Memo

From: **UK Space Agency, Met Office, ECMWF**

To: **Ofcom**

Subject: **Discussion of attenuation 175-191 GHz**

Date: **1 July 2020**

Executive Summary

The conclusion of this new study is that it has been determined that the protection provided by the additional path losses due to water vapour were over-estimated in the original Ofcom study. As a consequence, the proposed power limits and mitigation do not provide the expected level of protection to passive Earth Observation in the 175-191 GHz band and measurements from the AMSU-B and MHS instruments, which are used operationally for weather forecasting, including extreme events, would be at risk. In order to fully protect these measurements, we conclude that an additional 7 dB reduction in interference levels would be required.

Introduction

The recent Ofcom consultation "Supporting innovation in the 100-200 GHz range" focussed on sharing studies for bands centres on 118 and 183 GHz that are used by operational weather forecast and climate services. In undertaking technical studies on whether sharing is possible with the existing services using these bands, Ofcom made a number of assumptions. Of particular importance for the bands between 175-191 GHz, was that a global mean atmospheric profile was used to calculate atmospheric attenuation, to calculate how much an emission at the surface is reduced due to atmospheric absorption before reaching a sensor on a satellite. On examining this assumption, we note that this does not cater for cases where the atmosphere is much drier than the global mean profile. The strongest test would be to repeat the calculations assuming no atmospheric water vapour, because that is by construction the most extreme case possible (water vapour can't go negative). However, in this short memo we note for realistic winter atmospheric conditions actual attenuation rates, and encourage Ofcom to repeat the technical studies fulling taking this into account.

Background

Most attenuation between 175 and 190 GHz is caused by water vapour molecules, and water vapour varies a lot from winter to summer and from region to region. In the UK values of the vertically integrated mass of water vapour in the atmosphere less than 5 kgm^{-2} occur quite regularly and exceptionally values less than 2 kgm^{-2} can occur. This integrated quantity is usually referred to technically as the Total Column Water Vapour (TCWV) and this term will be used throughout this note. It is the total weight of water per square metre and its units are kgm^{-2}. Sometimes this is equated to millmetres because if you took all the water vapour in the air in liquid form to the ground, 1 kgm^{-2} would have a depth of 1mm. A TCWV of 2 and even 5 kgm^{-2} is much less water vapour than the global mean profile has. Therefore, use of a global mean profile does not reflect the much lower levels of attenuation that commonly occur in winter in the UK, not the exceptionally low levels that can occur across continental regions of Europe, Asia and North America, where values under 1 kgm^{-2} are not uncommon.

In order to quantify this more precisely three steps have been taken, in consultation with the Copernicus Climate Change service (C3S) at the European Centre for Medium Range Weather

Forecasts (ECMWF) and Deutscher Wetterdienst (DWD), the German meteorological service, who's division for satellite-based climate monitoring provide satellite data products for C3S.

Firstly, the frequency of occurrence of very low value of TCWV in the ECMWF 40-year re-analysis has been examined. The ECMWF re-analysis (Hersbach et al. 2020) uses all available weather observations over the last 40 years, covering the so called "satellite era" when the atmosphere was consistently well observed due to observations on satellites. It uses modern state of the art techniques developed for operational weather forecasting, to integrate all these observations into a physically and spatially consistent analysis of all variables (temperature, water vapour, wind, clouds, rain) every day over the 40 year period. This analysis was kindly performed by Dr. Hans Hersbach of the Copernicus Climate Change Service at ECMWF.

Secondly, a similar study was done by DWD looking at a range of satellite observations of daily composites between 2003-2008 (MERIS (Near-Infrared) cloud-free, over land and coastal ocean (Lindstrot et al. 2012), SSM/I (Microwave) all-sky, over the ocean and open water surfaces up to 50 km near coast line (Schröder et al. 2015)) from ESA Data User Element (DUE) GlobVapour project (Lindstrot et al. 2014) to look at the frequency of low TCWV amounts, but without the use of a model. It is also a global product, but shows detail over the UK. This data was kindly provided by Dr Nabiz Rahpoe and Anna Christina Mikalsen of DWD.

Lastly, the Met Office studied the relationship between TCWV and attenuation so we know, for a specific frequency band, what attenuation in dB corresponds to a particular TCWV, so that the plots from the Copernicus Climate Change Service and DWD can be interpreted directly in terms of attenuation. This was kindly provided by Dr Emma Turner of the Met Office.

Frequency of occurrence of low TCWV

Figure 1 shows that TCWV less than 5 kgm^{-2} occurs widely in the UK on between 1% and 3% of days according to ERA5, and locally up to 10%. Figure 2 shows the DWD analysis showing 10% more widely over the UK.

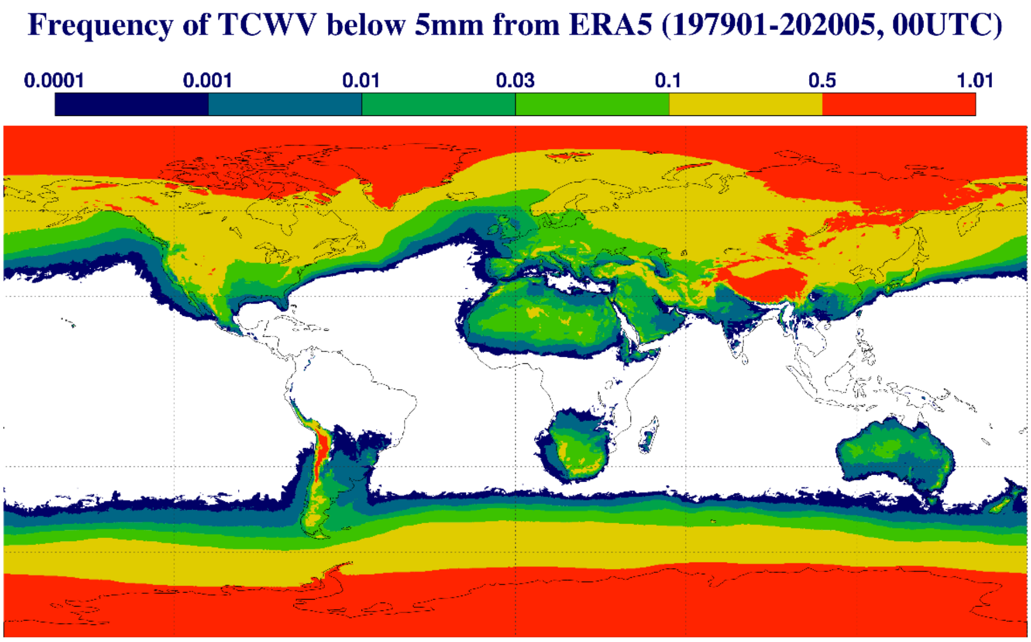

Figure 1: Frequency of occurrence of TCWV < 5 mm (kg m-2) from ERA-5

Figures 3 and 4 show the same quantities but for a threshold of 2 kgm^{-2} and show a low occurrence in ERA-5, less than 1%, whereas the DWD analysis shows 1-2%. Nonetheless both agree that TCWV < 2 kgm^{-2} do occur in the UK, and it is not an exceptionally rare event.

These very low values are associated with cold, dry air arriving from polar regions, which will be associated with some of the most severe winter freezes that occur, with extreme low temperatures and high impact. It is very important in these situations that operational weather forecast models have very accurate knowledge of atmospheric water vapour, because this will be critical to how low temperatures fall.

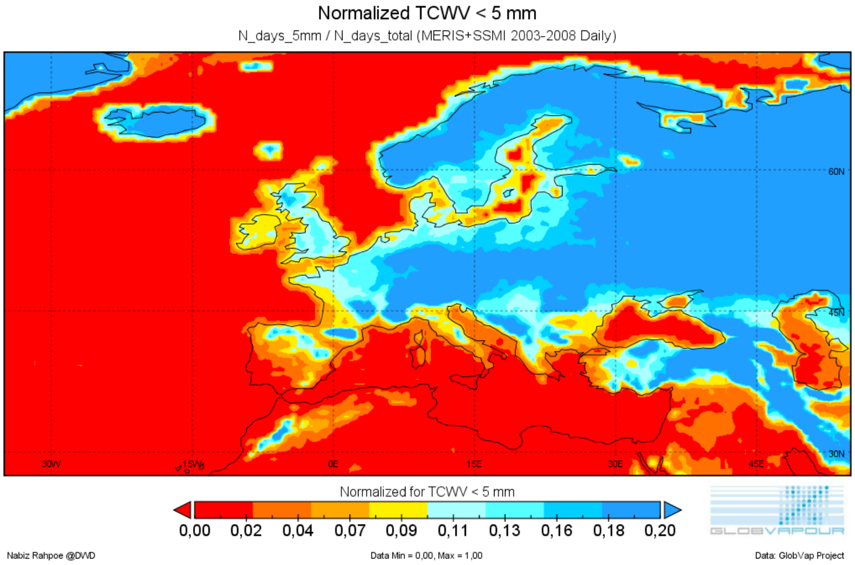

Figure 2: Frequency of occurrence of TCWV < 5 kg m^{-2} (mm) from GlobVapour project daily composites, analysed/visualized at DWD.

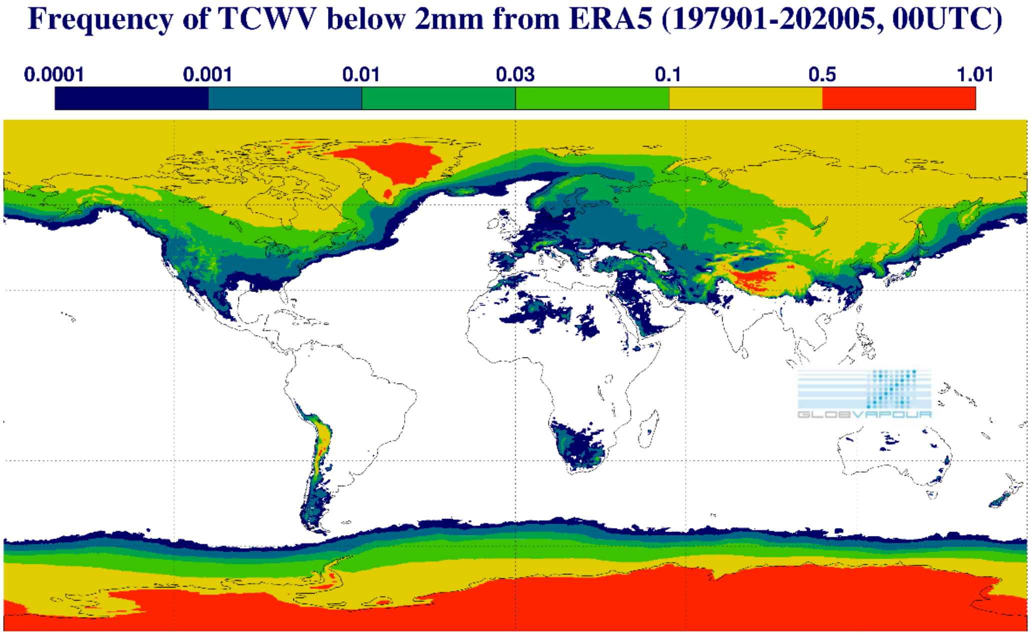

Figure 3: Frequency of occurrence of TCWV < 2 kg m^{-2} (mm) from ERA-5

Relationship of attenuation to TCWV

As noted earlier, it is important to interpret these TCWV values in terms of atmospheric attenuation. A radiative transfer (Turner, Rayer and Saunders, 2019) was used to calculate attenuation from a diverse range of atmospheric profiles, representing the full range of global variability, and then plotted total attenuation in 1 GHz intervals from 175 to 190 GHz against TCWV. This is shown in Figure 5.

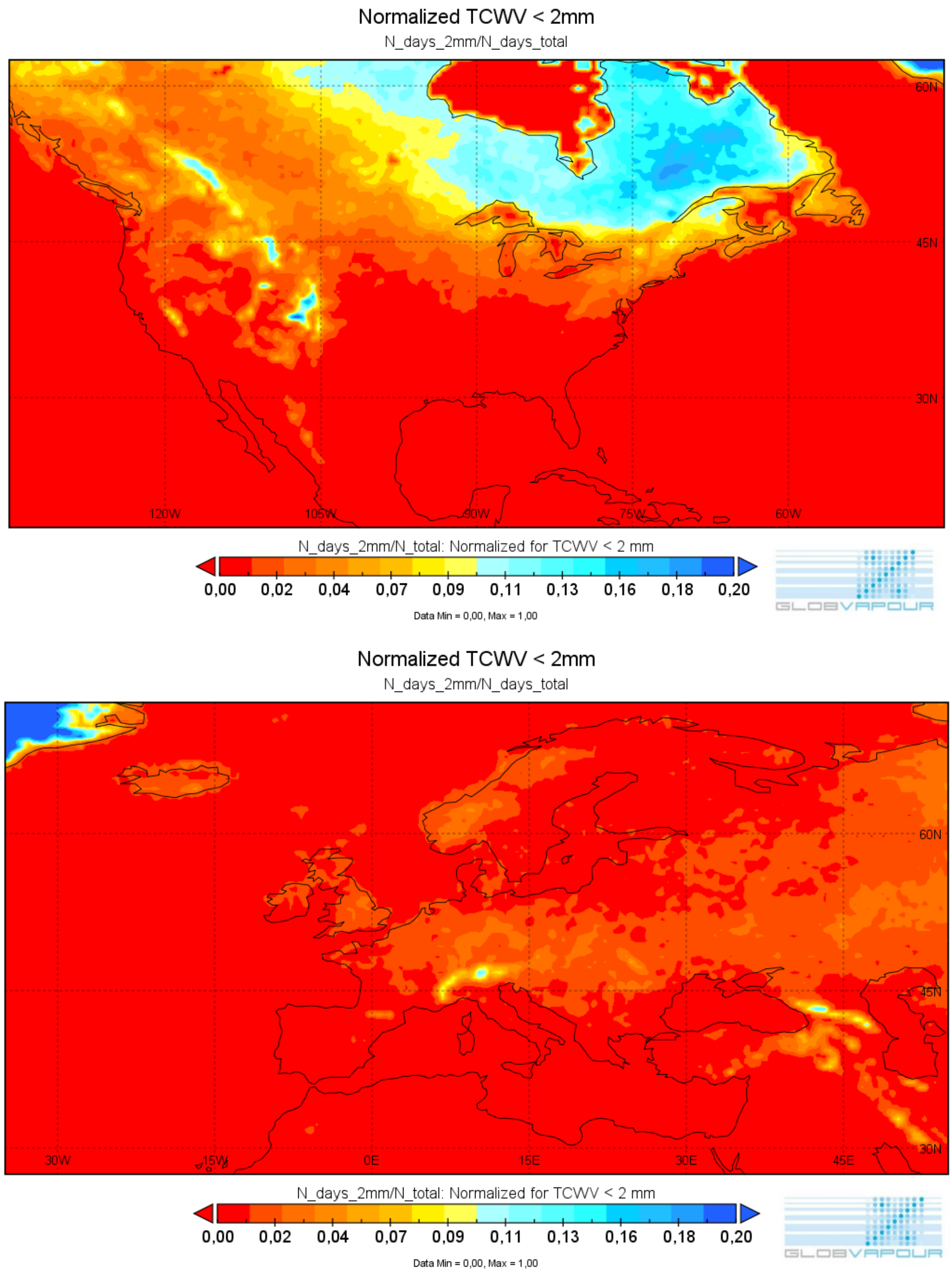

Figure 4: Frequency of occurrence of TCWV < 2 kg m^{-2} (mm) from GlobVapour project daily composites between 2003 – 2008 (MERIS+SSM/I), analysed/visualized at DWD.

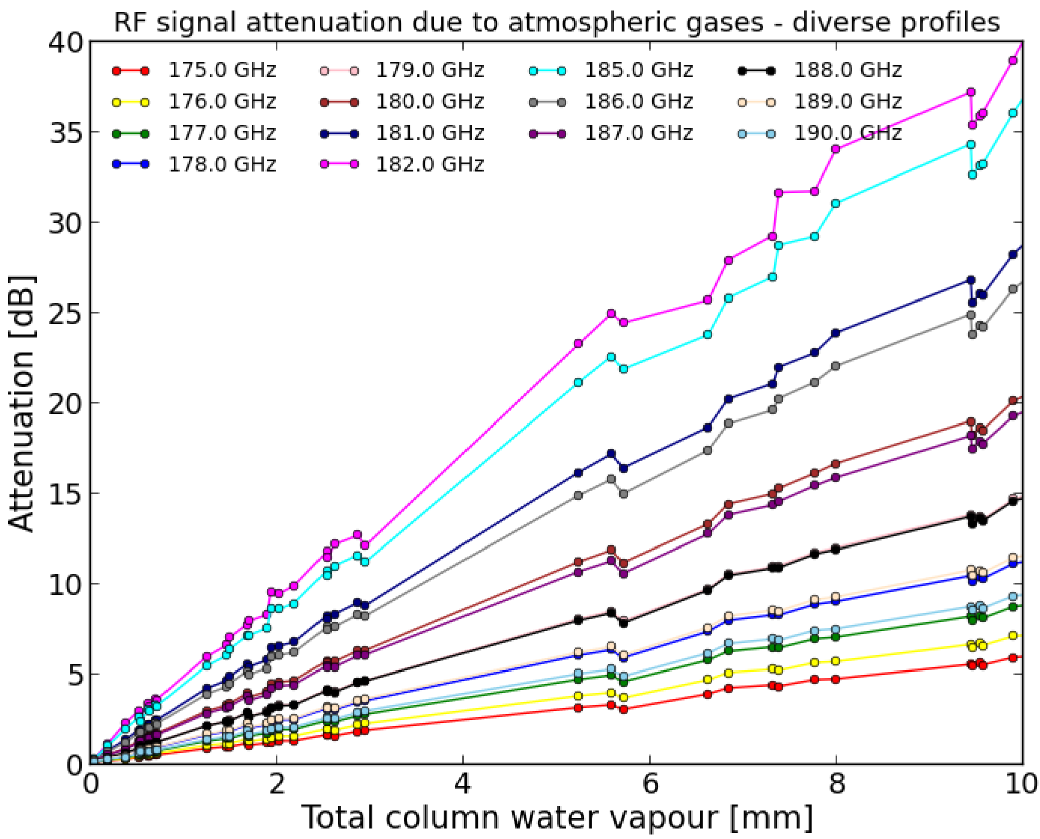

Figure 5: Attenuation as a function of TCWV

It can be seen that total attenuation is close to a linear function of TCWV, with only a small variation arising from other details of the atmospheric profiles. The total attenuation for 2 kg m^{-2} (mm) TCWV ranges between 1 dB (175 GHz) and 8 dB (182 GHz). This compares to 8 dB at 175 GHz for the profile used in the Ofcom study. At 5 kg m^{-2} (mm) this ranges between 3 and 20 dB. The attenuation is lowest furthest from 183.31 GHz, because that is the centre of the water vapour spectral absorption line. We conclude that the Ofcom calculations should assume atmospheric attenuation 7 dB lower than assumed at 175 GHz,

Conclusions

Noting that attenuation is lowest for 176 GHz and 190 GHz, we should consider primarily these channels. These are the critically important frequency of the double side banded channel of the AMSU-B and MHS instruments which fly on both the American and European operational weather satellites, which were developed in the UK for the European Meteorological Satellite Organisation (EUMETSAT). The frequency is also used by operational missions from Japan, NASA (USA), NOAA (USA), China, France and India. It provides water vapour vertical profile information in the lowest 5 km of the atmosphere. Studies (e.g. Geer et al. 2018) show that this has the equal highest impact of any type of observation to the skill of weather forecasts from very short range (next 24 hours) out to one week ahead. It is particularly important for forecasts of high impact weather, such as severe storms, cold air outbreaks and resulting extreme winter conditions and in determining accurate the so called "jet stream" which is highly influential for UK weather. As well as the investment in space instrumentation, operational and research centres have spent the last two decades investing in ever more sophisticated systems to exploit the observations. The impact and value of this data across multiple operational centres is described by Geer et al (2018).

For this channel the attenuation for 2 kg m^{-2} and 5 kg m^{-2} TCWV respectively is 1 and 3dB. Therefore, to correctly assess the risk the EESS services, this is the level of atmospheric attenuation that should be assumed. Then we come back to the question of risk. At 2 kg m^{-2} the ERA-5 and DWD analysis shows that we will see attenuation of less than 1 dB around 1-3 % of the time. This will of course be concentrated into the winter months, when often extreme weather has more impact.

In these calculations we neglect two important processes that further increase the power received at the satellite for a given power source on the ground. Firstly, the atmosphere has a spectrum of turbulent scales, and this impacts atmospheric attenuation. It gives rise to a range of water vapour values over a satellite field of view, not a single uniform field with the mean water vapour amount. This means attenuation also varies and due to the non-linearity of the radiative transfer equation this means the total field of view attenuation will be lower. This process is described by Calbet et al. (2018) and neglecting it causes significant biases in the modelling of satellite observations. The second process we neglect relates to clouds. Clouds cause scattering. If the cloud is thin (e.g. cirrus) with low attenuation this will increase the signal received at the satellite. As we neglect both these processes we are overestimating total attenuation and therefore underestimating the potential impact of terrestrial emitters.

It is concluded that the maximum attenuation by the atmosphere that should be assumed in studies of sharing at these frequencies is 1 dB, which is 7 dB lower than assumed by Ofcom. This means the power levels that will allow sharing between new ground based applications and existing EESS services will have to be lower than calculated by Ofcom. The value of the Numerical Weather Prediction to the UK and other economies is described in the report from a workshop at ECMWF in 2018 (https://www.ecmwf.int/en/learning/workshops/radio-frequency-interference-rfi-workshop), which demonstrates the critical importance of carefully ensuring that sharing does not cause interference to existing EESS users.

References

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