UK Space Agency

Response to Space Science Response to Ofcom Call for input on a strategic review of satellite and space science use of spectrum

Space Science Spectrum Use

Introduction

The UK Space Agency has a wide remit to support, promote and grow UK participation and benefits from space science activities. We have a strong emphasis on growth[1] which we will achieve through our six pathways to growth; New opportunities; Exports; Innovation; Science; Education; and Space for smarter government. The implementation of this strategy is outlined in our response[2] to the Industry Space Growth Action Plan[3].

Almost everything the UK does in space[4] is cooperative and while we have a growing national programme, through working with international partners, the UK participates in a much wider range of space activities than it could undertake alone. A large fraction of the UK Space Agency investment is channelled through the European Space Agency (ESA) and there is UK interest in all of the ESA and EU space science programmes. The UK Space Agency also has significant roles in providing sensors and support for missions outside Europe, for example through working closely with the US, and in supporting the rapidly growing commercial space science sector, particularly in Earth Observation.

The UK Space Agency has agreed to work with techUK in developing coordinated responses to this call for input. We have divided our responses between telecommunications, science and satellite navigation. This response by the UK Space Agency covers only spectrum used for publically funded science, by which we mean Earth observation, Meterology, Space Science and Space Exploration. The input by techUK provides the corresponding response for telecommunications and satellite navigation. This mirrors the approach to the workshops organised by Ofcom and the structure of the call for input.

This contribution has been developed through wide consultations with stakeholders, however it can not be guaranteed to have captured everything.

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

The UK Space Agency welcomes this initiative by Ofcom to fully understand the spectrum needs of the space science sector and the enormous value the space sector brings to the UK. The timing of this call for input coincides with a comprehensive spending review and as a consequence, at this time we are unable to share any information on future government spending plans.

[1] Civil space strategy 2012 to 2016, https://www.gov.uk/government/publications/civil-space-strategy-2012-to-2016
[2] Government response: space growth action plan, https://www.gov.uk/government/publications/government-response-space-growth-action-plan
[3] Space growth action plan, https://www.gov.uk/government/publications/space-growth-action-plan
[4] National space programmes 2014 to 2015, https://www.gov.uk/government/publications/national-space-programmes-2014-to-2015

We are especially pleased to see an emphasis on international aspects. This is particularly relevant to the space sector, where it is most common for missions to be delivered through international partnerships. Previously we have had concerns that while the Ofcom charter directs policy towards the interests of UK citizens and consumers it does not necessarily support UK business development, particularly in overseas markets, or support the aspirations of the science programmes of other countries which collaborate with the UK on space science and earth observation. The UK does its part in supporting space science and we concentrate our efforts in particular areas. We rely on and our our citizens benefit from the science activities of other states.

Societal benefits, for example understanding our planet and climate, space exploration, astronomy and cosmology, and the inspiration of young people to take up STEM subjects arising from space programmes are all strong benefits but are notoriously difficult to measure against financial metrics.

An aspect missing from the approach is the European legislative aspect. There are obligations placed on the UK arising from EC decisions. These impact many sectors, generally with the aim of supporting European aspirations and enabling the single market. As a member of the European Union, the UK government has responsibilities to support several EC programmes, including the Copernicus Earth Observation and Galileo Satellite navigation programmes. This was not covered in the CFI but it may constrain UK decision making. For example, Article 4(3) of the Treaty on European Union (TEU) requires Member States to facilitate the achievement of the Union’s tasks and to refrain from any measure which could jeopardise the attainment of the Union’s objectives. The Copernicus[5] space programme has been adopted under Article 189(2) TEU and consequently spectrum decisions adversely impacting Copernicus may be a breach of the duty of sincere cooperation under Article 4(3). This may have a direct bearing on the UK’s position with respect to support for current and future WRC agenda items, which under the treaty should aim to protect Copernicus and Galileo spectrum from undue interference.

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)?

We broadly agree with the overview. With regard to the ‘end-user applications’, we would add that commercial applications of earth observation data and imagery are an important and growing market and should therefore be included in the overview.

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)?

This was a good overview but in practice the situation is more complex and several important applications and services were missing from the analysis. Some additional detail is given below.

[5] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R0377&from=EN

Earth Observation programme

The UK Space Agency views Earth Observation as a priority activity. We published our UK strategy on Earth Observation in October 2013[6] outlining the actions required to deliver the UK's earth observation objectives.

The UK Space Agency drives the shared UK vision for Earth observation (EO) from space with international leadership in development and use of EO-derived information and technology. We work with partners in academia, government and industry to strengthen our world-leading position in EO science and technology, building on the excellent track record of UK scientists, technologists and businesses. The UK leads the development of many major international space programmes, developing and exploiting EO missions to address critical gaps in our understanding of the Earth system. There are applications in:

- Natural resource management
- Agriculture and Food security
- Risk assessment & Emergency response
- Environmental protection & Climate services
- Urban planning
- Insurance & Financial services
- Transportation & Communication
- Consumer, Retail & Tourism
- Defence and surveillance
- Atmospheric physics and space weather monitoring

The global earth observation market (including satellite manufacturing, data sales and value added products)-was ~$13.2 billion in 2013. Data sales in 2013 were valued at $1.5 billion[7] with optical data comprising ~80% market share. The next decade will see a doubling of the number of earth observation satellites launched, with ~300 by 2021. Government remains the primary user of Earth Observation data and the Satellite Applications Catapult and the UK Space Agency "Space for Smarter Government Programme" ensures that Earth Observation data, products and services are easily accessible to policy-makers, government agencies, educators, business users and wider consumer markets. We direct space programmes to meet our international obligations for climate and environmental monitoring, improving the capability and efficiency of the public and private sectors, expanding consumer choice and inspiring a new generation of scientists and entrepreneurs.

[6] UK strategy on earth observation, https://www.gov.uk/government/publications/uk-strategy-on-earth-observation

[7] Figures derived from latest surveys by EuroConsult, http://eijournal.com/print/articles/emerging-programs-markets-drive-earth-observation-growth and EARSC http://earsc.org/news/earsc-industry-survey-2014

Figure 1 - Optical and Radar Earth observation comparison

The UK Space Agency has identified four key strategic priorities for its activities in Earth observation that best deliver the Pathways to Growth of the UK's Civil Space Strategy. We will:

1. Leverage from our membership of European programmes (ESA, Eumetsat, Copernicus) to secure maximum returns in scientific excellence, programme efficiencies, and economic growth for all UK stakeholders in academia, government and industry.

2. Build on UK leadership in processing, analysis, quality assurance and control, modelling and visualisation of space data for environmental research and climate applications.

3. Become the global leaders in Synthetic Aperture Radar (SAR) technologies and their exploitation, especially for civil resilience, natural hazard management and maritime security.

4. Increase UK leadership in developing small, low-cost missions.

In the last 40 years, satellite based active Earth Observation has co-existed with terrestrial services. More recently, there have been more instances of interference to space sensors, especially in the lower frequency bands. This has largely remained manageable through the deployment of more aggressive mitigation techniques. Active remote sensing is able to share more readily with some services than others, dependent on the service characteristics. The rapid expansion in mobile broadband and WiFi use of spectrum is threatening the ability of the sector to continue to make high quality measurements, especially over urban areas due to the cumulative impact of many small interference sources, which are difficult to mitigate.

<u>Space Science and Exploration programmes</u>

The UK plays an important role in international space science and exploration missions. Current operational missions with strong UK involvement include:

GAIA – An ESA mission to make a 3D survey of our galaxy
STEREO – A NASA solar science mission studying space weather
Hinode – A Japanese mission studying solar flares and coronal mass ejections
Swift – A NASA mission to study gamma ray burst

Rosetta – An ESA mission studying Comet 67P Churyumov-Gerasimenko including the Philae lander
SOHO – A joint ESA/NASA mission observing the sun and space weather

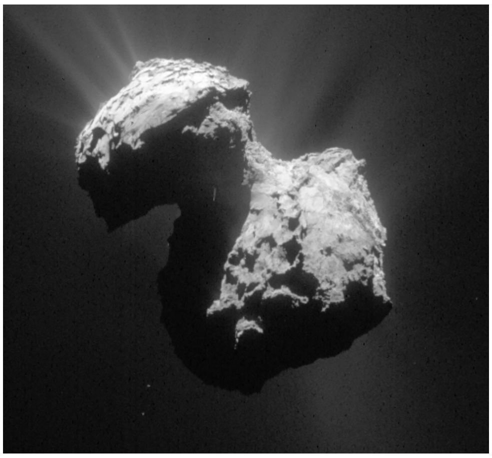

Figure 2 - Comet 67P/C-G on 7 July 2015. Credits: ESA/Rosetta/NAVCAM – CC BY-SA IGO 3.0

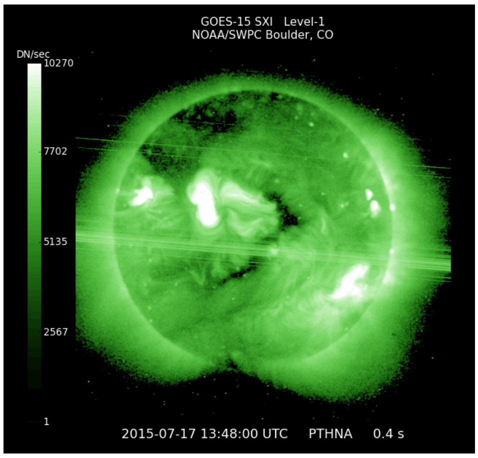

Figure 3 - Solar flares (GEOS image NOAA/SWPC)

Those currently in development include:

PLATO – A mission aiming to seek out planets around other stars
LISA Pathfinder – a pre-cursor for a mission to detect gravity waves
JUICE – A mission to explore Jupiter and its moons Io, Europa, Ganymede and Callisto
MIRI – An infra-red instrument for the James Webb Space Telescope, successor to Hubble
Solar Orbiter – a mission to study the sun and the development of solar storms
Euclid - a high-precision survey mission to map the geometry of the Dark Universe
Bepi-Columbo – a mission to Mercury

The UK also have a national CubeSat programme, to allow educational establishments and commercial organisations in-orbit flight experience for their scientific experiments and new technologies, providing relatively affordable space-based scientific data. The agency's first satellite, UKUBE-1 was launched in 2014.

<u>National Space Flight and Spaceports</u>

The UK Government announced in March 2015 a shortlist of sites for a UK space port, with the ambition to have this operating by 2018. Work is ongoing through the Department for Transport (DfT), the Department for Business, Innovation and Skills (BIS), the UK Space Agency (UKSA), the Ministry of Defence (MoD) and the Civil Aviation Authority (CAA) on the regulatory requirements needed to support a national programme of space flights and this may have an impact on spectrum use as suborbital space planes are both aircraft and spacecraft and therefore cut across spectrum services.

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?

The representation of the value chain is comprehensive as it includes the main actors in the sector. At the end of the chain there could have been an additional segment called 'ancillary services' comprising of financial and legal services, insurance and brokerage services and other support products and services. While only accounting for 2% of the UK space economy, annual turnover within this sub-sector is over £230m[8]. These services will be important within the space science sector as well as more widely.

Overall, UK space economy turnover is dominated by space applications that account for 78% of the total turnover, followed by space operations (12%) and space manufacturing (8%). However, most of the space applications turnover comes from telecommunications, and more specifically Direct-To-Home (DTH) provision (most notably BskyB). Therefore, we do not expect the space science sector to follow the same trend of the overall space economy in terms of breakdown of turnover by segment. For the space science sector we would expect the majority of turnover to be in the upstream segments; but with major benefits arising from future opportunities in the downstream markets making new use of earth observation data to provide added value services.

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.

The role of the UK Space Agency has already been introduced, table 1 summarises by application where we see UK and UK funded organisations appearing in the value chain. In addition to UK activities, the UK Space Agency and other UK public organisations have memorandums of understanding and collaborative agreements with the majority of the world's space agencies. The UK has a special relationship with the United States and works closely with NOAA and NASA on space science, astronomy, earth observation and space weather.

[8] The Case for Space 2015, the impact of space on the UK economy, London Economics, July 2015

Table 1 – Value chains (UK and UK funded)

Application	UK Users	Providers	Help to deliver
Ground Based Radio Astronomy	Astronomers, Cosmologists	STFC	STFC
Passive Earth Sensing	Meteorologists, Climate studies, Earth scientists, Government, Industry, Citizens	ESA, Eumetsat, Industry, EU	UK Space Agency, Satellite Applications Catapult, Met Office, Universities, STFC, NERC Industry
Passive Space Sensing	STFC, Universities	STFC, Universities, ESA	UK Space Agency, STFC
Metsat & climate	Meteorologists, Climate studies Earth scientists, Government, Industry, Citizens	ESA, Eumetsat, Industry, EU	UK Space Agency, Satellite Applications Catapult, Met Office, Universities, NERC Industry
Active Earth Sensing	Meteorologists, Climate studies, Ionospheric studies, Research scientists, Government, Industry, Citizens	ESA, Eumetsat, Industry, EU	UK Space Agency, Satellite Applications Catapult, Met Office, Universities, STFC, NERC Industry
Active Space Sensing	Space scientists	ESA	ESA
TT&C	All missions	ESA, Eumetsat, Industry, Universities, STFC, Catapult	UK Space Agency, ESA, Eumetsat, Industry, Universities, STFC, Catapult
Space Exploration communications	All Missions	ESA, Industry	UK Space Agency, ESA
Space Science data communications	All Missions	ESA, STFC, EU, Universities, Industry	UK Space Agency, Satellite Applications Catapult, Met Office, Universities, Industry

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.*

We have split the response to this question into several sectors.

Q16 Ground Based Astronomy – RAS

This input will be covered by the STFC and Committee for Radio Astronomy Frequencies (CRAF) responses.

Q16 Earth Sensing – EESS active and passive

Satellite based Earth observation is a growing application. Typical service characteristics are given in the ITU-R RS series of recommendations. Recommendation ITU-R RS.577-7, gives advice on the frequency bands and required bandwidths used for spaceborne active sensors operating in the Earth exploration-satellite and space research services. Recommendation ITU-R RS.515-4 provides information on the frequency bands and bandwidths used for satellite passive sensing.

The UK Space Agency funds this activity directly, through our ESA and national programmes. The UK also supports the Earth sensing programmes of the European Union through our UK contribution. Figure 4 shows some of the main Earth observation bands and highlights the current European instruments and missions using these bands.

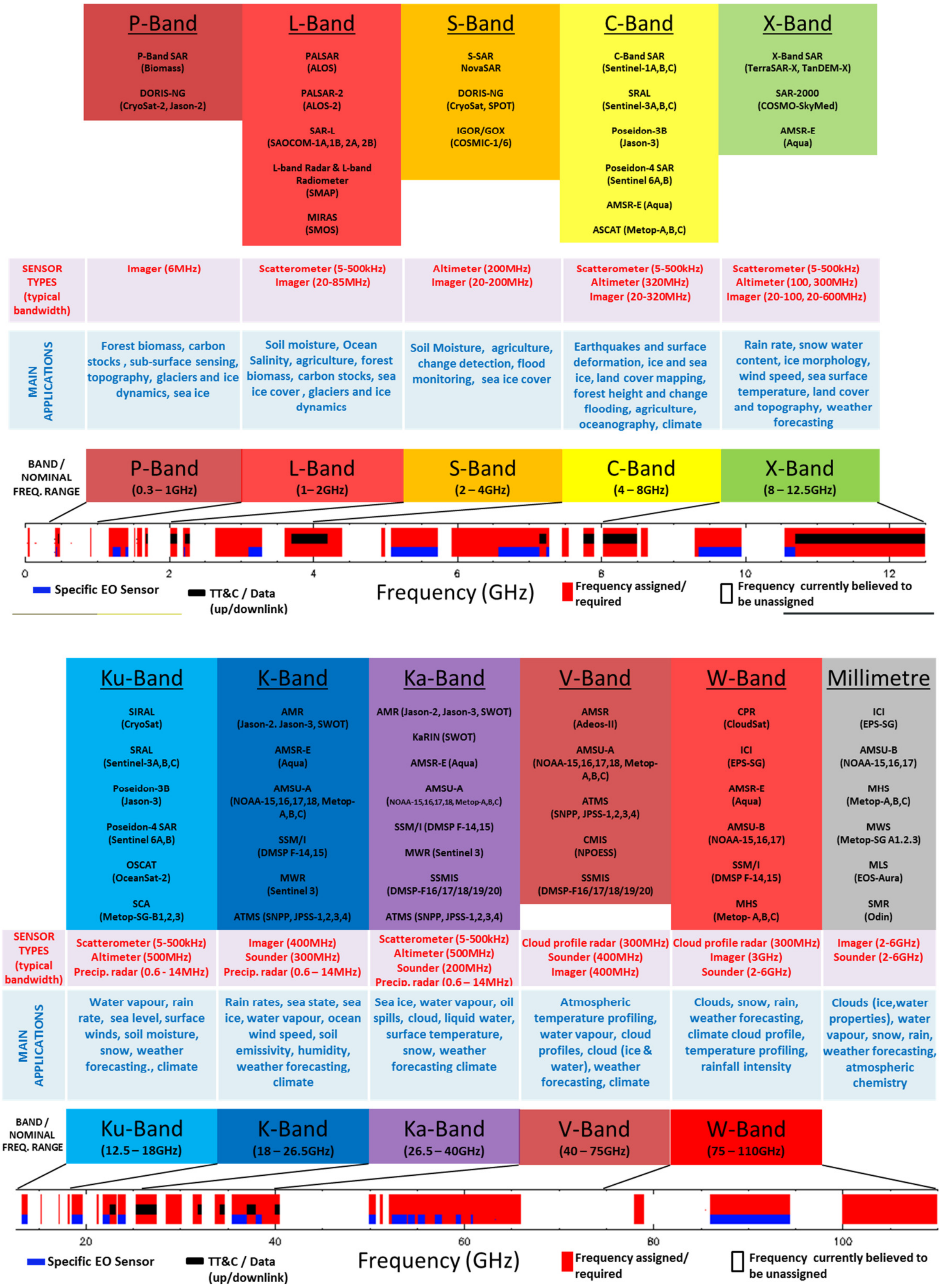

Figure 4 - Major Earth observation spectrum bands with applications and required bandwidths

In some cases, especially with respect to climate measurements and weather forecasting, specific frequencies are needed. Figure 5 shows some of the key resonances. It is usually important to measure the slope as well as the peak of these resonances in order to extract information, for example profiles of atmospheric temperature can be determined by monitoring the pressure broadening of the oxygen and water resonance lines. In addition, the many minor resonances and atmospheric windows where there is relatively low absorption, for example around 35 GHz, 90 GHz and 135 GHz are also important.

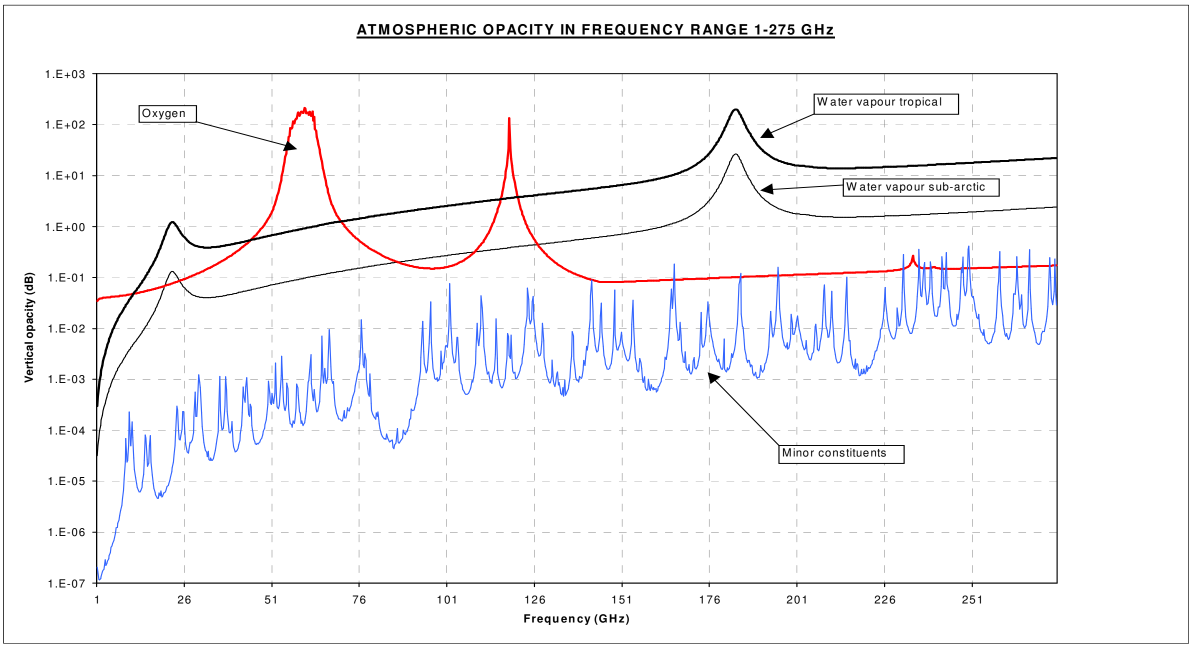

Figure 5 – Atmospheric opacity 1 – 275 GHz

In general, it is not just one band that contributes to a measurement, for example several bands are often needed to extract information from various levels. This is especially true for atmospheric science (see meteorology section) but it is also the case for other services where much more information can be gained from observations at multiple wavelengths. In radar systems, the main direct backscatter comes from elements with dimensions approximately equal to the wavelength. In addition to this, lower frequencies generally penetrate more deeply into the surface of materials. This has strong implications for what radar return intensity and coherence can tell us about the target. An illustration for the monitoring of forests is shown in Figure 6.

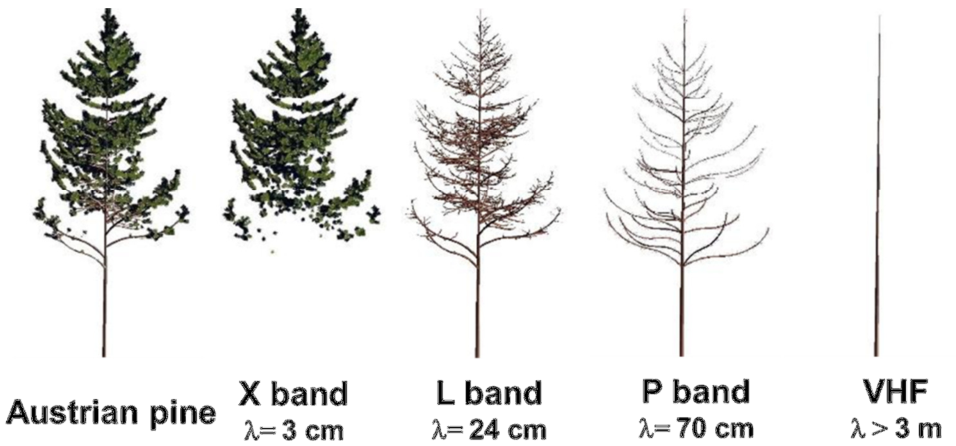

Figure 6 – Radar returns from vegetation at various wavelengths

Radars operating at all these wavelengths are needed to get a full picture of the forest. The same applies across most applications, from meteorology to geology. For example lower frequencies are needed to measure ice thickness and higher frequencies give increased resolution of terrain.

In the case of both optical and radar sensors, the spatial resolution and hence the data downlink requirements have steadily increased, the last 15 years have seen a factor of ten increase in resolution, which represents around a hundredfold increase in data. Sub-metre imagery is now widely available.

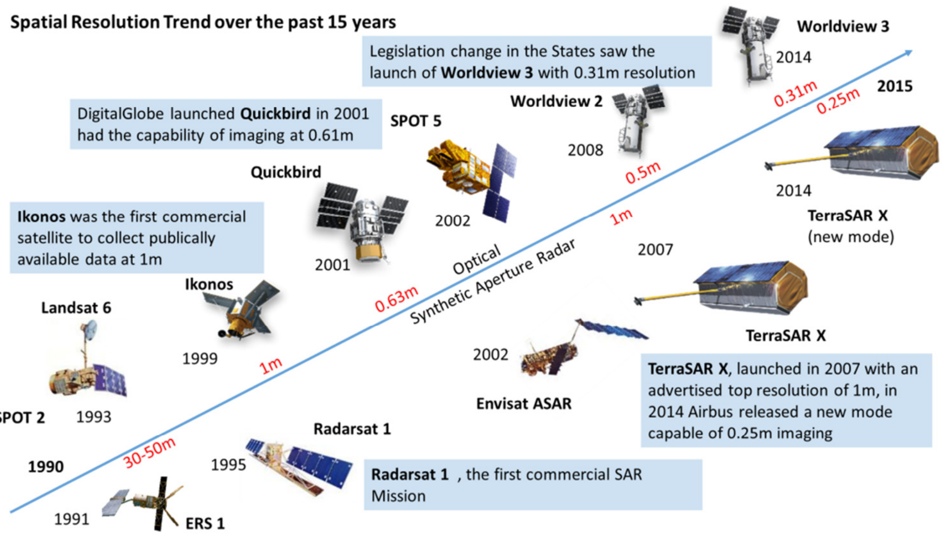

Figure 7 – Trends in spatial resolution of sensors

Active remote sensing by satellite may be considered intermittent, in that measurements can only be taken within the satellite field of view and as most are low earth orbiting, this field of view is limited. However, together with the increase in resolution there has been a reduction in return time between images of the same area from weekly through daily to potentially several times per day through using constellations of satellites. Trends are moving towards more small satellites that are cheaper and faster to deploy, there are forecast to be over 2000 new nano/micro satellites launched by 2020.

The frequency utilisation is global, including all land, sea and polar regions. Gateways may be located in the polar regions which results in more passes per day, however the congestion in spectrum in these regions is becoming a problem. Ground stations can be located anywhere and networks of ground stations allow more data to be transferred, a reduction in latency between observation and downlink and greater frequency re-use. Intra-satellite links are now more extensively used via geostationary data relay satellites. Through the use of a data relay, satellite data can be downloaded even where there are no ground stations. Relayed data is typically downloaded at Ka band to ground stations located near the data hub. In the UK, a European Data Relay Satellite terminal has recently been deployed in Harwell.

In a sense, everyone is a user of earth observation data where it is used for public good services, e.g. weather forecasting, climate change, environmental monitoring, public protection and disaster relief etc. The benefits from these can be sizeable. For example, the UK Met Office has estimated the benefits to the UK economy from more accurate weather forecasting to be in the billions each year, with much of this due to space technologies. The commercial Earth observation data market is also predicted to be £1.8Bn by 2020[9] with value added services perhaps twice this amount, and scientific data produced by earth observation satellites can lead to a wide range of unpredictable 'spillover' benefits to other firms, sectors and wider society. A key driver is the reducing cost of data to the users. Copernicus data policy which will see full and open (free) access to Sentinel data down to 10m resolution for all users. Another major driver is the application of "big data" and data fusion where multiple datasets are used to achieve a goal. The UK are world leaders in development of Earth observation instruments and platforms and it is a significant source of employment in both the upstream and downstream.

The main band used for satellite Telemetry, Tracking and Control (TT&C) are S-band (2025-2110 MHz up and 2220-2290 MHz down). The figure 8 shows how this use has evolved over time. In some cases there are over 90 satellites sharing parts of S-band.

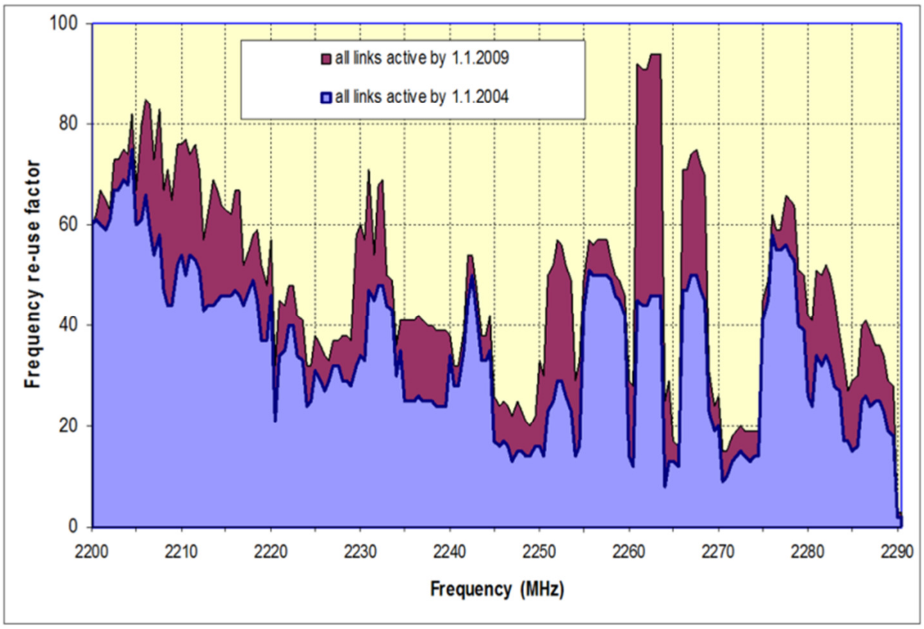

Figure 8 – Utilisation of S-band TT&C

X-band is not available for EO TT&C but 8025-8400 MHz is used for payload data downlinking. This band is becoming critically congested in regions where there large concentration of earth stations.

The UK Space Agency are a member agency of the Space Frequency Coordination Group (SFCG), which maintains and regularly updates a database of current and proposed missions and ground segment which is available from the SFCG website[10 11].

The SFCG X-band database is publically available and is not limited to EESS missions and also covers the Space Research (SRS) and Space Operations (SOS) services. While principally a

[9] Source - Satellite Applications Catapult, 2014.
[10] https://www.sfcgonline.org/home.aspx
[11] Towards its frequency coordination function, SFCG maintains a database of frequencies and bandwidth used by sensors and telemetry systems for all member agency missions covering all frequency bands. At the August 2015 plenary committee meeting, it was agreed to merge this database with the X-band database to develop a comprehensive single database covering all missions and frequency bands.

database of government supported missions, it also covers many all commercial missions where that data has been made available to SFCG.

A recent copy of SFCG x-band database Microsoft Excel 97-2003 Worksheet

The data includes 375 missions and 317 ground stations and includes information on:

- Mission name and ITU filing
- Launch date
- Associated ground stations, characteristics and locations,
- Spacecraft orbital parameters
- Spacecraft radio communication characteristics (power, antenna, frequencies and bandwidths, coding)
- Operational status (operational, development, under consideration, end of mission, launch failure, filing suppressed)
- Ownership and information source

Figure 9 shows a scatter plot of frequency vs bandwidth, for current (July 2015) operational and planned missions.

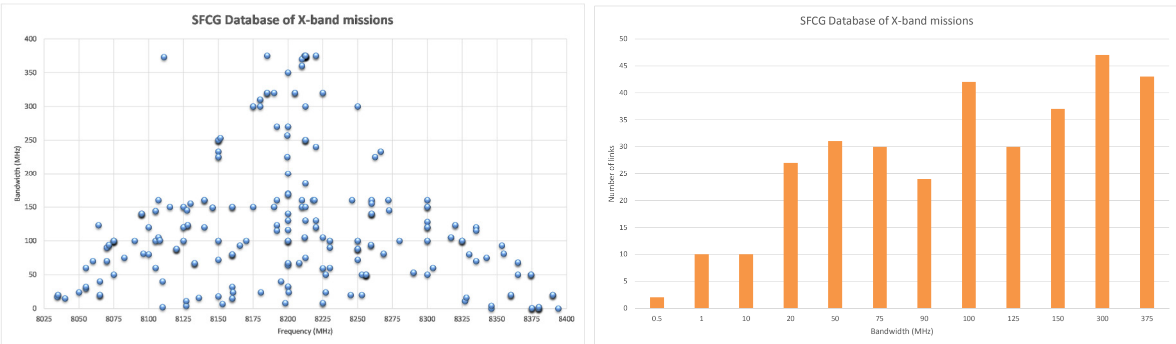

Figure 9 – SFCG x-band mission database

The mean mission bandwidth is 133 MHz and is increasing. Forty of the missions in the database are using bandwidths of over 300 MHz and twenty six missions now utilise the full bandwidth available in the 8 025 – 8 400 MHz allocation.

Ka-band (25.5-27 GHz) is planned for use by satellites with very large data rates requirements. Usage of this band is still limited at the moment, due to the need to develop the related terrestrial infrastructure, but substantial increase of usage is expected in the near future.

In addition, some spectrum at S-band and Ka-band is used for inter-satellite links. S-band (2025-2110 MHz forward and 2220-2290 MHz return) is used for controlling NGSO satellites when not in visibility of a ground station. Ka-band (22.55-23.55 GHz forward and 25.25-27.5 GHz return) is used for large data exchanges with NGSO satellites.

Q16 Passive Space Sensing / Space based Radio Astronomy – SRS (Passive)

To be covered in the STFC response.

Q16 Meteorology applications – Metsat

Satellite meteorology is an important element contributing to the forecast skill for weather, which has improved considerable with the inclusion of satellite data. In Europe, the EUMETSAT organisation of 30 European states, including the UK, provides an operational agency for meteorological satellites, working with users and defining the requirements at user and system level and is responsible for the overall system design and development. The European space agency develop and design the spacecraft and instruments which are then operated by EUMETSAT who run operations and deliver data, products and support services to users in the European and national meteorological services. UK membership of EUMETSAT carries with it a responsibility to protect the spectrum allocations used by EUMETSAT missions from interference.

The current fleet of European meteorological satellites includes the METOP, JASON and Sentinel series in low Earth orbit and the METEOSAT series of geostationary satellites. Figure 10 gives an indication of the development to 2040:

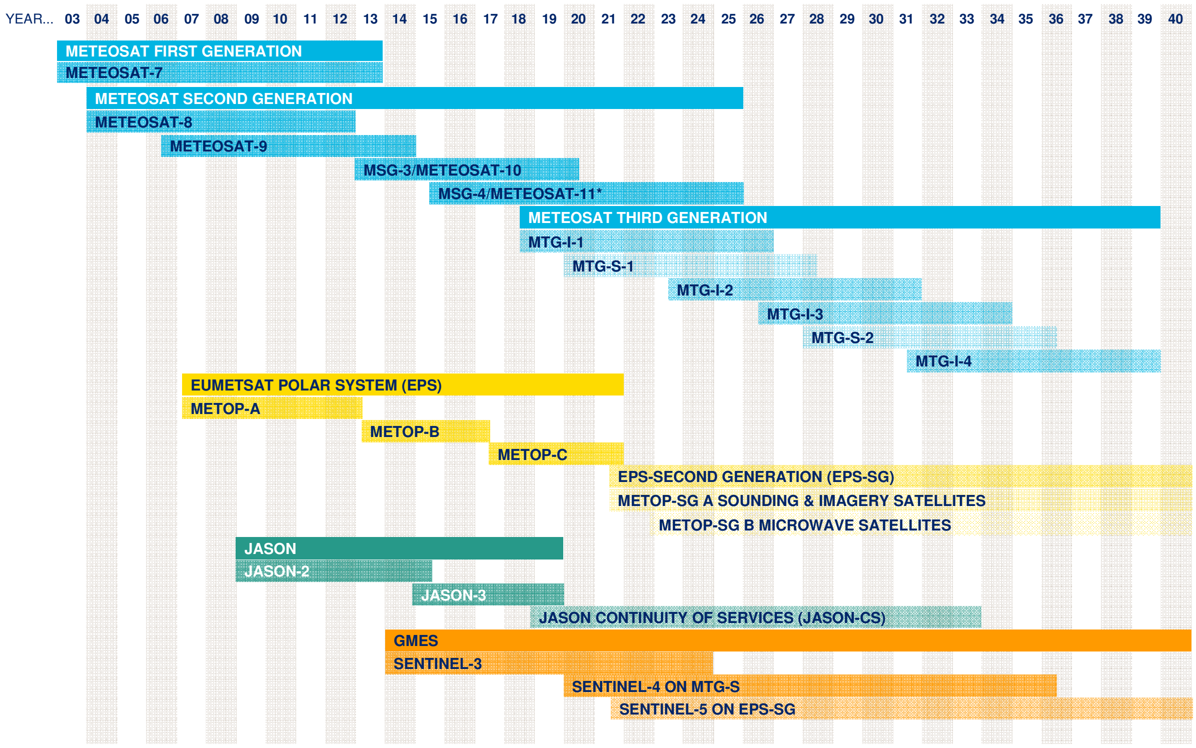

Figure 10 - European Metsat development programme

A summary of the current and future frequency bands used by Metsat systems is presented in table 2.

The atmospheric opacity (see figure 5) is an important attribute in the selection of spectrum bands for passive remote sensing of climates. The water vapour resonance lines near 22 GHz and 183 GHz and the Oxygen resonances near 58 GHz and 119 GHz are important, as are the atmospheric transmission windows. Notable examples of these windows are at optical and infra-red wavelengths. These are not currently shared with other radiocommunication services. Generally, it is not only channels at the exact resonance that are measured but also channels on the slope of the resonance. This gives additional information, e.g. on pressure and temperature.

Table 2 - summary of spectrum use by meteorological satellites

Communications	**Passive Sensing (All Global)**	**Active Sensing**	**Other Instruments**
401 – 403 MHz UK 406 – 406.1 MHz Glob 460 – 470 MHz Euro 1544 – 1545 MHz Euro 1675 – 1710 MHz UK 2025 – 2110 MHz Euro 2200 – 2290 MHz Euro 3700 – 4200 MHz UK 7750 – 7900 MHz UK 8025 – 8400 MHz UK 10.7 – 12.5 GHz UK 25.5 – 27 GHz UK	1400 - 1427 MHz 6425 -7250 MHz 10.6 - 10.7 GHz 18.6 – 18.8 GHz 19.15 - 19.55 GHz 22.21 - 22.5 GHz 23.6 – 24 GHz 31.3 – 31.5 GHz 33.65 - 34.35 GHz 36 - 37 GHz 50.2 – 50.4 GHz 51.56-51.96 GHz 52.6 – 54.25 GHz 54.25 – 59.3 GHz 86 - 92 GHz 100 - 122.25 GHz 148.6-151.5 GHz 155.5 – 158.5 GHz 164 – 167 GHz 174.8 – 191.8 GHz 226 – 231.5 GHz 238 – 248 GHz 313 – 356 GHz 439 – 467 GHz 657 – 692 GHz	5150 – 5250 MHz Euro 5250 – 5350 MHz UK 5350 – 5460 MHz UK 5460 – 5470 MHz UK 5470 – 5570 MHz Euro 13.4 – 13.75 GHz Euro 35.55 – 35.75 GHz Euro 94.05 GHz Euro	1164 – 1215 MHz Euro 1215 – 1240 MHz Euro 1559 – 1610 MHz Euro

The radiofrequency bands below 1 THz which are used by passive sensor instruments are presented in the following tables. These highlight the current and future uses of instruments which are flying or will fly on several of the spacecraft indicated earlier. The entries in green represent new bands being brought into use.

Table 3 - overview of the frequency use of the passive microwave sounding instrument on the current and future NGSO Metop and Metsat satellites

Instrument	Centre Frequency	Bandwidth	Comments
AMSU-A1/A2 (Metop & NOAA)	23.8 GHz 31.4 GHz 50.3 GHz 52.8 GHz 53.596 ± 0.115 GHz 54.40 GHz 54.94 GHz 55.50 GHz 57.290344 GHz + sub 89 GHz (15 channels)	270 MHz 180 MHz 180 MHz 400 MHz 170 MHz 400 MHz 400 MHz 330 MHz 375 MHz 6000 MHz (2.1/1.1 kbps)	Advanced Microwave Sounding Unit-A (AMSU-A) Temperature of the global atmosphere in all weather conditions
MHS (Metop) similar to AMSU-B (NOAA)	89 GHz 157 GHz 183.311 ± 1 GHz 183.311 ± 3 GHz 190.311 GHz (5 channels)	2.8 GHz 2.8 GHz 0.5 GHz 1 GHz 1.1 GHz (3.9 kbps)	Microwave Humidity Sounder (MHS) Humidity of the global atmosphere

Current use (NGSO)

Instrument	Centre Frequency	Bandwidth	Comments
Microwave Sounding Mission (MWS) Metop-SG-A	23.8 GHz 31.4 GHz 50.3 GHz 52.8 GHz 53.246+/-0.08 GHz 53.596+/-0.115 GHz 53.948+/-0.081 GHz 54.40 GHz 54.94 GHz 55.50 GHz 57.290344+/-0.217 89 GHz 164 – 167 GHz 183.311+/-7.0 GHz 183.311+/-4.5 GHz 183.311+/-3.0 GHz 183.311+/-1.8 GHz 183.311+/-1.0 GHz 229 GHz	270 MHz 180 MHz 180 MHz 400 MHz 2x140 MHz 2x170 MHz 2x142 MHz 400 MHz 400 MHz 330 MHz 2x78 MHz 4x36,4x16,4x8,4x3 4000 MHz 3000 MHz 2x2000 MHz 2x2000 MHz 2x1000 MHz 2x1000 MHz 2x500 2000 MHz	MWS allows for all-weather soundings over a wide swath in the spectral region between 23.8 and 229 GHz, with a footprint size of 17 - 40 km at nadir, depending on the channel. (Metop predecessor: AMSU-A/MHS)

Future use (NGSO)

Table 4 - New passive sounding frequencies for future NGSO MetSat satellites

Instrument	Centre Frequency	Bandwidth	Comments
Microwave Imaging Mission (MWI) Metop-SG-B	18.7 GHz 23.8 GHz 31.4 GHz 50.3 GHz 52.61 GHz 53.24 GHz 53.75 GHz 89 GHz 118.7503+/-3.2 GHz 118.7503+/-2.1 GHz 118.7503+/-1.4 GHz 118.7503+/-1.2 GHz 165.5+/-0.725 GHz 183.31 +/- 7.0 GHz 183.31 +/- 6.1 GHz 183.31 +/- 4.9 GHz 183.31 +/- 3.4 GHz 183.31 +/- 2.0 GHz	200 MHz 400 MHz 200/1000MHz 400 MHz 400 MHz 400 MHz 400 MHz 4000 MHz 2x500 MHz 2x400 MHz 2x400 MHz 2x400 MHz 2x1350 MHz 2x2000 MHz 2x1500 MHz 2x1500 MHz 2x1500 MHz 2x1500 MHz	The Microwave Imaging Mission (MWI), providing precipitation and cloud imaging in the spectral range from 18.7 to 183 GHz with footprint sizes between 10 km and 50 km depending on the frequency. (Metop predecessor: ---)

Instrument	Centre Frequency	Bandwidth	Comments
Ice Cloud Imaging Mission (ICI) Metop-SG-B	183.31 +/- 7.0 GHz 183.31 +/- 3.4 GHz 183.31 +/- 2 GHz 243.2 +/- 2.5 GHz 325.15 +/- 9.5 GHz 325.15 +/- 3.5 GHz 325.15 +/- 1.5 GHz 448 +/- 7.2 GHz 448 +/- 3.0 GHz 448 +/- 1.4 GHz 664+/- 4.2 GHz	2x2000 MHz 2x1500 MHz 2x1500 MHz 2x3000 MHz 2x3000 MHz 2x2400 MHz 2x1600 MHz 2x3000 MHz 2x2000 MHz 2x1200 MHz 2x5000 MHz	The Ice Cloud Imaging Mission (ICI), providing ice-cloud and water-vapour imaging in the spectral range from 183 to 664 GHz, with a footprint size of 15 km. (Metop predecessor: ---)

Table 5 - frequency use of the passive microwave sounding instrument on the current NGSO (66° inclination)

Instrument	Centre Frequency	Bandwidth
AMR (Jason-2 & -3) AMR-C (Jason-CS / Sentinel-6)	18.7 GHz 23.8 GHz 34 GHz	200 MHz 400 MHz 700 MHz
Advanced Microwave Radiometer (AMR) measures at each frequency (combined) to determine atmospheric water vapour and liquid water content. The main 23.8-GHz frequency is used to measure water vapour, the 18.7-GHz channel is highly sensitive to wind-driven variations in the sea surface and the 34-GHz channel for the correction for ocean surface and non-raining clouds.		

Current use (NGSO)

Instrument	Centre Frequency	Bandwidth
MWR (Sentinel-3)	23.8 GHz 36.5 GHz	400 MHz 1000 MHz
The MicroWave Radiometer (MWR) measures the thermal radiation emitted by Earth. The 23.8 GHz channel is used mainly to determine the delay of the altimeter pulse by tropospheric water vapour. The 36.5 GHz channel primarily addresses the delay from non-precipitating clouds.		

Future use (NGSO)

Active instruments generally fall into several categories:

- Scatterometers. There are microwave radar sensors which measure the scattered reflections produced while observing the surface of the earth from several (3 or more) angles of view as the satellite passes over. Scatterometers are especially useful for measuring wind speed and direction over the oceans. Typical signal bandwidth is of the order of a few MHz at 5.3 GHz.

- Radar Altimeters. These are downward pointing radars that accurately measure distance to and movement of the earth surface through timing and Doppler measurements of radar reflections. In meteorology, they provide measurements of ocean surface topography, wave height and wind speed. Typical bandwidth is several hundred MHz, e.g. 320 MHz at 5.3 GHz and 350 MHz at 13.5 GHz.

- Synthetic Aperture Radars (SAR). These are advanced radars that make use of the motion of the satellite and/or antenna to scan an area and through signal processing synthesise the effect of a much larger antenna and thereby increase the spatial resolution of the image. In meteorology they are used for mapping land and sea ice flows, and wind and pressure movement of the oceans. The bandwidth requirement depends on the required spatial resolution. SARs have a higher sensitivity to interference and new C-band designs can now utilise only the 5 350 – 5 470 MHz due to interference from WiFi in the adjacent band segments.

Table 6 shows the current and future meteorological use.

Table 6 - Bands used by active sensors

Current use

Instrument	Centre Frequency	Bandwidth
ASCAT (Metop)	5255 MHz	1 MHz
Advanced Scatterometer (ASCAT) Near-surface wind speeds and diections over global oceans. Scatterometer wind measurements are used for air-sea interaction, climate studies and are particularly useful for monitoring hurricanes.The data are also applied to the study of vegetation, soil moisture, polar ice, tracking Antarctic icebergs and global change.		

Instrument	Centre Frequency	Bandwidth
POSEIDON-3 and 3B (Jason-2 & -3) POSEIDON-4 (Jason-CS / Sentinel-6)	5300 MHz 13.575 GHz	320 MHz 320 MHz
Poseidon-3 and -3B solid state altimeters measure sea level, wave heights and wind speed at 13.575 GHz and estimates atmospheric electron content at 5.300 GHz-		

Future use

Instrument	Centre Frequency	Bandwidth
SCA (Metop-SG-B)	5355 MHz	2 MHz
The Scatterometry Mission (SCA) on Metop-SG is providing back-scattered signals in the 5.3 GHz band at higher resolution as its predecessor instrument ASCAT on Metop.		

Instrument	Centre Frequency	Bandwidth
SRAL (Sentinel-3)	5410 MHz 13.575 GHz	320 MHz 350 MHz
The Synthetic Aperture Radar Altimeter (SRAL) is a dual-frequency, nadir-looking microwave radar altimeter employing technologies from the CryoSat and Jason altimeter missions.		

For both active and passive sensing it can be noted from the comparison of the bands used by instruments on operational satellites and those under development, that:

- there is a very strong need for continuity in the measurements and in the retrieval of meteorological data on global basis;
- frequency bands in use by passive and active sensing instruments today will continued to be used by successor instruments tomorrow and in the long term future;
- further bands already allocated to EESS (passive) at higher frequencies will be used to complement measurements at other frequencies or to observe additional meteorological parameters.

<u>Data links</u>

Spectrum is used for TT&C and spacecraft ranging, the downlinking of observation data to major ground stations, the relay of pre-processed data through geostationary satellites to user terminals, the relay of signals from data collection platforms and the direct transmission of observation data to meteorological user stations. Table 7 summarises which bands are used now and planned for future use.

Table 7 Spectrum used for Metsat communications

Application	Orbit	Timescale (Current /future)	Bands
Telemetry/Telecommand and Ranging	GSO/NGSO GSO/NGSO	current/future current/future	2 025 – 2 110 MHz 2 200 – 2 290 MHz
Instrument raw data downlink	GSO NGSO GSO/NGSO GSO/NGSO	current current/future future Future	1 675 – 1 710 MHz 7 750 – 7 900 MHz 8 025 – 8 400 MHz 25.5 – 27 GHz
Low rate direct dissemination to user stations	GSO	current	1 675 – 1 710 MHz
High rate direct dissemination to user stations	GSO/NGSO NGSO	current future	1 675 – 1 710 MHz 7 750 – 7 900 MHz
Data dissemination (EUMETCast) via commercial GSO satellites	GSO	current/future	3 700 – 4 200 MHz 10.7 - 12.5 MHz
Data Collection Systems	GSO/NGSO NGSO	current/future future	401 – 403 MHz 460 – 470 MHz
Search and Rescue	GSO/NGSO GSO/NGSO	current/future current/future	406 – 406.1 MHz 1 544 – 1 545 MHz

The trend is for higher resolution imagery and lower latency. S-Band (2 025 – 2 110 MHz and 2 200 – 2 290 MHz) continue to be the key spectrum resource for the operation of MetSat satellites for TT&C and Ranging. The identification of appropriate S-Band frequencies for new missions and further on coordinating and notifying those is now a difficult and very long process.

The next generation of GSO and NGSO MetSat systems will need to use the bands 7 750 – 7 900 MHz, 8 025 – 8 400 MHz and 25.5 – 27 GHz. As there are no alternative bands available in the Radio Regulations, it is important to ensure the long term availability and protection of these bands on a global basis. In these bands the downlink will generally be by a small number of dedicated earth stations, none of these are currently in the UK.

The growing requirement for higher bandwidth is illustrated by figure 11 which has been taken from the SFCG x-band database, with several missions now using the entire 375 MHz of bandwidth.

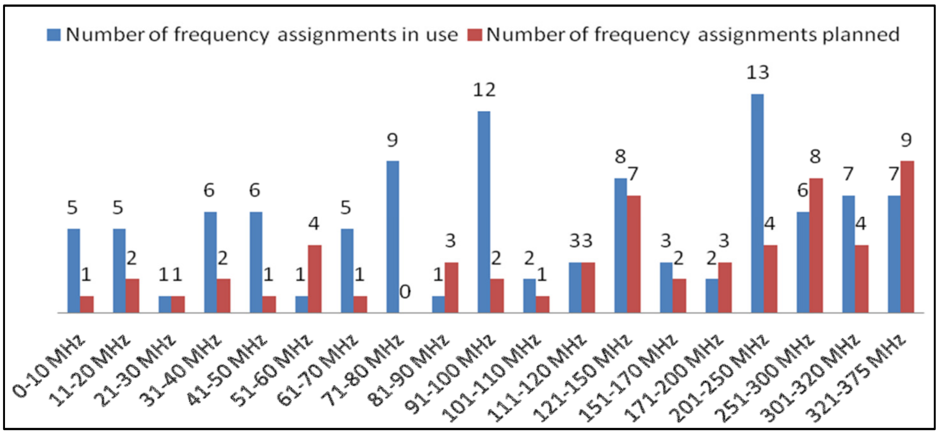

Figure 11 – Bandwidth utilisation for the 8 025 – 8 400 MHz spectrum by science satellites (SFCG).

As well as the standard MetSat bands, commercial satellites in Ku-Band and C-Band are used for regional/global dissemination of meteorological satellite data via EUMETCast. There are currently 419 registered users of the EUMETCast service in the UK, the majority receiving the service in Ku-band.

In the UK, there are relatively few users for Direct Readout. There are 2 known users Metop operating at 1 701.3 MHz (1 707 MHz back-up) and 3 users for the MSG LRIT Direct Readout at 1 691 MHz. There is a growing trend for reception in 7 750 – 7 900 MHz and RSA may be of interest to protect these users.

<u>Q16 Active Space Sensing – SRS (active)</u>

Active space sensing covers a wide range of applications in sensing the mesosphere, thermosphere, ionosphere and magnetosphere as well as remote sensing of the moon, other planets and asteroids in the solar system. It is mainly carried out using ground based radars, though space based radars also play an important roles, especially those in orbit around other bodies of the solar system. There are applications ranging from pure science, for example Radar astronomy and exploration to planetary protections, to practical applications in resilience, including Space weather observables and determination of the trajectories of space debris and near Earth objects.

Ground based radio sensing of the upper atmosphere, principally the ionosphere and magnetosphere has a long history but is still important and increasingly so for the study and response to the risk of global disruption due to severe space weather. Sensing is in general restricted to frequencies at UHF and below, with ground based ionospheric radars generally operate at powers of <1kW and below 30 MHz. Exceptions are ionospheric heating systems which operate at powers of several MW in the 2-10 MHz range. VHF radars operating around 40-50MHz and up to 30kW are used for studies of the Mesosphere, Stratosphere and Thermosphere. A 50 MHz system is operated by STFC on behalf of NERC at Capel Dewi (52.42°N, 4.01°W) near Aberystwyth. Incoherent scatter radars are used to measure the ionosphere, e.g. plasma waves and operate between around 50MHz and 1 290 MHz, with the majority operating in the 400-450MHz segment with large antenna arrays and pulse powers of several MW.

Satellite based sensing of the upper atmosphere is frequently based on measuring the effect on GNSS signals passing through the atmosphere. This is a good example of science using sources of opportunity from other radio services. Sensing can also be based on satellite beacons being received on the ground and vice versa. The applications are in ionospheric physics, meteorology, HF propagation prediction, space weather and in developing improved GNSS corrections. Measurements may be made on the ground or by satellite and frequently are made from multiple locations to generate mapping data.

Space sensing radars are also used for the tracking of space objects. This is largely a military activity due to the sensitivities of space surveillance. The equipment parameters, site locations and spectrum usage characteristics are classified. On the civil side, STFC have developed a capability at Chilbolton in Hampshire using a 25m dish antenna and spectrum at 1 275 MHz and 3 075 MHz at peak powers of 700kW. The European Space Agency have also recently developed two prototype civil space tracking radars operating around 1 200 – 1 400 MHz and located in Spain and Germany.

Active space sensing of planets and asteroids is in general not an activity undertaken from the UK[12], though it has been in the past using large radio telescope facilities. However, there are UK interests in the science data from systems operated by other states, particularly the US facilities in Green Bank, Arecibo and Goldstone which are often used together with other facilities in bi-static radar modes. Protection of these facilities listed in table 8 is important to UK science.

Table 8 – Summary of major planetary radar facilities

Radar location	Frequency band(s)	Bandwidth	Power	Associated receive sites
Goldstone	7 190 MHz 8 560 MHz 8 600 MHz	80 MHz 50 MHz 120 MHz	80 kW 500 kW 1 MW	Goldstone, Green Bank, Arecibo Goldstone, Green Bank, Arecibo, Socorro Goldstone, Green Bank, Arecibo
Arecibo	430 MHz 2 380 MHz 4 600 MHz	0.6 MHz 20 MHz 50 MHz	2.5 MW 1 MW 500 kW	Green Bank, Arecibo Green Bank, Arecibo, Socorro, Moon Arecibo, Green Bank
Green Bank	8 600 MHz	100 MHz	500 kW	Green Bank, Socorro, Goldstone

Some of the applications of active space sensing are imaging below the lunar surface, imaging Mercury and Venus, radar studies of the Jupiter system, imaging and refining the orbits of near earth asteroids which may pose a threat to the earth and demonstrating general relativity.

<u>Q16 Space exploration communications – SRS (deep space & near Earth)</u>

Space exploration uses spectrum mainly for TT&C and payload data communications between missions in space and the earth. The band use is segmented into near Earth and

[12] Note this response is not intended to cover military and space situational awareness sensors concerned with the detection and tracking of space objects.

deep space and mission spectrum use is co-ordinated by an inter-agency group, the Space Frequency Coordination Group (SFCG).

Near Earth is defined as systems operating within 2M km of the Earth surface. Deep space is defined by the ITU as anywhere more than 2 million km from earth. However, ITU-R SG7 has recently clarified that missions to deep space may use deep space allocations in the launch, early orbit phases, earth flybys or when returning to Earth. Therefore a reasonable assumption is that deep space allocations should be used by missions intended to operate in deep space.

The principle space research allocations are at S-band (2 025-2 120 MHz up and 2 220-2 300 MHz down) which is used for TT&C, and X-band (7 145-7 235 MHz up and 8 400-8 500 MHz down) which is used for TT&C interleaved with payload data.

Since the introduction of IMT in 2 110-2 120 MHz, the deep space segments at 2 110-2 120 MHz up and 2 290-2 300 MHz down have suffered harmful interference. They are now only usable in a few countries where IMT is not deployed. The bands are now only used for legacy missions – remembering that some deep space missions are approaching 40 years of operations.

Space Research missions are moving to Ka-band 1 (22.55-23.15 GHz up, 25.5-27 GHz down) for those missions requiring large data uplink and/or downlink capability, interleaved with TT&C functions. This is a relatively recent allocation and has not yet been exploited in full.. The James Webb Space Telescope (launch 2018) will require very high data bandwidth for a deep space mission of 28Mb/s at Ka band.

Deep space missions requiring large data uplink and/or downlink capability use 31.8-32.3 GHz down and 34.2-34.7 GHz up, interleaved with TT&C functions

Systems are considering moving up to Q-band (37-38 GHz down and 40-40.5 GHz up) and this spectrum is planned for future manned lunar missions.

In addition, some spectrum at S-band and Ka-band is used for inter-satellite links. S-band is used for controlling NGSO satellites when not in visibility of a ground station and these bands are also used for some rendez-vous and docking operations in the manned spaceflight programme.

The reason for using these frequency bands is historic rather than a specific molecular resonance, indeed these resonances need to be avoided in order to minimise propagation loss through the atmosphere. With missions that can take decades to reach their targets, there is little scope to change these frequencies. However, deep space communications requires significant infrastructure, typically very large dish antennas are needed and the number of sites is therefore limited. While communications with individual missions may be intermittent, ground stations typically serve several missions and therefore their use of spectrum is continuous.

Requirements for data bandwidth are increasing, especially with the increase in planetary exploration and higher resolution instruments, for example ESA, under the cosmic vision programme have planned missions to Mars with Exomars (2018) and Mercury with Bepi-Columbo (2017). The PLATO mission will look for Exoplanets, Euclid will map the dark universe, JUICE will visit Jupiter's icy moons and the James Webb Space Telescope will replace Hubble. SRS deep space is also used for solar and hemispheric observations. Solar Orbiter (2018) will require a link rates of 150kb/s[13] and new space weather monitoring missions (~2020) will be extensive users of these allocations.

The European Space Agency owns 10 Earth stations in its network. While none are located in the UK, there is UK interest due to our funding of ESA. There are also several non-ESA owned stations with cooperative agreements supporting ESA missions.

Table 9 – ESA Ground Station Network

ESA Network:	**Location**
New Norcia, Australia	31.0°S 116.2°E
Perth, Australia	31.8°S 115.9°E
Redu, Belgium	50.1°N 5.1°E
Kourou, French Guayana	5.3°N 52.8°W
Cebreros, Spain	40.5°N 4.4°W
Maspalomas, Gran Canaria, Spain	27.8°N 15.6°W
Villafranca, Spain	40.4°N 3°9W
Kiruna, Sweden	67.9°N 21.0°E
Santa Maria, Azores, Portugal	37.0°N 25.1°W
Malargüe, Argentina.	35.8°S 69.4°W
ESA cooperative stations:	
Malindi (Kenya)	3.2°S 40.1E
Santiago (Chile)	33.5°S 70°7W
Svalbard (Norway)	78.3°N 15.2°E

The networks of other space agencies (USA, Canada, Russia, Japan, etc.) are also important to the UK. Frequently we collaborate on missions and use the science data from their missions. In addition, there are several ground stations in the UK that receive data on a commercial basis which are shown in table 10. UK operators, e.g. SSTL and Airbus also operate ground stations around the world in support of their missions.

Table 10 – UK space science ground stations

UK Stations:	**Location**
Goonhilly, Cornwall (GES Ltd)	50.0°N 5.2°W
Dundee, Fife (University of Dundee)	56.5°N 3.0°W
Harwell, Oxfordshire (STFC)	52.0°N 1.5°W
Chilbolton, Hampshire (STFC)	51.2°N 1.3°W
Guildford, Surrey (SSTL)	51.2°N 0.6°W
Bordon, Hampshire (SSTL)	51.1°N 0.9°W

[13] This may not seem very much compared to say mobile broadband, but this link is over a distance of 1.5M km.

Estimating the number of users is difficult in this case as space research is largely a public good activity. We therefore interpret this question to relate to organisations. The UK lead is the STFC Astronomy & Space Science Programme, the UK Space agency support this through our ESA and national programmes. The principle users of the data are research councils, universities and research organisations.

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).

The 2012/3 market turnover[14] for the space sector is £11.8bn of which 2% is attributable to Space Science and 3% to Earth Observation, approximately £550M per annum[15]. The total societal benefits are notoriously difficult to evaluate. EU cost benefit analysis studies have indicated a benefit-cost ratio of 10 for EU Earth Observation programmes. This ratio is supported in estimates of the value of meteorological services to the UK, which are estimated to be £1bn-£1.5bn[16] per annum at a cost of £120m. Table 11[17] shows the UK Space agency investment in space in 2014/15.

Table 11 – UK Space Agency Investments

ESA programme	2014 (i) subscriptions €000	2015 (i) budget €000
Mandatory Activities and Science Programme	123,409	113,742
Earth Observation	63,390	78,676
Telecommunications & Integrated Applications	43,155	67,360
Robotic Exploration	20,208	41,576
Human Space Flight & Microgravity	4,573	10,167
GSTP (ii)	15,810	11,788
Navigation - Galileo	10,642	4,278
Space Situational Awareness	1,351	1,978
Total	**202,530**	**329,565**

National Programme	£000
Core Programme	19,108
NSTP	9,641
Major projects - NovaSAR	5,636
IPSP	7,064
Total national grants and other funding	**41,449**
Other operational programme costs	2,785
Total National Programme	**44,234**

In 2014/15 the International Partnerships in Space Programme was launched, which will see at least £26m committed across two years.

Earth Observation

The use of Earth observation products has consistently demonstrated good potential for job creation, innovation and growth across many market sectors. Many non-space industrial sectors benefit, for example water transport, oil and gas, non-life insurance, renewables energy and agriculture. UK participation in Earth Observation cannot be separated from the

[14] *The Case for Space 2015: the impact of space on the UK economy*, London Economics, July 2015
[15] UK space industry: size and health report 2014, https://www.gov.uk/government/publications/uk-space-industry-size-and-health-report-2014
[16] Met Office, Value for money review, http://www.metoffice.gov.uk/media/pdf/c/a/PWS_Value_for_Money_Review_-_March_20151.pdf
[17] UK Space Agency, Annual report and accounts 2014/2015 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/441292/Annual_report_final_web.pdf

international perspective; this is largely an EU/ESA/EUMETSAT activity. UK funding for European programmes is 14% and for ESA programmes 16%.

European commission studies[18] have indicated a current European Earth observation downstream market value of €1bn in 2015 rising to €2.8bn by 2030, largely facilitated by the Copernicus programme[19], which will support free and open data provision with full and assured continuity of service. The Commercial EO Data market is predicted to grow at an average of 14% CAGR over the next 6 years.

The estimated market potential attributable to Copernicus has been estimated at €2.6bn by 2030 supporting 20,500 direct jobs and 63,000 indirect jobs[20]. A key element of the programme is the Sentinel series of 6 families of Earth observation satellites, which are developed through ESA and a complimentary set of contributing missions operated by national, Europe and international organisations. The sentinel satellites are being rolled out between now and 2020. The availability of free data, including high resolution optical and radar imagery is expected to produce a step change in the utilisation of this data.

A European evaluation of socio-economic impacts from space activities[21] provides a description of the main benefits resulting from EO satellite data applications. In general terms the study finds three main economic benefits deriving from satellite data: efficiency gain; cost avoidance or reduction; and new activities, products or services. The study identifies eight main areas that profit from EO. One area is the agriculture sector where the economic benefits are ultimately the saving on water supply, thanks to better irrigation decision, and crop management, as well as saving on pesticides. Another example relates to the maritime sector where EO satellites could be used to optimise vessel routes as well as oil platform operations. In this context the economic benefits are again operation costs savings and socially increased safety. Moreover, EO data provides valuable information to Governmental authorities in the context of disaster management and other emergency services. In these cases, EO data can help preventing, as well as responding to these natural disasters.

Meteorology is another sector that relies heavily on satellite data and the demand coming from the EO satellites (e.g. ESA ones) is growing. For instance, the number of registered user station with EUMETSAT to download near-real time satellite data has grown more than 150% from 2005 to 2011[22]. Also the European Centre for Medium range Weather Forecasting (ECMWF) has almost doubled his reliance on satellite data for weather forecast from 2003 to 2007[23]. Better forecast benefits the daily life of citizens as well as the industry sector and the Government.

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[18] http://www.copernicus.eu/main/economic-studies

[19] The Copernicus programme http://www.copernicus.eu/ collects data from multiple sources: earth observation satellites and in situ sensors such as ground stations, airborne and sea-borne sensors. It processes these data and provides users with reliable and up-to-date information through a set of services related to environmental and security issues.

[20]Assessing the Economic Value of Copernicus: "European Earth Observation and Copernicus Downstream Services Market Study", December 2012, http://www.copernicus.eu/ most likely scenario, downstream €1.8B p.a. supporting 16,000 jobs, upstream €800M p.a. supporting 4,500 jobs

[21] 'Evaluation of socio-economic impacts from space activities in the EU', Booz&co, March 2014

[22] Evaluation of socio-economic impacts from space activities in the EU', Booz&co, March 2014

[23] Evaluation of socio-economic impacts from space activities in the EU', Booz&co, March 2014

While difficult to quantify with any degree of certainty, there is good evidence of strong returns from investments in EO. As noted above, the benefits from better weather forecasting are in the billions with much of this due to space technologies. Better climate data can also help better policy making through improving our understanding of the climate, which in turn can lead to better adaptation and mitigation policies and so reduced damages from climate change. Avoided EU damages from better disaster monitoring and response have also been estimated to be over €100m p.a.[24] Contracts awarded to firms to build satellites and instruments also create economic value, and scientific data produced can also lead to a range of unpredictable 'spillover' benefits to other firms, unrelated sectors and society more widely.

There are also many non-market benefits including, for example, better health (through, e.g. food security and better climate change response), better policy making (climate change, disaster management, security) and environmental protection and improved biodiversity.

Space Science

The economic benefits of space science are very difficult to quantify as lead times are generally long, and it will be many years before the benefits to industry and the public are fully realised[25]. Contrarily to EO, space science does not have major downstream segments and the primary aim is the increased knowledge of space. It is difficult to say what new knowledge generated from space science missions will lead to, so any attempt to quantify benefits – particularly before the event – will be simplistic and heavily reliant on assumptions made. As for EO, we can expect that investment in space science results in spillover benefits, meaning the scientific advancement will be valuable not only for the space sector, but also for other sectors and society more widely as it will generate innovation activities such as new or improved products and services[26]. For instance, technologies developed for the Rosetta mission have driven new non-space related applications such as the ultralight wristwatch-style insulin pump[27]. Anecdotal evidence, as well as core economic theory, highlights the importance of scientific advancement for long term economic growth.

In the field of space exploration benefits are almost impossible to quantify. Some benefits include technological development achieved as a result of these missions as well as a better understanding of the origins of the universe[28] and increased knowledge of space and other planets. Space exploration also has an inspirational value, encouraging young people to study STEM subjects which can ultimately help further growth of the sector (alleviating skills shortages) and so society more widely.

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[24] ibid
[25] Evaluation of socio-economic impacts from space activities in the EU', Booz&co, March 2014
[26] 'Space Exploration and Innovation', Summary report, Technopolis, 13 October 2010
[27] Space Foundation, The Space Report, 2013
[28] Evaluation of socio-economic impacts from space activities in the EU', Booz&co, March 2014

In the more recent years private initiatives have emerged, such as the X prize, and although small, these projects and the involvement of the private sector could grow in future years[29]. Space tourism is another industry that is expected to grow in the future.

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

The major driver in the coming years will be promoting space as an enabler of growth, including applications in big data.

In December 2014 the government published “Our plan for growth: Science and Innovation”, this is a long term strategy to make the UK the best place in the world for science and business. Science and Innovation are at the heart of the UK’s long term economic plan. The UK’s ability to capitalise on its cutting edge research base will be critical to our future prosperity and societal wellbeing.

The UK Space agency aims to ensure that this criticality and utility of the space sector to science, enterprise and economic growth are understood by policy makers, commerce and the general public. The space sector is now worth £11.3bn annually to the UK economy. This represents about 6.5% of the global space and services market, but the UK Space agency plan to grow that to around 10% by 2030; boosting the economy to £40 billion a year. Much of this growth is expected to come from downstream applications, including those based on space science and earth observation. This will necessarily result in an expansion of the space science sector and the use of data and services from space.

The new ESA centre in Harwell anchors the UK’s investment in ESA, which will remain our main delivery mechanism for space missions. We have been increasing our contribution to an expanding ESA with the aim of promoting growth in the space science sector. Space, aerospace and telecommunications are increasingly important activities at Harwell, which is the “UK Space Gateway” site for academia and industry. The site, which already hosts 5000 people working in 200 high-tech organisations is pulling in industry, particularly from abroad. The satellite applications catapult, located at Harwell is providing a focus and resource for access and exploit space data.

The UK Space agency national programmes are developing the sector throughout the UK, working with Local Enterprise Partnerships and the Devolved Administrations to identify opportunities to engage new businesses with space technology, data, expertise and facilities. The Space for Smarter Government Programme is a strategic, national, programme established and led by the UK Space Agency and delivered in collaboration with the Satellite Applications Catapult to drive the uptake and use of space products, data and services across government departments. The aim is to increase the public sector use of space as an enabling technology to stimulate innovation and growth whilst at same time making government more efficient and ‘smarter’.

[29] Evaluation of socio-economic impacts from space activities in the EU’, Booz&co, March 2014,

MetSat

It is estimated[30] that the overall benefits to EU citizens from weather forecasting are between €15Bn and €61Bn per year:

Table 12 – Estimated benefits of weather forecasting

Catagory	Minimum Benefit	Likely Benefit
Protection of property and infrastructure	€1.3 billion/year	€5.5 billion/year
Added value to the European economy	€10 billion/year	€41 billion/year
Private use by European citizens	€4 billion/year	€15 billion/year
TOTAL	**€15 billion/year**	**€61 billion/year**

This does not allow for lives saved or the benefits to defence and security. Also not captured are additional benefits expected from the positive impact of increasingly accurate weather forecasts on the performance of downstream forecasts of weather-dependent phenomena.

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).

Much of this has already been covered in the responses to previous questions. According to the UK Spectrum Strategy[31], the dependence of meteorological and climatological activities on access to spectrum will continues and will even rise in the future. This is due to the growing challenges of climate change and the need of accurate weather forecast. In general, the demand for earth observation services is expected to increase

[30] The case for EPS/Metop second generation cost/benefit analysis. 2013
[31] ‘The UK Spectrum Strategy, Delivering the best value from spectrum for the UK’, DCMS, 10 March 2014

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?

The Square kilometre array is primarily an investment in radio-astronomy. It is not intended to replace UK radio astronomy facilities and, while important, this investment represents a relativity small part of the overall UK investment in space science. UK investment in this facility does not really have any bearing outside astronomy on the space science use or the Earth Observation use of the passive bands.

There is a risk that in assuming the majority of UK spectrum use by space sciences is “spectrum in the UK”. This might better be described as “spectrum over the UK” as the spectrum use is mainly by satellites. Much of the data of interest to UK stakeholders may be from other parts of the world although we have specific additional interests in making observations over the UK, with many applications in meteorology, climate studies, geology, hydrology, agriculture, land use, planning, environmental monitoring, compliance, surveillance and security.

Science is continually making better instruments and improving measurement technique. This increases spectrum efficiency but does not reduce demand, especially in the context of a growing sector.

The UK Space Strategy aims to increase the space sector fourfold by 2030. A large element of this is Earth Observation. As satellite systems improve in sensitivity and capability, it is most likely that the use of science spectrum over the UK will increase. It is unlikely that there will be any reduction in demand.

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?

We agree that many space science applications need freedom from interference. It may turn out to be costly, but we should resist the temptation to allow market forces to overrule science value in prioritising spectrum. The enforcement of active mitigation to protect science users can be controlled in the UK by the UK regulator, with remedial action taken as necessary as it was for interference to SMOS, but this may not be the case globally, which may impact global data sets. The experience with Dynamic Frequency Selection (DFS) demonstrates it is difficult to maintain standards when there is a direct performance benefit to systems not following the rules.

Receiver filtering is important and is already implemented. There are limits to the out of band rejection that can be received given the constraints of sensor mass and sensitivity. SFCG maintains a database of sensor characteristics and instances of interference. Studies by the SFCG have found that in most cases, interference to EESS is caused by unwanted emissions rather than receiver inadequacies.

Spurious emission standards that are difficult to achieve may come under pressure for relaxation based on commercial considerations. It may be hard for the UK to resist changes to limits, or prevent the marketing of non-compliant equipment from outside the UK, that would adversely impact adjacent bands.

Science makes extensive use of signal processing to extract measurements from data. Improvements in signal processing have led to more sensitive and more accurate measurements. Science sensors typically operate at the boundaries of what is achievable and it is unlikely additional signal processing will be able to compensate for interference without compromising the measurement. Where very fine measurements are being taken, e.g. in Synthetic Aperture Radars, low levels of interference are practically impossible to differentiate from valid measurements. This risks interference corrupting datasets in unknown ways, devaluing the results.

The proposal for a global database of science satellites is a good one. Much of this data already exists, for example in the databases maintained by the SFCG, in ITU filings etc. The UK Space Agency have already made Ofcom aware of these databases. The creation of an online active database as might be used for systems seeking white spaces is a risky route to sharing due to the need to very frequently update and distribute the database. It is likely this would need to be done on at least a daily basis to allow for spacecraft manoeuvres and schedule updates.

Geographic sharing really only applies to astronomy and for those data links where there are relatively few ground stations required. Earth observation sensor links generally cover an entire country. It may be possible on a regional basis for measurements that only need to operate over specific regions, the sea, rainforests or ice caps. However, most space based sensors provide data that has multiple uses, e.g. Earth observation radar sensors that produce data useful for meteorology, agriculture, deforestation and climate change studies in remote regions and can also be useful for urban planning, landslips, subsidence, geology, tracking vessels etc.

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.

We would like to see a long term commitment to identify bands that will not be targeted for new sharing. A concept of safe havens, where systems can operate with long term confidence is needed. This is particularly important to space science systems due to the long development / operational cycles, which may span many WRCs.