Site activity: We receiver, archive and distribute data from weather and Earth resource satellites, currently most are operating in L-band (1.690-1.710GHz) and X-band (7.75-8.4GHz). Currently we are a receive-only site, but that might change for possible cube satellite support in the future. Our funding is government based via NERC and we have been doing this operationally since 1978. Web site is: www.sat.dundee.ac.uk

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

Generally we agree with the overall approach to the review.
In particular the workshop held at Ofcom on 10th July to elaborate on certain aspects of the questions and process was very helpful.

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 feel that the 'navigation' application area is more like the science sector in the sense that the functionality of the service and the number of end users the system can support is not strongly dependant on the spectrum allocation. This is different to most of the other 'satellite sector' applications where more users and/or more content (e.g. in the BSS cases) requires more spectrum to be allocated and/or more bandwidth-efficient approaches (with a corresponding increase in power demands).

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)?

We believe there is a further division of spectrum usage for the space science sector that is similar to the distinctions made in, for example, section 3.12 of the Ofcom document. We would consider the following:

- **Satellite TTC is transmit and receiver, but only used by the spacecraft operator (or under their direction) and must be internationally standardised both in frequency (i.e. spectrum) and in data formats, etc, so in the launch & early orbit, or emergency cases, the TTC sites around the world can cooperate to safely control the satellite.**
- **Satellite data downlinks are usually on receive-only terminals (though they may be co-located with TTC equipment, but not always). Again they operate in internationally agreed bands to avoid interference and to permit cost-effective reuse of ground stations. Generally they are not very standardised in modulation, coding, etc, compared to commercial operations such as BSS & VSAT terminals as the missions vary a lot and there is no significant market to achieve the economy of scale that most commercial services rely on. The CCSDS body has done a lot to help, but often only a handful of missions have identical data link settings.**
- **Active sensing spectrum (e.g. SAR) is again by international agreement due to the need for interference control both for the satellite and for ground services. The bands used do need a wide range of frequencies to achieve different goals (e.g. long wavelength to penetrate forest, short for leaf density mapping or high precision deformation measurements, etc) but the specific frequency ranges are arbitrary and based on historical precedent and band usage.**
- **Passive sensing in the microwave range often has frequencies that MUST be used as they relate to atomic resonance lines, etc. As such the science cannot be done if**

spectrum is re-allocated because of the fundamental reasons for choosing the bands.

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?

Generally we think the "value chain" shown in the Ofcom document as Figure 2 is a reasonable approach to categorising the different section. Our main comment on the question of revenues is we have very little insight in to the value ultimately derived from our services.

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.

(See Q15)

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.

(See Q16)

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).

(See Q17)

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

(See Q18)

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).

(See Q19)

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.

(See Q20)

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?

(See Q22)

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?

(See Q23)

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.

(See Q24)

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?

As for Q4's answer.
We follow the academic publications for our annual reports to our funding body as they rate us primarily on a UK science basis. We are aware from feedback comments that a lot of people use our services for personal interest, to supplement weather forecasting services, and even in some cases we hear from international pilots who drive value in route planning from our products. But we do not know what the equivalent financial benefits of all of these (often unreported) activities are.

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.

In Dundee we have been involved in:

- **The manufacture/installation of ground station equipment in the past (RF electronics, receivers, antenna tracking control hardware and software), and;**
- **On-going in the operation of an Earth station for the collection and distribution of UK science data, and;**
- **Together with Plymouth Marine Laboratory to generate environmental products from the raw data for ocean health, fishing management, etc.**

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.

Currently the frequency ranges of operation that are used to provide all of the services we directly supply (i.e. not including things like GPS-based timing, etc) are:
1690 - 1710 MHz "L-band"
7750 - 7900 MHz "X-band"
8025 - 8400 MHz "X-band"
In addition we occasionally use VHF (145MHz), UHF (430MHz) and S-band (2400MHz) in relation to cube satellites support, but that is not currently a primary activity.

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).

Our most directly measured usage is in academic research as that is what our funding body performs and we provide reports on this with a major review every 5 years. For the period of 2009-14 we supported:

- **294 peer-reviewed journal papers**
- **278 non-peer-reviewed publications**
- **21 PhD completed theses & 26 MSc/BSc projects**

In addition we also make a lot of data available for free to registered users (also free

registration) and for the same period we saw around 8000 new registrations per year and around 4.9 million image downloads per year.
We have less visibility as to the regional use of the data, as users are not compelled to reveal what the data is used for, or where. We do know that a significant proportion of the use is outside of the UK so is not directly within Ofcom's remit, but there remains a substantial volume of data used within the UK.
Converting the data usage in to economic activity is much harder task and is not one that we have attempted. The academic-related activity is of the order of £1M though it is hard to assess how much contribution our data was as a proportion of that (i.e. without our data what change in activity would have occurred).
For the "free" data we supply we know the majority if for personal or similar academic use, however, we also know there is some amount of important economic activity derived from the data (e.g. use in conjunction with weather forecasts for farming and insurance business, for commercial flight planning, etc) but again we have little visibility of how much, the equivalent financial value, or where it occurs (i.e. within the UK or elsewhere).

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

The common factor in all missions we see is an increase in the volume of data generated by the various instruments. In turn this pushes up the download data rates and as a result we see missions migrating from L-band to X-band as a result, and in some cases to Ka-band (e.g. Eumetsat are looking to this for polar satellite data dumps and geostationary links).
Currently the missions we are using are operating in the power-efficient region of modulation and forward error-correction (e.g. QPSK modulation and FEC rates of around 0.5, etc) as there is currently enough bandwidth in X-band to support them. In the future we anticipate this may no longer be the case and they will move to a more spectrum-efficient area of Shannon's curve and that, in turn, will make them less tolerant of noise and interference while demanding bigger ground station antennas and/or more on-board power.

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).

We expect to see roughly the same number of overall missions, but the instrumentation may be split between two, or perhaps more, satellites due to power, redundancy, or launch constraints. Overall we see the overall download data rates increasing by a factor of 2-10 over period of a decade or so for each series of satellites. In the next 5-10 years we expect still to be operating with power-efficient systems, but beyond that we expect a move to slightly less power efficient but more bandwidth efficient modulation and coding.
In terms of spectrum allocation, all we can say is the satellites are almost certainly going to be

concentrated in the X-band allocations we currently use by virtue of international operations. However, we can't tell, nor control, the future choice of specific frequencies as we are not the satellite operators. As a result, we ask that the whole bands used for science data downloads is treated as a valuable science resource for the UK. The use of Ka band for high speed data dumps is also something we expect to become common in 10+ years.

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.

To support higher data rates we see a need for better receivers, but these are a significant expense in our case (e.g. at £50-100k each for such programmable receivers when bought commercially, the replacement of all 5 operational receivers for our station is significantly more than our entire annual budget). Other techniques such as polarisation diversity (e.g. operating LHCP & RHCP simultaneously to double the effective bandwidth) might be called upon, and that in turn greatly increases the RF and reception chain cost and complexity. We also expect to need larger antennas and are concerned by the potential sources of interference, particularly with any systems operating at high spectral efficiency.

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?

We have no informed comment on this.

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 have some comments on possible mitigation techniques, though clearly our application area of data downlinks from polar orbiting satellites is a slightly unusual case:

- **In our case, of direct broadcast by polar satellites, it is unlikely that focused satellite beams would be used to any great degree. It has been done before (e.g. one of the Landsat designs) but it goes against the passive access operations that have been used in the past and that is suited to help in disaster areas, etc, where sites may conflict with other scheduled reception sites, and/or be unable to coordinate with the satellite operator(s).**
- **Most satellites designed from the 1990s onwards have been operating communication systems that are only a few dB away from the Shanon limit. As such, there is relatively little to be gained in terms of spectrum efficiency without a significant power impact. For Earth observation and other science satellites this trade-off is rather different compared to, say, BSS where operating revenue is directly related to bandwidth utilisation and significant on-board power is not need for other instruments, etc. Furthermore, in our case we do not control the design or operation of the satellites, so are forced to work with what others have decided to do.**

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?

We have considered techniques to deal with terrestrial uses of the same or adjacent spectrum and have the following observations:

- **Sharing with terrestrial uses is a possibility but not a trivial thing to do successfully due to the vast power differences between the satellite and ground links. Controlling interference is also made more difficult by the limitations of high speed programmable receivers where typically 8-bit A/D and filtering are the practical technological limits so the receivers have difficulties with out-of-channel signals if they are more than 20dB or so higher than the wanted one.**
- **In our case we know the contact periods accurately in advance, so time-sharing the spectrum is a possibility if the terrestrial users can stop (or greatly lower power) during the ~15 minutes slots we need, typically 10-20 times per day.**
- **Achieving some form of interference cancellation for 1-2 fixed terrestrial users is another possibility, but a mobile terrestrial system would be a lost cause. However, as we have tracking antennas for the polar orbiting satellites it is much harder to do than for geostationary links due to the changing amplitude and phase of the interference as the antenna moves. Significant research would be needed to evaluate the effectiveness of such approaches in practice.**

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 ask Ofcom to try and preserve the existing science band allocations for international use, as just one or two countries allowing commercial and/or significant terrestrial uses (especially mobile cases) of those frequencies would eventually cause big problems globally which would be against the UK's interests, and the UK-funded ESA interests as well.