**Way back in nineteen sixty-seven, a couple of smart cookies called Suki Manabe and Richard Wetherald were working on a project for the United States Weather Service, to build a numerical model that could be used to study the climate. In those days of course, the world’s most powerful mainframe supercomputers had far less computing power than the mobile phone you have in your pocket today, so Manabe and Wetherald were trying to make the physics as simple as possible so that the valve-driven contraptions of their time wouldn’t overheat and cause a major fire in the basement of the building.**

**To achieve that simplification the two scientists wanted to know the minimum number of discrete levels in the atmosphere, and which greenhouse gases it was essential to include in the model so that it would adequately reflect the way temperatures vary with altitude. They were kind of focussed on water vapour initially because that is the main greenhouse gas by far, but when they included the other main gases, they created a data table representing the first ever robust estimate of how much the world would warm if carbon dioxide concentrations doubled. That estimate was two-point three six degrees Celsius, not far off today’s super computer model estimates of three degrees Celsius. What their model also found though, was that while increased levels of carbon dioxide caused a warming effect in the lower part of the atmosphere that we call the troposphere, it actually had a cooling effect higher up, in the region known as the stratosphere. Now you might think, ‘well that’s handy, the tropospheric warming that we humans have apparently caused by our profligate carbon dioxide emissions will surely be offset by this stratospheric cooling, right? Which means we can all calm down and stop panicking’. And that would be nice, wouldn’t it? If it were even remotely true, which it isn’t. A slew of recent research papers has found that, far from being an advantageous temperature offset, cooling in the upper layers of our atmosphere could have consequences that we could well do without. It may be endangering the safety of the satellites that run our daily lives, and even more worryingly, there’s now evidence that it’s opening up another hole in the ozone layer. This time it’s not above Antarctica though, it’s at the other end of the world above the Arctic – which is just what we need isn’t it!?**

**Hello and welcome to just have a think,**

**I’ll come onto that rather daunting Ozone layer hole a bit later in the video, but first of all, it’s worth having a quick look at that original work by Manabe and Wetherald, because it’s apparently a bit of an iconic thing in the climate modelling world.**

**So, here’s a very basic representation of how the earth’s atmosphere is composed. Down here near the surface you’ve got the troposphere, which goes up to about 11 kilometres. Then there’s the stratosphere which reaches up to about 50 kilometres. After that you’ve got the mesosphere, which is where meteors tend to provide us with their impressive light shows. Then finally there’s the thermosphere which goes right out to about seven hundred kilometres above the earth’s surface. That’s where low earth orbit stuff like the space station and most commercial satellites can be found.**

**As we go upwards, you might instinctively expect the air to get progressively colder, and for the most part you’d be right, certainly until you reach the stratosphere anyway. Then some weird stuff happens that actually causes air temperature to start rising again. To explain the intricate detail of why that happens, I recommend jumping over to my YouTube buddy Simon Clark’s channel. Simon has a PhD in theoretical atmospheric physics, and in twenty-twenty-two he made this brilliantly entertaining explainer video all about the upper levels of our atmosphere. You can jump straight to that video by clicking up there somewhere or by following the link that I’ve left in the description section. By the way, Simon also recently published this book, called Firmament, which explains in language that you and I can understand exactly how all the earth’s atmospheric systems interact, and I have to say, it’s pretty mind-blowing stuff!**

**At the very basic level that I can get my head around, greenhouse gases in the lower atmosphere absorb the long wave length infra-red radiation leaving the surface of the planet, which causes it to warm up. By the time you get to the stratosphere, most of this available thermal energy has already been captured, so thing get colder. But the other atmospheric molecule we’ve all heard about is Ozone. Ozone mainly rattles around at between about fifteen and thirty kilometres up, and it’s very good at absorbing the SHORT wave length light coming INTO the TOP of the atmosphere from the sun. That light warms up the Ozone molecules, and the heating that occurs as a result is enough to overcome the cooling effect of being further away from the Earth’s surface. Weird though it is, that temperature swing from warm to cold to warmer again is a completely normal function of our planet’s atmosphere. What Manabe and Wetherald did in their pioneering work more than fifty years ago was to simulate atmospheric temperatures changes based on three levels of CO2 concentrations –a hundred and fifty parts per million, three hundred parts per million, and six hundred parts per million. Down here at the surface we can see the two-point three-six degrees Celsius rise that the model predicted when CO2 concentrations doubled from three hundred to six hundred parts per million. What Manabe and Wetherald’s models showed, was that a doubling of atmospheric CO2 concentrations would lead to a significant decrease in stratospheric rewarming, starting at somewhere around twelve kilometres up and becoming more and more pronounced the further up they looked. By the early 2000s, real-world measurements of multidecadal changes in the thermal structure of the atmosphere were available from weather balloon networks, satellite-based microwave sounders, and reanalyses of conditions from the near surface up to the lower part of the stratosphere, at between twenty and twenty-five kilometres up. What those measurements revealed was significant anthropogenic influence, not only as a result of well-mixed greenhouse gases, but also from the depletion of stratospheric ozone and it’s subsequent recovery thanks to the landmark Montreal Protocol of nineteen eighty seven, AND changes in particulate pollution as industry and transport systems got larger and dirtier, and then more recently started getting cleaner.**

**This latest paper, published in May twenty-twenty-three by a team at the Woods Hole Oceanographic Institution, is the first to use modern satellite technology to continue those stratospheric measurements from twenty-five kilometres all the way up to fifty kilometres, where measurements are less affected by pollution and changes in stratospheric ozone and where the temperature signal of CO2 increase is expected to be considerably larger.**

**The researchers compared and compiled data from several different satellite sources and drilled into quite a considerable amount of detail to produce their graphs and charts , which had enough sensitivity to detect atmospheric changes from events like the Mount Pinatubo volcanic eruption in nineteen-ninety-one.**

**What they found was that taking measurements right up to fifty kilometres improved the detectability of a human fingerprint by a factor of five. The additional cooling that they found up there as a result of increased CO2 concentrations pretty much completely dismisses the theory that our warming planet is simply a result of changes in solar activity. If that was the case then the upper layers of the atmosphere would be warming, not cooling. So that’s one myth busted.**

**But, what about those other, slightly worrying consequences that I mentioned earlier?**

**Well, satellite data provides incontrovertible evidence that higher concentrations of carbon dioxide molecules have permeated right up through all the levels of our atmosphere, not just the stratosphere. This paper, published in October twenty-twenty-two, found that the mesosphere and lower thermosphere cooled by one point seven degrees Celsius between two-thousand-and-two and twenty-nineteen, and that the expected doubling of CO2 levels towards the end of this century will further cool these zones by about seven point five degrees Celsius. According to analysis carried out by NASA, that cooling is a causing an additional contraction of our atmosphere that can’t be explained by natural variation like the recent slow-down in solar activity. Those changes might sound pretty negligible, but believe it or not they’re enough to reduce the amount of drag experienced by orbiting satellites. That’s actually beneficial for the satellites themselves because if they don’t have to fight so hard against drag then they’ll be able to stay in orbit for longer. But as science writer Fred Pearce points out in this recent article for three-sixty Yale, that effect also holds true for the increasingly large amount of space debris that is also hurtling around our planet. There are apparently more than thirty thousand bits of orbiting detritus that are more than ten centimetres in size. A decrease in atmospheric drag means that this debris will ALSO now stick around for much longer before falling back towards earth, and that increases the risk of catastrophic collisions with the space hardware that we now rely on for so much of our modern technology. Now I don’t want to get too hysterical here, but it’s fair to say that more collisions will cause more debris, which increases the risk of yet more collisions, and so on and so on, and if we start to lose significant numbers of these things then it could disrupt stuff we now take for granted, like mobile telephony, television broadcasting, GPS guidance systems, internet access, weather forecasting, and environmental monitoring.**

**What really caught my attention though was this paper, published in June twenty-twenty-one explaining how fragile our ozone layer is, and how susceptible it appears to be to the additional high level stratospheric cooling we’ve just looked at. Most folks assume we fixed the Ozone layer when the world banned the use of chlorofluorocarbons, or CFCs, back in nineteen-eighty-seven. That was what the Montreal protocol was all about wasn’t it? We certainly stopped the main human cause of the problem, but it was always going to take decades for nature to restore ozone levels back to where they were. That process was initially predicted to take until about the middle of this century. We looked at what drives ozone depletion in a video last year, which you can jump back to by clicking up there somewhere. It’s mostly caused by very cold clouds that form in the stratosphere during the winter seasons over the poles. Thankfully, Antarctica appears to be continuing on its path to Ozone recovery, but the additional stratospheric cooling caused by increased human emissions of CO2 now seems to be opening up a new hole above the Arctic, as this twenty-twenty NASA satellite image shows.**

**The authors of the paper are not sure what’s causing the difference in temperature influence between the two poles, but they do make the very important observation that, unlike the vast uninhabited frozen wilderness at the southern end of our planet, the regions immediately surrounding the Arctic include some of the most densely populated areas on the earth, and given that ozone depletion is closely linked with rises in cases of skin cancer as a result of over exposure to harmful ultra violet sunlight, it might be worth adding this consequence to the ever increasing list of reasons to start taking far more urgent action, not only to eradicate human-induced carbon dioxide emissions into our atmosphere but also to warn people in more northern climes about the dangers of over exposure to sunlight so that we can start adapting our behaviour accordingly.**

**Just a thought! And as always feel free to leave yours down in the comments section below.**

**That’s it for this week though. Thanks, as always to our fantastic Patreon supporters, who enable me to run this channel on a full-time basis without having to include ads and sponsorship messages in any of my videos. If you feel I’ve earned that level of support from you and you’d like the chance to influence future content, then you can do that over at Patreon dot com forward slash just have a think where you’ll also get early access to all my videos plus exclusive additional monthly content from me.**

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**As always, thanks very much for watching! Have a great week, and remember to just have a think. See you next week.**