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Your response

Question	Your response (expanded for each question at the end of this reponse)
Do you have any comments on our analysis of the current use of spectrum bands in the frequency range 100-200 GHz, or the potential future use of these	Confidential? – Ɏ / N In this response NCEO provides a first analysis of the relevant EESS sensors available worldwide which we will expand in a dedicated

frequencies? Do you have any comments on current or future use of the specific bands 116-122 GHz, 174.8-182 GHz and 185-190 GHz?	report for Ofcom. These include both passive and active instruments, It is clear that specific bands in the spectrum, currently assigned to EESS, are very important for weather forecasting including hazards and for climate monitoring. Continuity and consistency of EESS performance at 183 GHz (+/- 10 GHz) for these sensors is vital for climate applications. This band is used for long-term trends and understanding of water vapour, a natural greenhouse gas expected to increase under climate change. We would suggest Ofcom does not experiment with licence-exempt outdoors between 174.8 and 192 GHz.
Are there any further bands above 100 GHz which you think Ofcom should consider making available on a technology and service neutral basis? Which benefits might be realised from enabling access to further bands?	Confidential? – ¥ / N NCEO have not conducted an exhaustive study of band allocation in this region. However, since the consultation document recognises terrestrial use is currently light, we think that it should be possible to reinforce allocation of bands between 100 and 200 GHz which are not in the range of satellite remote sounding. In other words it might be possible to leverage spectrum not of significance to EESS. This might be sufficient to understand if terrestrial applications are able to grow in this region and with what fidelity. Note, co-existence of use of EESS bands is certainly possible for indoor applications. The question for EESS exploitation is really around contamination by non-regulated angular emissions and their reflections towards space. We suggest raising 95-114 GHz to a higher priority giving access to 14 GHz in the consultation range (instead of the suggested bands) and 20 GHz overall.
Do you have any comments on the approach we have used to assess the potential effect of our proposals on EESS?	Confidential? – ¥ / N NCEO welcomes the emerging approach in the strategy which is to simulate likely conditions. We believe that it is critical to ensure that the simulations account for the full range of conditions – particularly scattering in clouds, scattering in urban areas, atmospheric conditions including extremes (e.g. cold, dry polar atmospheres).
Do you have any comments on our proposals to authorise devices to operate	Confidential? – ¥ / N

on a licence-exempt basis in the 116-122 GHz, 174.8-182 GHz and 185-190 GHz bands?	We suggest a two stage approach: a trial phase, assessment period followed by a longer-term period if trials are suitable. We would propose starting a license exempt period, ideally non-EESS bands, in the 100 to 200 GHz region. A finite term for licence exempt missions could be operated alongside a monitoring programme to verify and diagnose the actual pattern of signal emissions. A fixed period for assessment allows for review of emissions and more confidence in regulations.
Do you have any comments on our proposal to create a 'Spectrum Access: EHF' licence to authorise increased power use in the 116-122 GHz, 174.8-182 GHz and 185-190 GHz bands?	Confidential? – ¥ / N NCEO and NERC do not operate our own satellites. We have also not performed calculations to assess the effects of increased power use on these bands; however, see our response to question 3. We note that expert space agencies have assessed power use and recommend that inputs from bodies of which the UK is a member state (ESA and Eumetsat) are most carefully considered. Our experience of radiative transfer suggests that Ofcom should consider carefully, working with the EESS community, the e.i.r.p. limit for licenced devices which are operating outdoors in terms of their effects on passive e.i.r.p. Although it is recognised that a licensed regime would certainly facilitate the enforcement of the operational conditions (elevation-dependent e.i.r.p. mask, limit on the main beam elevation angle), clarification is sought on the mechanisms envisaged for conformance checking and interference monitoring and mitigation. We emphasize that it continues to be important for regulations in the UK to be in-line with global international standards in this area. Our understanding is that the relevant regulated power densities are given by Table 2 of Recommendation ITU-R RS.2017 which was approved 08/2012. This includes recommendations for passive and active nadir sounders as well as passive limb sounders.

Natural Environment Research Council

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

NERC-NCEO Responding to the Supporting innovation in the 100-200 GHz range (Ofcom)

March 2020

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1 Introduction to the Response from NERC and NCEO

This response to the Ofcom review is produced by the National Centre for Earth Observation (NCEO) on behalf of Natural Environment Research Council (NERC) which is part of UK Research and Innovation (UKRI); UKRI_NERC annual expenditure of over £400M/annum, here we concentrate only on the Earth Observation (EO) aspects that we are expert in and which are extremely relevant to our business.

We note that our response is on behalf of the EO public laboratory and academic research community in the UK and therefore is reflective of interests beyond NCEO and UKRI-NERC, i.e. including the HE sector. It would be valuable for this point to be recognised where necessary, for example in interactive tables. We are happy to provide further information to Ofcom to help in this process.

Within the spectrum exploited by EO science and beneficiaries, there are essential, international satellite services operating in the region between 100 GHz and 200 GHZ. In fact, there is increasing use of novel EO passive (and potentially active) sensors above 100 GHz which should not be ignored. These sensors access new information complementary to that provided by sensors below 100 GHz.

Below we articulate more detailed information on our organisation so that the expert nature of the response is clear.

The Natural Environment Research Council (NERC) is the UK's leading public funder of environmental science. Part of UKRI, it invests more than £330 million each year in cutting-edge research, postgraduate training and innovation in universities and research centres; UKRI itself has a budget of over £7 billion from the taxpayer and comprises seven research councils, Innovate UK and Research England. NERC scientists study the physical, chemical and biological processes on which our planet and life itself depends – from pole to pole, from the deep Earth and oceans to the atmosphere and space. NERC partners with business, government, the public and the wider research community to shape the environmental research and innovation agenda. NERC science provides knowledge, skills and technology that deliver sustainable economic growth and public wellbeing. Overall, the NERC research base supports new knowledge exploited by many organisations in the UK, including the public weather service of the Met Office, the government in its commitment to the Paris agreement and net-zero carbon by 2050 and Defra in its development and monitoring of environmental regulations.

The National Centre for Earth Observation (NCEO) is one of NERC's six primary Research Centres and specialises in satellite and other remote sensing data. NCEO has more than 130 expert scientists distributed across leading UK universities and research organisations and hosts key satellite data processing and archival facilities for the research community. NCEO provides the UK with core expertise in Earth Observation science, data sets and merging techniques, and model evaluation to underpin Earth System research and the UK's international contribution to environmental science. NCEO scientists work strategically with space agencies, play significant roles in mission planning, and generate internationally-recognised data products from 20 different satellite instruments.

NERC and NCEO have a range of stakeholders and partners across government and business. We have liaised with the UK Space Agency in producing our response. NERC works closely on research science

exploitation with the Met Office, the National Physical Laboratory and the Satellite Applications Catapult and the UK Space Agency. It provides advice to government ranging from BEIS organisations such as the UK space Agency to Defra and its EO Centre of Excellence. Indeed EO is being examined as a valuable tool across government. NERC works with both upstream industry building satellite instruments for EO, particularly next generation satellite instruments to address key scientific questions, and downstream industry working on EO applications building on scientific techniques and data. NERC trains significant numbers of scientists who subsequently join these organisations and provide much-needed capability. We have liaised with the UK Space Agency and Met Office in developing our response.

We feel it is important to articulate our understanding of satellite (and ground-based) sensors operating in the 100 to 200 GHz range. We intend to release this also as an NCEO report in the near future. Here we summarise that knowledge in three subsections covering passive and active vertical viewing (downward/upward looking) sensors followed by passive limb (tangential/horizontal) sounding sensors of the atmosphere. The underlying science behind microwave EESS observations can be found at: ftp://www.wmo.int/Documents/www/RFREQU/handbook/ch5_1passive.pdf.

1.1 EESS Passive radiometers in the 100 to 200 GHz region

There are a large number of passive imagers and sounders on Earth Exploration Satellite Services in space which are operating in the 100 to 200 GHz region of the spectrum. These instruments satellites provide temperature and water vapour information (sounders) which are key for data assimilation plus data on ice in the atmosphere (imagers), which are important for improvement of cloud model parametrizations. Examples of the sounders with channels in the 183.3 GHZ water vapour absorption band are the Advanced Technology Microwave Sounder (ATMS) on board SNPP, NOAA-20, the Microwave Humidity Sounder (MHS) on board EUMETSAT MetOp-A, MetOp-B and C, NOAA-18, 19 (replacing AMUS-B), the Special Sensor Microwave - Imager/Sounder (SSMIS) on board NOAA DMSP-F16, 17, and 18, Sondeur Atmosphérique du Profil d'Humidité Intertropicale par Radiométrie (SAPHIR) on board the ISRO-CNES Megha-Tropiques, the GMI on board the GPM core satellite. The Micro-Wave Humidity Sounder -2 (MWHS-2) on board CMA FY- 3C, and 3D has also channels within the 118.75 GHz oxygen line. Most of these instruments have also channels in the window region with frequency between 150 and 166 GHz.

An important characteristic is the prevalence of these microwave sounders in operational systems for weather forecasting in major satellite suites belonging to the United States, Europe (including the UK) and China; India also utilises relevant microwave bands in one mission. Operational means that these satellite instruments are always available and are utilised in near real-time (latency of data availability of 3 hours or less) in the weather forecasts used every day by billions of people to access up-to-date information in all weather conditions. It is estimated that the value of benefits to the UK economy alone from public service warnings is £1.5bn per annum whilst the benefits of all weather forecasts to the US economy is believed to be 11.4 billion USD per annum.

A second key point is that the use of multiple closely-spaced channels in particular bands is fundamentally governed by the presence of oxygen and water vapour spectral lines (118 GHz and 183 GHz respectively) whose shape and intensity provide sensitivity to different parts of the atmosphere.

The use of all channels therefore gives information on temperature and humidity at different altitudes which is essential information for the models of atmospheric circulation and their predictions of evolving weather systems. Precipitation measures can also be obtained from the data. Large impacts are obtained utilising such information, including in clouds where scattering of radiation will be significant in providing information in cloudy situations. For example, records of water vapour in the atmosphere (humidity) provide a climate record extending over 30 years starting in 1988 and relying on the 183 GHz channels as a consistent feature. Temperature, water vapour and precipitation are defined as essential climate variables by the Global Climate Observing System. Various climate data records of WV and P that rely on these MWS measurements are freely available and widely used. It is critical for climate monitoring, climate analysis and climate services that microwave observations in these frequency ranges continue to be unaffected by interference from other sources.

Thirdly, channels in the window region near 150 and 166 GHz provide information on clouds, light precipitation and particularly solid precipitation such as precipitation-sized ice particles. This is important for observations of snowfall.

Radiometer	Current Satellites	Lifetime (exp.)	23 GHz	31/36 GHz	50-60 GHz	89/91 GHz	118 GHz	150/166 GHz	183/190 GHz	229 GHz	
(AMSU/A) MHS	NOAA-18/19 MetOp-A/B/C	2006-10-19 to ≥ 2024	(23.8)	(31.4)	(12 ch 50.3-57.29)	89		157	2 ch 183.311& 190.311		Centref req (GHz)
			48x48*	48x48*	48x48*	16 x 16 nadir to 26 x 52 at the edge		16 x 16 nadir to 26 x 52 at the edge	16 x 16 nadir to 26 x 52 at the edge		IFOV (km²)
ATMS	Suomi NPP NOAA20 (JPSS series)	2012-03-06 to ≥2038	23.8	31.4	13 ch 50.3-57.29	89.5		165.5	5 ch 183.31		Centre freq (GHz)
			74x16*	74x16*	32x16*	16 x 16 nadir to 30 x 68 at the edge		16 x 16 nadir to 30 x 68 at the edge	16 x 16 nadir to 30 x 68 at the edge		IFOV (km²)
SAPHIR	Mega Tropique	2011-10-12 to ≥ 2019							6 ch. 183.31		Centre freq (GHz)
									10x10*		IFOV (km²)
MWHS	FY-3C/D (FY-3 series)	2013 to ≥2029				89	8 ch 118.75	150	5 ch. 183		Centre freq (GHz)
						32x16*	32x16*	32x16*	16x16*		IFOV (km2)
MWS	Metop-SG A1, A2 A3	2021-2042	23.8	31.4	14 ch 50.3-60.3	89		166	5ch 183.31	229	Centre freq (GHz)
			40x40*	40x40*	20x20*	17x17*	17x17*	17x17*	17x17*	17x17*	IFOV (km2)

Figure 1: list of current and future cross-track scanning MW radiometers equipped with precipitation sensing channels, and their main characteristics. All these radiometers (except SAPHIR) are on board operational satellites, including ATMS on board the operational JPSS series, and MWS, on board EPS-SG satellites (besides the Chinese MWHS).

Figure 1 summarises the sensors and the frequencies they use. It is important to note that frequencies identified are core frequencies and various channels are employed either side of the band centre e.g. from 174 GHz to 192 GHz for the "183 GHz" channel.

1.2 EESS Active sounders in the 100 to 200 GHz region

The last few years have seen the development of novel radars within window regions of this frequency range focused at the study of ice and mixed-phase clouds at high latitudes (G-band atmospheric radars: new frontiers in cloud physics by Battaglia et al., Atm. Meas. Tech., 2014, 7(1), 321-375 provides a review of science applications). Very recently differential absorption radars (the microwave analogous to differential absorption lidars) for the study of water vapour in clouds have been also proposed with channels within the 183.3 absorption band. The first of such radar with channels between 167 and 174.8 GHz has been developed by NASA-JPL (Roy et al., Boundary-layer water vapor profiling using differential absorption radar, Atmos. Meas. Tech., 11, 6511-6523 (2018); it is currently being operated from the ground and in airborne field campaigns. A radar at 199.5GHz (window region) radar has also been developed by UK-RAL within the CEOI-funded GRaCE project and it is currently operated at the Chilbolton observatory, UK). However, deployment of G-band radars have been proposed as part of ESA and NASA studies for in cloud water vapour studies with channels in the 183.3 GHz band. NASA-JPL is currently developing miniaturized G-band radars to be deployed in cubeSats.

1.3 EESS Limb sounders of the atmosphere (passive) in the 100 to 200 GHz region

In addition to the vertical viewing sensors, the science community has realised a number of EESS missions which are important for limb sounding of the atmosphere. These instruments observe at a grazing angle to the atmosphere to provide profiles of temperature and humidity in the stratosphere particularly.

Frequency bands at 118 GHz and 190 GHz (183 GHz band) are used by Microwave Limb Sounder (MLS) on Aura to profile temperature and water vapour in the upper troposphere and stratosphere. This instrument has been in continuous operation since 2004. Together with the preceding instrument on UARS, the observations form a unprecedented record of ozone depletion and climate change which has been exploited to provide policy advice to governments across the globe.

Atmospheric limb-opacity limits frequency bands to sound the mid/upper troposphere to the 100-200GHz, extensively demonstrated by MLS, and 300-350GHz ranges. At higher frequencies, limb-paths are opaque below the tropopause so can only be used to sound the stratosphere. Antenna pattern main beam widths for limb-sounders in the 100-200GHz range are broad and have sidelobes given additional contributions from other altitudes and potentially the surface.

We do not know of any evidence of radio-frequency interference in these systems from ground-based systems although in theory this is possible due to sidelobes intersecting with the surface from observations at a few km altitude above the horizon. We note that estimates of sensitivity for microwave limb sounding were reported and approved in ITU Recommendation ITU-R RS.2017.

2 Expanded Response to Ofcom questions

2.1 Question 1

Question 1: Do you have any comments on our analysis of the current use of spectrum bands in the frequency range 100-200 GHz, or the potential future use of these frequencies? Do you have any comments on current or future use of the specific bands 116-122 GHz, 174.8-182 GHz and 185-190 GHz?

In this response NCEO provides a first analysis of the relevant EESS sensors available worldwide which we will expand in a dedicated report for Ofcom. These include both passive and active instruments which are described in detail in Section 1 above. Passive nstruments have been operated in these frequencies since 1988 in both nadir (downward looking) and limb (horizontal tangential views).

It is clear that specific bands in the spectrum, currently assigned to EESS, are very important for weather forecasting including hazards and climate monitoring. Continuity and consistency of EESS performance at 183 GHz (+/- 10 GHz) for these sensors is vital for climate applications. This band is used for long-term trends and understanding of water vapour, a natural greenhouse gas expected to increase under climate change.

Given the value of these bands, it is not clear why Ofcom has chosen them for this license relaxation experiment. There may be some misunderstanding of the spread of channels around the overall definition of band. For example, the 183 GHz channel includes bands used for EES between 174 GHz and 192 GHz.

We would suggest Ofcom does not experiment with licence-exempt outdoors between 174.8 and 192 GHz.

We would be happy to work with Ofcom to target bands for first release more closely. For example, it seems that raising 95-114 GHz to a higher priority than the suggested channels would give access to 14 GHz in the consultation range and have a much smaller effect on EESS sensors.

2.2 Question 2

Question 2: Are there any further bands above 100 GHz which you think Ofcom should consider making available on a technology and service neutral basis? Which benefits might be realised from enabling access to further bands?

NCEO have not conducted an exhaustive study of band allocation in this region. However, since the consultation document recognises terrestrial use is currently light, we think that it should be possible to reinforce allocation of bands between 100 and 200 GHz which are not in the range of satellite remote sounding. In other words it might be possible to leverage spectrum not of significance to EESS. This might be sufficient to understand if terrestrial applications are able to grow in this region and with what fidelity.

In this respect it could be useful to undertake a closer study with the EESS community to clearly map which channels are used for EESS and understand where frequencies might already be available under ITU for outdoor emissions at the surface.

Note, co-existence of use of EESS bands is certainly possible for indoor applications. The question for EESS exploitation is really around contamination by non-regulated angular emissions and their reflections towards space.

We suggest raising 95-114 GHz to a higher priority giving access to 14 GHz in the consultation range (instead of the suggested bands).

2.3 Question 3

Question 3: Do you have any comments on the approach we have used to assess the potential effect of our proposals *on EESS*?

NCEO welcomes the emerging approach in the strategy which is to simulate likely conditions. We believe that it is critical to ensure that the simulations account for the full range of conditions – particularly scattering in clouds, scattering and reflection in urban areas, atmospheric conditions including extremes (e.g. cold, dry polar atmospheres). In cold and dry atmospheres, microwave radiation may propagate much greater distances than in warmer, more humid atmospheres, noting that water vapour has extensive effects across the spectrum.

NCEO has undertaken any simulations of EESS bands in the 100-200 GHz range. However, our scientists have excellent expertise in the propagation of radiation through the atmosphere at other wavelengths. We are very clear that scattering and reflection make important differences to the angular distribution of microwave radiation. We also note that limb sounding needs further study to understand its sensitivity to surface-tangential ("horizontal") views including sidelobe sensitivity for microwave instruments.

2.4 Question 4

Question 4: Do you have any comments on our proposals to authorise devices to operate on a licence-exempt basis in the 116-122 GHz, 174.8-182 GHz and 185-190 GHz bands?

We suggest a two stage approach: a trial phase, assessment period followed by a longer-term period if trials are suitable. We would propose starting a license exempt period, ideally non-EESS bands, in the 100 to 200 GHz region. A finite term for licence exempt missions could be operated alongside a monitoring programme to verify and diagnose the actual pattern of signal emissions. A fixed period for assessment allows for review of emissions and more confidence in regulations.

We would be very happy to discuss possible approaches with Ofcom which would allow for flexibility and a full assessment of the implications of new interfering emissions in this range.

2.5 Question 5

Question 5: Do you have any comments on our proposal to create a 'Spectrum Access: EHF' licence to authorise increased power use in the 116-122 GHz, 174.8-182 GHz and 185-190 GHz bands?

NCEO and NERC do not operate our own satellites. We have also not performed calculations to assess the effects of increased power use on these bands; however, see our response to question 3. We note that expert space agencies have assessed power use and recommend that inputs from bodies of which the UK is a member state (ESA and Eumetsat) are most carefully considered.

Our experience of radiative transfer suggests that Ofcom should consider carefully, working with the EESS community, the e.i.r.p. limit for licenced devices which are operating outdoors in terms of their effects on passive e.i.r.p. Although it is recognised that a licensed regime would certainly facilitate the enforcement of the operational conditions (elevation-dependent e.i.r.p. mask, limit on the main beam elevation angle), clarification is sought on the mechanisms envisaged for conformance checking and interference monitoring and mitigation.

We emphasize that it continues to be important for regulations in the UK to be in-line with global international standards in this area. Our understanding is that the relevant regulated power densities are given by Table 2 of Recommendation ITU-R RS.2017 which was approved 08/2012. This includes recommendations for passive and active nadir sounders as well as passive limb sounders.

International regulations have provided standards to which microwave satellite instruments have been designed so consistency of approach is important. A large number of microwave missions will be launched in the next 10 years and designed to operate in the frequency bands in this consultation, including instruments in which the UK government has invested through its international collaborations.