselves in insulators and ungrounded conductors. From here the charge can build up. So, the charge builds up, the electric fields get stronger and eventually they can reach levels which can cause breakdown. This leads to a spark, which isn't good news for electronic components. Sometimes the effects are relatively minor but sometimes, occasionally, very rarely, an entire satellite can be lost if this happens in the wrong place. So, we build models here at BAS of the space weather environment, taking into account the plasma waves in space. One particular type of wave called chorus has been shown, or we've shown that it's important for accelerating these electrons to high energies. We can measure these both in space and on the ground and this is where Halley comes in. We have a VLF receiver of Halley, which detects the very low frequency radio waves from the chorus emissions and we use them to help us study the effects of space weather on the radiation environment and also any potential links with linking space weather to climate change and also for lightning detection.

I: That is amazing and you're doing all of that from Antarctica.

R: The VLF receiver is in the Antarctic. There is also a SuperDARN radar which was in the Antarctic, its currently in the Falkland Islands and this radar measures electrical currents in the atmosphere. Basically, what happens during geomagnetic storms, you get these beautiful displays of the Aurora but you also get strong electrical currents which heat the atmosphere and they cause it to expand. This can slow down satellites and space debris and increase the risk of collisions. This is one of the main uncertainties in orbit prediction models. So, the BAS operates a SuperDARN radar in the Falklands and its part of a global network of such radars that can measure and model the heating due to these currents and the effects on space debris and satellites in orbit. So, different aspects of space weather. One is the environment itself, and then the other is also it can affect the trajectories of satellites and space debris in low Earth orbit.

I: That is fascinating. Does all solar activity impact Earth?

R: That's a very good question because we see beautiful pictures of the Sun on Twitter or Facebook, people are always putting up these beautiful pictures showing eruptions on the surface of the Sun. The ones that are important are the ones that are directed towards the Earth. Back in, I think it was 2012, there was a massive eruption on the Sun, that had it been directed towards the Earth could have caused significant problems. As it was, it went off to the side, so it didn't come towards the Earth. You can have a huge explosion on the Sun that doesn't influence the Earth. It's only the ones that come in our direction that are important. You imagine if someone is firing bullets or something, if they go off in a different direction, you're safe. If they're coming towards you, you duck.

I: Well, it would be very difficult for the Earth to duck. What if there was something big coming towards us? I assume part of the modeling is to predict what might happen. Is there anything in the works or any kind of, this is what to do if a major explosion on the Sun is coming towards our planet?

R: We've learned a lot over the last 10 or 20 years with the modelling work and the observations to be able to forecast the radiation environment up to 24 hours ahead and our model does that, and it's updated every hour. So, that's available on the web for people to use. We also provide a measure of the risk of damage as well. So, this information is actually used by satellite operators and engineers and if something is happening, or they don't like the look of the situation at the moment, they will basically… they might bring more people into the building to monitor what's going on. They would certainly stop doing non-essential stuff. So, if they were about to issue a command for a satellite to do a manoeuvre or something that requires extra communications with the satellite, they would probably avoid doing that because that's the sort of thing that space weather could potentially interfere with. The information is used and the operators and engineers are always vigilant to possible problems due to space weather.

I: Clearly there are major events that could put a lot of things at risk, but it feels that most are probably the stuff that you monitor or model is the less flashier events, lets say, that is, the continuous changes in the space weather. How do people use those models to make better choices in both protecting stuff in orbit, but maybe even protecting stuff on Earth at high latitude?

R: I think for the satellites on orbit, the great thing about the model and past data sets is that satellite operators and engineers can go back and look at how their satellites have behaved. In fact, they probably do it the other way around. They probably look to see when they've got problems and then they can say, actually on this day we had a particular problem with our satellite and then they can go and have a look at the space weather conditions on that day. We call that post event analysis, so all this information is there, the model results are there. The great thing about the model is that it models the whole radiation environment, whereas of course we've just got spot measurements from particular satellites. So, this information they can use and it's statistical. Its not always obvious that an event has been caused by space weather, for example. There could be other factors: just age, or just degrading for other reasons, or even a small impact. They might have a database of anomalies, which they could then compare with the space weather environment and they then get confidence. So, they can say, actually if we get this kind of condition again, this might happen. Of course, it's not a one-to-one correspondence because as I mentioned earlier, these charges build up over time. So, it's a bit like the straw that broke the camels back in that you can have a big storm, it can build up and nothing can happen and then maybe something rather benign happens but its just enough to make that electric field exceed the breakdown levels. So, it is challenging, for sure.

I: I can imagine. To conclude, you've done a lot of interesting public outreach, even turning space weather into sounds. Can you tell us a bit about that?

R: The amazing thing about the VLF signals that we detect at Halley is that they are actually in the audio frequency range. So, they're in a frequency range from about 10 hertz to 10 kilohertz, which is exactly the same as the sounds that we hear. Of course, the radio waves that we detect, they're radio waves, not sound waves, but we can convert them directly into sound and then play them back through loudspeakers. So, we get to experience, if you like, some of the space weather environment through our own ears and it turns out that the sounds are quite remarkable. The chorus wave is actually so-called chorus because when you convert it to sound it resembles the twittering of birds in the dawn chorus and you have a beautiful cacophony, all kinds of variations. These waves, every time they sound different [wave sound played]. They are some just totally incredible sounds and then these waves, which you detect on Earth at Halley, they can also be detected directly *in-situ* in space where they are generated. So, when you detect them on Earth, you've got a lot of crackling in the background. The crackling comes from lightning, because every time you have a lightning flash it gives out a massive pulse of radio waves, some in the VLF range, so you continually hear crackling on Earth. [wave sound played].

I: From other parts of the world?

R: Yes. This is what's incredible.

I: That's fascinating.

R: This is totally amazing as well. The signals, the kind of crackles that we hear at Halley typically come from the Amazon and Congo basins, both of which are over 8,000 kilometres [4,970 miles] away. So, these signals have travelled all the way from the Amazon or Congo basins and then they sound as crackles and they kind of pollute, if you like, the chorus sounds. Another amazing signal actually, comes from the lightning because some of the radio waves from lightning leak out into space and then they travel along the Earths magnetic field line, if you like, and then they're collected in the other hemisphere. The signals get distorted because the higher frequencies travel faster than the lower frequencies and so what starts out as like a ping or a crack actually comes back as a whistling sound, a descending tone like this [wave sound played]. We call that a whistler. You've got all this activity going on and its rather fascinating because it also depends on time of day, whether there is a geomagnetic storm going on. So, it's like it has its own kind of symphony, if you like and it's basically Earths natural radio.

I: That is fantastic. Thank you very much for taking the time to explain all of this incredible science about space weather and how we are turning those models even into sounds.

R: That's right. You're welcome. Thank you.

Thank you for listening to The Big Questions. Head over to iflscience.com for the latest and greatest science headlines. The music in this episode is credited to Audioblocks.com. See you next time.

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