Question 1: Do you have any comments on our approach to this review?:

No.

Question 2: Do you have any comments on our broad overview of the satellite sector set out in this section? In particular, do you have comments on the completeness of the list of applications, their definitions and their use of the relevant ITU radiocommunications service(s)?:

Question 4: Do you have any comments on our representation of the value chain for the satellite sector? How do you think industry revenues are broken down between players at different positions in the chain?:

Question 5: What is the extent of your organisations? role(s) in the value chain? Which satellite applications (as summarised in Table 1 in section 3) does your organisation:
- use
- provide: or
- help to deliver?

Please list all applications that apply and your role in each in your response.:

Question 6: For each of the satellite applications you use, provide or help deliver (as identified in Question 5), and taking into account your role in the value chain, where applicable please provide:
- the specific spectrum frequency ranges used for each application, distinguishing between the frequencies used for service provision, for the feeder / backhaul links and for TT&C
- the coverage area for services links or, in the case of TT&C and feeder / backhaul links, the location of the gateway station(s)
- the estimated number of users (e.g. MSS terminals, DTH subscribers, FSS earth stations)
- an estimate of the average use by end user (for those applications for which the demand for spectrum is driven by end user traffic) and
- for applications for which the demand for spectrum is driven by other factors, please state what the factor is and the scale of the factor (e.g. for DTH TV the number of TV channels broadcast by format).

Please provide your response with respect to the UK, the rest of Europe, and other parts of the world where this may be relevant to UK use.:

Question 7: For each of the satellite applications you provide, please could you indicate how UK consumers and citizens benefit from their use? Where possible please also provide an indication of the scale of the benefits (either qualitatively or quantitatively).:

Question 8: From your perspective, what high level trends will affect the satellite sector in the coming years?:

Question 9: For each of the satellite applications you use, provide or help deliver what do you see as the a) current demand trends, and b) underlying current and likely future drivers of demand for the satellite application(s) your organisation uses or provides?

Please include in your response for both a) and b) above:
- the scale and future impact of the trends/drivers on demand
- any variations in the type and scale of trends/drivers by geography (i.e. in the UK, the rest of Europe, and other parts of the world where this may be relevant to UK use) and why
- whether future demand is expected to be temporary or intermittent, and the reasons for this.

In your response, please provide any evidence which supports your position on the drivers of demand (e.g. forecasts, studies and statistics).:

Question 10: Taking into account the drivers you have identified in your response to Question 9 above, what (if any) challenges is your organisation concerned about in meeting potential future demand? Please provide the information by application and band, along with any supporting evidence, if available.:

Question 11: Do you have any comments on the list of potential mitigations we have identified? What likely impact would each of the mitigations have on spectrum demand? E.g. what order of magnitude increase in frequency re-use might be achieved? To what extent do you believe that these mitigations apply only to certain applications?:

Question 12: What other mitigation opportunities do you foresee that we should consider? For what applications are these likely to be applicable and what scale of improvement are they likely to deliver?:

Question 13: Beyond the activities already initiated and planned for the satellite sector (e.g. as part of WRC-15), do you think there is a need for additional regulatory action that may, for example, help your organisation to address the challenges it faces?

In your response, please indicate what type of action you consider may be needed and why, including any evidence to support your view.:

Question 3: Do you have any comments on our broad overview of the space science sector? In particular, do you have comments on the completeness of

the list of applications, their definitions and their use of the relevant radiocommunications service(s)?:

Yes. The wording is too focussed on remote sensing of the planet's surface and the critical area of remote sensing the atmosphere is largely ignored. Passive remote sensing of the 4D atmospheric temperature, humidity, composition, clouds, aerosol has required major investment and is delivery equally major economic benefit. It should be explicitely mentioned.

Question 14: Do you have any comments on our representation of the value chain for the space science sector? How do you think industry revenues are broken down between players at different positions in the chain?:

Yes. The phrase "entities that collect data and make it available to others. Examples include the Met Office, which provides a wide range of meteorological services, and research bodies ,which make available research based on space science data." fails to capture the nature of the business activities between data providers and data users in this area. It is not a case of delivery of data to organisations like the Met Office and ECMWF who then pass it on. These organisations engage fully with the full supply chain, influencing the design and acquisition strategy for observations that use EM spectrum, fully understanding and contribution to the design of the Global Observing System and employ very complex systems that transform the raw data to products that have high economic value, such as weather forecasts. These processes are extremely accurate and sensitive to small errors in the observations. Consequently these organisations are engaged in the full process and together with Satellite Agencies have invested in generating the Global Observing System we now have, that relies on maintenance of a number of key bands for EESS. Therefore in answer to Q15 we will note several points in the value chain where ECMWF is active.

Question 15: What is the extent of your organisations? role(s) in the value chain? Which space science applications (as summarised in Table 2 in section 3) does your organisation:
- use
- provide, or
- help to deliver?

Please list all applications that apply and your role in each in your response.:

Equipment manufacturers / Satellite Operators
ECMWF provides bguidance to satellite operators on requirements, what configuration will maximise potential impact, and we work closely with operators during the planning phase for future missions. Sometimes this involves direct contact with equipment manufacturers, though often these lines of communication are via the Satellite Operators.

Service, Content & Application Providers
ECMWF takes raw data and evaluates it, working closely with Satellite Operators to ensure data quality is at the required level. Issues with data quality, including RFI, are identified where this is possible, quantified and communicated back to Service Providers.

Users
ECMWF is a key user that turns raw observations into analysis and forecasts for Weather, Water and Climate, as well as air quality. These activities are the main ECMWF activity and have major economic value for UK and European industry, government and commerce.

Question 16: For each of the space science applications you use, provide or help deliver (as identified in Question 15), and taking into account your role in the value chain, where applicable please provide:
- the specific spectrum frequencies used, distinguishing between the frequencies used for the science application, the frequencies use for downlinking data and, for TT&C
- whether the application is limited to use of specific frequencies and why (e.g. due to fundamental characteristics of the phenomena being measured and/or availability of technology designed for that frequency)
- whether the applications use continuous or intermittent measurements
- the typical resolution and associated measurement bandwidths, including an indication of any implication for spectrum requirements
- the geography this use extends over (e.g. land or sea, and regional or global)
- the location of the gateway station(s) for TT&C and downlinking data
- the estimated number of users.:

Our interest in EESS bands include all the bands described by Markus Dreis in his presentation at the consultation meeting, as well as others operated by other Space Agencies. We use data from the following passive bands for EESS:

1.400-1.427 GHz on ESA's SMOS and NASA's SMAP.
This is limited to this specific frequency as the only band with suitable sensitivity to soil moisture, salinity, thin sea ice and all-weather high windspeed surface wind observations.

6.425-7.25 GHz on NASA/JAXA's AMSR-2
This is limited to this specific frequency as this is the only band with all-weather sensitivity to Sea Surface Temperature.

10.6-10.7 GHz on NASA/JAXA's AMSR-2, NASA's GMI, NASA's TMI
This is limited to this band as the only band with strong direct sensitiity to precipitation but small or negligible sensitivity to cloud and water vapour.

18.6-18.8 GHz on NASA/JAXA's AMSR-2, NASA's GMI, NASA's TMI, AMR on Jason-2
19.15-19.55 GHz on US DoD's SSMIS
These two bands are equivalent from a science perspective. The community has been encouraging satellite operators to move to only use 18.6-18.8 GHz.

22.21-22.5 GHz on US DoD's SSMIS
23.6-24 GHz on EUMETSAT and NOAA's AMSU-A, NASA's ATMS, US DoD's SSMIS, NASA's GMI, NASA's TMI, AMR on Jason-2 and China's MWTS-2.
These two bands are similar but not identical scientifically. However the user community has been encouraging satellite operators and instrument manufacturers to move exclusively to 23.6-24 GHz.

31.3-31.5 on EUMETSAT and NOAA's AMSU-A, NASA's ATMS, US DoD's SSMIS and China's MWTS-2.
36-37 on US DoD's SSMIS, NASA/JAXA's AMSR-2, NASA's GMI and NASA's TMI
These two bands are almost equivalent for cloud liquid water sensitivity, where they have a unique capability. However there is a difference in the sensitivity to snow cover. Generally the user community has encouraged cloud focused missions to use 31.3-31.5 GHz.

50.2-50.4 on EUMETSAT and NOAA's AMSU-A, NASA's ATMS, US DoD's SSMIS and China's MWTS-2.
51.56-51.96 GHz on NASA's ATMS and China's MWTS-2
52.6-59.3 on EUMETSAT and NOAA's AMSU-A, NASA's ATMS, US DoD's SSMIS and China's MWTS-2
These bands are needed to sound atmospheric 3D temperature profile information from the surface (at 50.3 GHz) to the upper stratosphere. They are vital to accurate NWP and this is the only frequencies where temperature sounding can be achieved without major impact from clouds. In particular the impact of ice cloud is very small. There is some limited residual impact of cloud, that mean other channels are needed for effective data screening.

86-92 on EUMETSAT's, MHS, NOAA's AMSU-A, NASA's ATMS, US DoD's SSMIS, NASA/JAXA's AMSR-2, NASA's GMI and China's MWTS-2 and MWHS-2
This is a unique band for screening the small impacts of cloud on the 50-57 GHz observations.

100-122 GHz on China's MWTS-2
This group of channels is unique in enabling limited 3D structure of ice cloud water content for thick ice clouds to be determined.

148.6-151.5 on China's MWHS-2, US DoD's SSMIS
155.5-158.5 on EUMETSAT's MHS
164-167 on NASA's GMI, NASA's ATMS
These three channels are almost equivalent. They are used with 86-92 GHz to screen ice cloud effects on the 174-192 GHz channels. The user community has been encouraging the adoption of 164-167 GHz across all instruments.

174.8-191.8 on EUMETSAT's MHS, NASA's ATMS, US DoD's SSMIS, China's MWHS and MWHS-2, NASA's GMI, and extended to 172-195 GHz on CNES-ISRO's SAPHIR.
This band is unique in providing 3D humidity information in most weather conditions though deep ice cloud must be screened for, which means they are used with the 86-92 and 164-167 GHz channels to achieve this.

We use or will use the following active bands for EESS:
5.3 and 13.8 GHz on Jason-2
5.255 GHz on EUMETSAT's ASCAT
This band is the only source of all-weather ocean near surface wind vectors.

13.4 GHz on NASA's Rapidscat
13.6 GHz on JAXA's DPR (GMI)
13.73 GHz on ISRO's Oceansat (recently failed, new launch planned)
This is an alternative to the C-band scatterometer. It provides higher resolution, but has some

contamination from heavy precipitation.

13.8 GHz on JAXA's PR (TRMM)
This band was used for 3D rain radar information.

35.55 GHz on JAXA's DPR (GMI)
This band is used for 3D rain radar information.

35.75 GHz radar altimeter on Jason-2, Saral-Altika
This band is used for altimetry, which is vital to long term monitoring of sea level as well as providing ocean wave information.

94.05 GHz on NASA's Cloudsat and ESA's EarthCARE (from 2017)
This band will be used for 3D cloud information.

220 GHz cloud radar. This is tentative but the Chinese Meteorological Administration has built a prototype instrument which is now starting test on the ground for a potential future spaceborne mission.

Whether the applications use continuous or intermittent measurements
- The measurements are intermittent, but with up to 18-20 passes per day (e.g. for 183 GHz humidity). In future a trend towards geostationary measurements with targeted "RapidScan" as available now in infrared, and a larger number of CubeSat/NanoSats will mean that observations will be taken with very high frequency at any given location.

The typical resolution and associated measurement bandwidths, including an indication of any implication for spectrum requirements
- At present these instruments measure a broadband signal across the protected band for passive EESS. In future this may change to a high spectral resolution sampling of some bands, but this is speculative.

The geography this use extends over (e.g. land or sea, and regional or global)
- Global over land and sea.

The location of the gateway station(s) for TT&C and downlinking data
- Data is acquired at a large number of Direct Broadcast stations, picking up continuous transmission from the satellite, and by global downlink stations. However these TT&C frequencies are different of course to the frequencies of the measurements.

The estimated number of users.
- The ECMWF products based on these observations are used worldwide, by individuals accessing weather forecasts through the media, by transport, by commerce, by governments. The user base is really global and most people's lives and livelihoods are affected to some extent by the reliability and quality of the products.

Question 17: For each of the space science applications you provide, please could you indicate how UK consumers and citizens benefit from their use? Where possible please also provide an indication of the scale of the benefits (either qualitatively or quantitatively).:

This question is of course very difficult to answer quantitatively. The use of ECMWF analysis and forecast products, that rely on the allocated EESS passive and active bands, affect the lives of almost everyone in the UK to a greater or lesser extent. Past studies commissioned by the the Met Office have shown that the return on investment in improved predictive capability is very large. I hope they will provide details on these studies, as they are equally applicable to ECMWF, as we work closely with the Met Office.

Question 18: From your perspective, what high level trends will affect the space science sector in the coming years?:

Weather forecasting and climate monitoring and prediction is moving towards higher resolution, and the accuracy requirements for the observations is becoming ever more demanding. Therefore the requirements for sharing will become equally more demanding (in other words interference that may not have been an issue in 2000 will be an issue in 2020 and beyond). This trend is expected to continue. Also weather forecasting is moving towards Earth System Forecasting, with increasing focus on air quality, land surface and the marine environment. This is driving a need for new observations. However this is not a major driver for new observations between 2 and 200 GHz, which is where the existing EESS bands are. They main new bands will be above 200 GHz, in the sub-mm wavelength region and into the infrared and visible wavelength bands. There is also some increasing trend to longer wavelengths (> 15cm) for biomass and soil moisture, building on the SMOS and SMAP experience.

Question 19: For each of the space science application(s) your organisation uses or provides, what are the a) current trends, and b) likely future drivers of demand for spectrum?

Please include in your response:
- the scale of the demand drivers
- the reason for additional demand (e.g. higher resolution radar data rates/bandwidth required) and whether this increased demand is for data delivery or for the taking of measurements
- whether increased demand can only be met at specific frequencies and why
- any variations in demand drivers by geography (i.e. regional or global), and why, and
- whether future demand is expected to be temporary or intermittent, and the reasons for this.

In your response, please provide any evidence which supports your position on the drivers of demand (e.g. forecasts, studies and statistics).:

The frequencies listed in response to Q16 continue to be essential to the core business of weather prediction and climate monitoring. The exception is these two bands:
19.15-19.55 GHz on US DoD's SSMIS
22.21-22.5 GHz on US DoD's SSMIS
The band at 18.7 can do the same job as 19.35 so the EESS community has requested Space Agencies to use only 18.7. Equally the band at 23.8 GHz is scientifically similar to the 22.1-22.5 GHz band and most agencies have moved to exclusive use of 23.8, dropping 22.3 GHz.

However the other EESS bands are all providing unique information only available at that particular band.

We expect more use of microwave bands from geostationary orbit (increasing frequency of observation, and opening up new applications). Preparations are well underway for such missions in Europe (ESA, working with China) and in the US (e.g. the GeoStar group). Furthermore various groups are developing instruments to fly on Nanosats/Cubesats, which will lead to constellations with larger and more continuous observation in the passive bands.

In addition increasing use will be made of bands above 275 GHz and its necessary to establish the appropriate regulatory framework for these bands also. In particular the EPS Second Generation will fly frequencies above 275 GHz on the new ICI instrument, with channels at 325, 448 and 664 GHz.

Question 20: Taking into account the drivers you have identified in your response to Question 19 above, what (if any) challenges is your organisation concerned about in meeting potential future demand? Please provide the information by application and band, along with any supporting evidence, if available.:

The concern of users like ECMWF is that the frequencies used for EESS for weather and climate are a unique natural resource and there is no alternative for how these critical observations are acquired. Therefore the driver is one of maintaining existing capability and return on the massive investment to exploit these bands. So the goal is to maintain what we have despite pressures.

Question 21: Are there any future developments, such as the radio astronomy SKA, that could reduce the demand for space science spectrum in the UK?:

No.

Question 22: Do you have any comments on the list of potential mitigations we have identified? What likely impact would each of the mitigations have on spectrum demand? To what extent do you believe that these mitigations apply only to certain applications?:

In principal we support all these mitigations. However it needs to be recognised that many if the bands used by EESS for weather and climate are what we call "noise limited". This means that the error on the observation is the main source of uncertainty. If the band is filtered to remove RFI then we lose bandwidth, measure fewer photons and the noise goes up. This is preferable to RFI, but if the noise is allowed to rise too much then the data becomes of no value. Therefore prevention of unwanted emissions is the preferred option above filtering of unwanted emissions. It would be critical that filtering did not allow more than a small (10%) rise in the Noise Equivalent Delta Temperature of the observations, equivalent to losing about 20% of the band.

Question 23: What other mitigation opportunities do you foresee that we should consider? For what applications are these likely to be applicable and what scale of improvement are they likely to deliver?:

None. However regulators are encouraged to continue to work very closely with the EESS community as the monitoring of global satellite data can give a strong indication where prohibited emissions are occurring and action could be taken to eliminate such sources.

Question 24: Beyond the activities already initiated and planned for the space science sector (e.g. as part of WRC-15), do you think there is a need for additional regulatory action that may, for example, help your organisation to address the challenges it faces?

In your response, please indicate what type of action you consider may be needed and why, including any evidence to support your view.:

All that is required is strong support to the existing level of protection for EESS and strong policing when emissions are found to be occurring in exclusive EESS bands, or above agreed levels in shared bands.