
# Climate Change Adaptation Report

## Exploratory review of potential impacts to space infrastructure

*December 2024*

# Executive Summary

UK Space Agency were invited to participate in the Fourth Round of the Climate Adaption Reporting Power (ARP4), which is implemented by the Climate Change Act 2008. This is the first time the Agency or the sector have participated. ARP4 involves public services reporting on their understanding of and activities in addressing the risks posed by climate change to their sector and operations. With the increasing societal and economic reliance on infrastructure provided by the space sector it was decided that it would be prudent to conduct some research to establish whether climate change is a risk the space sector needs to take action against.

This report took the approach to provide an initial, exploratory scope to establish whether there is merit in conducting further work to understand the risks climate change poses to space infrastructure. Through a review of climate change reports, published literature and stakeholder engagement, a number of impacts were identified to the space sector that could result in disruption to the operation of space activities. These include extreme weather disrupting launch activities, damaging ground infrastructure and interference with space signals. Rising carbon dioxide concentrations are altering the density of the upper atmosphere, where a large portion of satellites operate, leading to change in orbital dynamics. There is also risk of cascading impacts through interdependence between ground space infrastructure and terrestrial power and telecommunication networks. The level of concern of these impacts are considered to be low at present but increase looking into the future of projected climate change.

Due to the limited scope of this report, it was assessed as not appropriate to deliver specific recommendations on actions needed to address climate change in the sector. With the report providing a base of evidence that there is merit for further work, it does conclude with suggesting a number of activities that can be undertaken to develop the understanding of the risk further which can provide the insight for a fuller assessment. These activities are:

**Activity 1:** Ensure the space sector, being a sector of CNI, is considered within future programmes of work assessing infrastructure resilience.

**Activity 2:** Create a community of interest on the intersection of climate change risks and space infrastructure, consisting of policymakers, industry and academia.

**Activity 3:** Develop understanding of the interactions between space infrastructure and weather variables, i.e. collate data on nominal operational parameters.

**Activity 4:** Deliver a programme of work to assess the likelihood and level of impact of current and projected climate change models.

## Contents

# Introduction

The Climate Change Act 2008 is a legally binding framework for the UK to mitigate and adapt to the impact of climate change. Under this act, public bodies have a responsibility to report on the steps being taken to prepare for and respond to climate change. To support public bodies with this, the government publishes the UK Climate Change Risk Assessment with it's third, and most recent iteration being released in 2022, known as CCRA3.

This is the first cycle that the UK Space Agency and the space sector has provided a report. Space systems provide many of the key systems that have provided the data to monitor and inform our understanding and response to the changing climate. 28 out of 56 climate variables are only able to be measured from space. Advances in technologies and data techniques has unlocked an incredible level of capability to help protect our planet.

Space is one of the UK's sectors of Critical National Infrastructure (CNI) and the responsibility to assess the range of risks to the systems and assets led to the decision to participate in this process.[1] Space infrastructure has only one mention in the CCRA3 Technical Report, relating to attenuation of signals in adverse weather. However, it can be argued that space systems have a level of vulnerability to the same risks identified for digital infrastructure.[2]

The cause for space being designate as CNI, is due to the increasing range of space-based services that are fundamental to the safety, security and prosperity of modern societies and economies. To date, there has been no explicit assessment of climate change impacts to the sector and whether mitigations are needed to protect this vital area of infrastructure. This report is the beginnings of this process by providing:

- An understanding of space systems and their importance as an infrastructure sector.
- Exploration from limited sources of how space infrastructure could potentially be impacted by climate change.
- Outline of activities to be considered in order to address the anticipated impacts of climate change within the sector.

[1] Space was designated as a UK sector of Critical National Infrastructure in 2015, and is currently one of thirteen sectors. CNI is defined as "Those critical elements of Infrastructure (facilities, systems, sites, property, information, people, networks and processes), the loss or compromise of which would result in major detrimental impact on the availability, delivery or integrity of essential services, leading to severe economic or social consequences or to loss of life."

[2] UK Climate Risk Independent Assessment Technical Report- Chapter 4: Infrastructure (2021).

# Organisational Profile

*"We support the government to boost UK prosperity, understand the Universe, and protect our planet and outer space."*

UK Space Agency is an executive agency, sponsored by the Department for Science, Innovation and Technology.

The Agency works to nurture a thriving space ecosystem – a network of investors, scientists, engineers, academia and research labs – and a sector that generates an annual income of £18.9 billion and employs 52,000 people across the country.

Our staff include scientists, engineers, commercial experts, project managers and policy officials who:

- catalyse investment to advance space-based technology and maximise UK space sector growth
- deliver missions and capabilities that responsibly meet national needs and advance our understanding of the Universe
- champion the power of space to inspire people, offer greener, smarter solutions and support a sustainable future

To achieve the greatest impact, we focus most of our resource behind eight delivery Priorities. These are:

- launch: supporting satellite launch services from UK spaceports
- sustainability: taking a leading role in keeping space safe and accessible now and in the future
- discovery: supporting space science and exploration missions
- innovation: investing in bold new technologies
- levelling-up: boosting space investment and jobs across the country
- Earth observation: studying our planet to drive discovery and tackle climate change
- low-Earth orbit: delivering vital everyday satellite services
- inspiration: inspiring new space customers, investors and the next generation

# Context of this report

As this is the first participation of UK Space Agency and the space sector in the reporting process, this paper is written with the view to introduce and explore the merit for further work on the issue. Most of the information presented has been drawn together from published literature with some input from operators of space infrastructure and academic institutions. The scope of this work is to:

- Present a collective of the research of climate change impacts and relate it to *civil and commercial* space operations and activities.
- Identify areas of climate change risk that are applicable to space infrastructure.
- Highlight the gaps in understanding and the level of need required to develop the sectors understanding of climate change risks.

Out of context for this paper is looking at impacts to space-based military capabilities. Also excluded is how to mitigate the contributory actions of space activities, such as launch vehicle emissions and atmospheric burning up of satellites (*known as 'ablations'*). The Agency acknowledges this is a challenge and along with other pioneering space sustainability programmes, is funding separate research in how to manage this.

# Space Infrastructure

To help understand why impacts to space needs to be considered, this section will outline the applications of space infrastructure and the importance of it. It will also provide an understanding of the key segments of space infrastructure, which lays the foundation to understand how climate change can affect the areas of activities within space infrastructure.

## The importance of space

Space infrastructure provides a range of capabilities, of which they are briefly summarised below:

**Position, Navigation and Timing:** This capability is delivered by a set of satellite constellations collectively known as Global Navigation Satellite Service (GNSS) and include the US GPS and EU Galileo systems. They provide ultra-precise timing signals that are used for synchronising key infrastructure such as energy and IT networks and can be used to determine location and direction to aid navigation.

**Satellite Communications:** These are systems that can facilitate the transfer of voice and data traffic. Applications include direct-to-home TV, dedicated satellite phone networks and space-based broadband.

**Earth Observation:** A range of satellites equipped with a variety of sensors that can be used to observe our Earth for weather forecasting, climate and environmental monitoring as well as disaster response.

**Space domain awareness:** Both terrestrial and space based systems to be able to identify, track and monitor objects in orbit to enable situational awareness, and incident warning and management.

**Human spaceflight: I**nvolves sending humans into space, which has so far included missions to the International Space Station, lunar landings, and plans for future Mars exploration. This field contributes significantly to scientific research, technological advancements, and international cooperation.

**Space science and exploration:** Science based missions which aim to enhance our understanding of our own planet, Solar System and our Universe by examining the space environment.

## The segments of space infrastructure:

To facilitate the functioning of the capabilities previously listed, space infrastructure is usually arranged into the segments of ground, link, space, launch and user. Each have unique systems involved

**Ground segment:** Terrestrial based systems, assets, structures and services that are required for operating space infrastructure. These include mission operation centres and uplink and downlink ground stations

**Link segment:** This involves the mediums through which facilitate the connection of other segments. This is typically electromagnetic spectrum, but developments are being made with optical connections.

**Space segment:** Involves either the individual or a constellation of satellites. A satellite consists of a number of systems to control its spaceflight activities and its payload, which delivers the service for which the satellite was placed in orbit.

**Launch segment:** Refers to the infrastructure required to enable the launch of a spacecraft from the Earth's surface into orbit.

**User segment:** This is a diverse segment which involves a range of systems and activities that utilises and benefits from the signals and services provided by space infrastructure. These include mobile devices, such as a satellite phone and GPS receivers, to satellite TV receivers to the systems and professionals who analyse earth observation data.

*Figure 1* Exemplar image of space architecture, satellite communications

# The Climate Change risks that Space faces

This section will outline how our terrestrial and space environments are linked and how the current and projected changes can impact the operation of space activities and the space economy.

## Link between terrestrial and space environments

Space is often perceived as a domain unconnected from our terrestrial environment, where satellites seemingly orbit untethered and wirelessly beam down the services we have become dependent on as highlighted in the previous section. However, to facilitate these operations a complex array of ground systems are required in order to command, control and communicate with those satellites. To place satellites into orbit, they are first required to be built in and launched from terrestrial facilities. The Space Industry Regulations 2021 places a duty on launch operators to monitor meteorological conditions during activities.

Additionally, the growth of number of satellites has been in low Earth orbit (LEO). In the lower reaches of LEO (altitude of <500km) over a third of satellites operate which is within the Earth's upper atmosphere, the thermosphere. There is increasing understanding that changes in the lower atmosphere layers impacts the upper layers and thus influences the environment satellites operate in.

## Impacts to space infrastructure

### *Ground segment*

**Storm-force winds** can lead to large dish-antennas being taken out of nominal operational parameters and having to be placed in their stowed position until the wind speed has dropped to a safe working level. In extreme conditions, damage can be incurred with ground systems and where specialist equipment has been affected repairs can be subjected to long lead times. This can cause leading to the loss of data and facilitation of linking with a passing satellite, which can only be achieved in a specific scheduled window.

**Extreme heat** can strain electronic components of ground systems leading to possible damage and failure. This includes motors used to manoeuvre antennas and the digital infrastructure of radio equipment, data processing and storage systems. Another issue that warmer operational environment of radio equipment increases the *noise temperature* of the system which can impact the ability to detect weaker signals (particular issue for deep space missions), where operators will have to invest in cryogenic cooling equipment to ensure effective operations.

**Flooding and wildfires** pose a risk to the integrity of buildings and ground systems where they are situated in vulnerable locations. Where such are compromised, this could lead to impacts of being unable to perform space activities.

*Link segment*

**Heavy rain** has the effect of increasing signal attenuation and more dispersion of the data being downlinked. This is particularly at the case of higher frequencies, with the CCRA3 Technical Report citing frequencies of 5 GHz and above being at risk, in which there is a range of allocated applications for space.[3] This can be the difference between the data being received from satellites being useful or corrupted. GNSS signals (i.e. GPS, Galileo) are transmitted on frequencies between 1-2 GHz and as such are less susceptible to rain attenuation.

*Space or Orbital segment*

**Atmospheric carbon dioxide ($CO_2$) concentration** is being shown through a number of studies and modelling techniques to impact the upper layers of Earth's atmosphere leading to cooling and a reduction in density.[4] The implications of this is there is less drag on satellites that orbit within the thermosphere (altitude <600km) leading to extended lifetime of objects, including debris items, leading to an increased risk of collisions. This compounds another growing risk in the sector of the accelerating number of satellites operating in low Earth orbit, the large number of debris in orbit and the risk of objects colliding.

*Launch segment*

Launch operations are subject to a **range of weather parameters** that have to be strictly adhered to for safe operation of flight.[5] These include considerations of temperature, humidity, air pressure, precipitation and visibility, wind speeds, lightning, and cloud cover.

**Sea level rise** pose a risk to overseas launch sites which many of space actors, including the UK, rely upon where infrastructure has been constructed near to vulnerable coastlines. These include sites such as the John F. Kennedy Space Centre and Cape Canaveral sites in Florida which by 2100 is projected to be subjected to chronic inundation.[6]

With increasing activity in the space economy involving more satellites, this requires access to more frequent launches. Disruption to this can have knock on effects to the availability and scheduling of satellite launches which will have an influence on the wider supply chain.

[3] UK Frequency Allocation Table, Ofcom (2022)

[4] In conversation with Dr. Matthew Brown, Space Environment & Radio Engineering, University of Birmingham (November 2024). See also Climate change to increase lifetime of space pollution, British Antarctic Survey (2022).

[5] Falcon 9 Crew Dragon is subject to 14 weather criteria for launch. See NASA Facts.

[6] Future Flood Risk: John F. Kennedy Space Centre & Cape Canaveral Air Force Station, Climate Central (2019)

### *User segment*

Similar to the ground segment, **extreme weather** events can impact on the structures and systems that are operated by users to utilise the signals and data from space infrastructure.

Whilst space capabilities enhance the ability to monitor and predict the development of **wildfires**, where there is heavy smoke plume this can impact the useability of data captured by earth observation satellites. The smoke can obscure images and the ability to see the fire itself, and in the case of damage assessment. With the extent of recent wildfires the smoke plume can also impact quality of images within a large area.[7]

### *Interdependencies*

Modern infrastructure is increasingly becoming complex and interconnected, with systems being reliant on others for their functions, including across infrastructure sectors. Space is reliant on key terrestrial based infrastructure to allow it to operate. As such, climate change impacts to these systems can lead to cascading impact on the activities of space.

**Energy sector** is needed to provide power for the operation of the ground and user equipment. Disruption to power networks could lead to key space infrastructure sites unable to monitor and control their satellites and provide uplink/ downlink services.

**Telecommunication networks** are needed to connect operators to remote ground stations and to connect ground terminals into terrestrial networks (i.e. connection to the internet).

## Global risk

**Space is a global network** and, in most cases, now require on connections spanning the globe to facilitate the operation and dissemination of space-based services. Consequently, climate change impacts in overseas locations can impact the integrity of space capabilities for the UK.

As well as the operational impacts, space is reliant on a **global supply chain** for critical minerals, semiconductors and other components. Climate change is projected to impact this area and as such the designing and building of space infrastructure will be affected.

[7] Advances in Satellite Data for Wildfire Smoke Forecasting, Eos (2019). See also Canadian wildfire smoke dims the vision of Earth-observing satellites, Space.com (2023).

# Climate Adaptation Risks

The intention of this report is to provide an initial exploration of the possibility of impacts to space infrastructure from climate change and whether there are merits in further work. It has not been informed by detailed analysis of data and extensive stakeholder engagement and as such is limited in the depth of recommendations it can offer.

The information that this report has interacted with does closely align with risks, concerns and need for action in relation to infrastructure that was found in the CCRA3. Specifically, there was close alignment found with the risks identified to the telecommunications and ICT sector. Table 1 displays CCRA3 risks related to those identified in the previous section, the measure of actions required to equip the sector for anticipated impacts and their relatability to space sector.

*Table 1* Telecommunications and ICT risks from CCRA3

| Risk number | Risk description | Urgency Score | Relatability to Space |
|---|---|---|---|
| I1 | Risks to infrastructure networks (water, energy, transport, ICT) from cascading failures | More action needed | Disruption to terrestrial power and telecoms network can cascade impacts to operations of space infrastructure. |
| I2 | Risks to infrastructure services from river and surface water flooding | More action needed | Ground based systems can be disrupted and damaged from flooding. |
| I3 | Risks to infrastructure services from coastal flooding and erosion | Further investigation | Minimal impact in UK, but number of key overseas launch sites space economy is reliant on are at risk. |
| I7 | Risks to subterranean and surface infrastructure from subsidence | Further investigation | Ground based infrastructure at risk if developed on vulnerable location. |
| I13 | Risks to digital from high and low temperatures, high winds and lightning | Further investigation | Extreme weather events can take equipment out of nominal operational parameters and can lead to loss of function and damage. |

The relatability of space to telecommunications is expected with space systems being essentially a communication network albeit routed through satellites. There is yet to be an explicit assessment on the likelihood and impact of climate drivers on space infrastructure. However, having established the relatability to the Telecommunications and ICT reports, we can use the assessments to deduce a loose understanding of the level of risk to the space sector.

## The level of risk

At present, the greatest concern of climate change impacts to space infrastructure is through its dependencies on other terrestrial systems, principally energy and telecommunications. Of the climate driver risks described in Table 1, for both the energy and telecommunications sector vary slightly with the latter having a slightly lower level of risk. With climate projections for 2050 and beyond, the level of risk to the sectors do rise notably meaning that there is greater chance of disruption by cascading impacts. What complicates this assessment further is that the understanding of these interdependencies is considered to be "significantly underestimated".[8]

The CCRA3 outlines how the significant risk pathways for infrastructure lie with increased summer temperatures and extreme winter rainfall.[9] Specific to the telecommunication sector, the level of concern from direct impacts is of concern, with the greatest level currently around the integrity of fixed infrastructure. This increases from present to the future as more flooding and severe weather events are projected to occur.

*Table 2* Level of Risk to Telecommunications sector

| | | Level of risk to Telecommunications[10] | |
|---|---|---|---|
| **Risk** | **Risk description** | **Present** | **2050+** |
| I1 | Risks to infrastructure networks (water, energy, transport, ICT) from cascading failures | High | High |
| I2 | Risks to infrastructure services from river and surface water flooding | High | High |
| I3 | Risks to infrastructure services from coastal flooding and erosion | Medium | Medium |
| I7 | Risks to subterranean and surface infrastructure from subsidence | Low | Medium |
| I13 | Risks to digital from high and low temperatures, high winds and lightning | Low | Medium |

[8] CCRA3: Telecoms and ICT Sector Briefing
[9] See CCRA3 Technical Report Chapter 4: 4.2.1.2.1
[10] See Footnote 9 for source of definitions.

From this assessment, it can be said that equally space system operators' short term concerns should focus on the risks from flooding and understanding the risks from cascading failures as a result of disruption to energy and telecommunication networks. Looking into the future, a more holistic approach is needed to consider all the climate drivers identified in Table 1. With infrastructure often designed and built for a medium to long-term lifespan, any immediate plans for new systems will need to consider the risks posed by their projected evolution.

Climate change is a global risk and as previously presented, space is a global infrastructure. The scope of this report only engaged with the detailed projections and impacts for the UK. However, in addition to the view herein outlined the global impacts need to be considered as to the likelihood and level of impact it will have on the internationally dispersed elements of space systems.

## Actions in response to the risk

At this stage there is insufficient analysis for this report to deliver specific recommendations of actions needed within the space sector to prepare for the impacts of climate change. Having presented the similarities of risks to space systems with other sectors, it would be prudent for space actors to consider the suggested adaption activities and apply, where appropriate, to their infrastructure and activities.

Considering the detail this report has explored; the following activities are suggested to develop a more fuller assessment of the risk and action needed for the space sector. This is with the view of providing a more thorough report at the next ARP round.

**Activity 1:** Ensure the space sector, being a sector of CNI, is considered within future programmes of work assessing infrastructure resilience and interdependencies.

**Activity 2:** Create a community of interest on the intersection of climate change risks and space infrastructure, consisting of policymakers, industry and academia.

**Activity 3:** Develop understanding of the interactions between space infrastructure and weather variables, i.e. collate data on nominal operational parameters.

**Activity 4:** Deliver a programme of work to assess the likelihood and level of impact of current and projected climate change models.

# Conclusion

The UK Space Agency are not operators of space infrastructure but are the UK's government body responsibly for nurturing and supporting sustainable growth and responsible activities of the UK's space ecosystem. This involves identifying and mitigating the risks to the sector.

Space systems are crucial to our understanding of changing climate as they provide much of the data required to inform the science. However, no explicit consideration has been given to how space operations could be impacted by the risk of climate change.

This report presents space infrastructure as a key set of systems located on the ground and in orbit which facilitates many functions of our modern societies and economies. Through exploration of literature there were found to be a number of climate change risks that has potential to impact activities of space infrastructure. These impacts are viewed to be low risk in the present, but do escalate with the projected climate change.

This report found there is merit for further work to understand the intersection of climate change impacts and space infrastructure. Four activities are provided as a suggestion to foster work in this area in order to provide a fuller report in the next round of ARP reporting.

# Annex A: Summary of risks to space infrastructure from climate-related hazards

This table provides a summary of how climate hazards have the potential to impact space infrastructure, with the associated segment identified.

*[G=Ground; Li=Link; S=Space; La=Launch; U=User]

| | | Infrastructure Segment* | | | | | |
|---|---|---|---|---|---|---|---|
| **No** | **Hazard** | **G** | **Li** | **S** | **La** | **U** | **Potential Consequences** |
| **Climatic** | | | | | | | |
| **1** | Extreme winds | x | | | x | | Damage to ground systems, including antennas<br><br>Take ground systems out of nominal range, unable to operate which result in missing link opportunities with passing satellite<br><br>Launches unable to happen if beyond safe limits |
| **2** | Extreme heat | x | | | x | x | Strain and potential damage of electrical equipment which is unable to be cooled<br><br>Present technical challenge in ability to detect weak signals due to system noise temperature<br><br>Launches unable to happen if beyond safe limits<br><br>Health impact to workforce |
| **3** | Flooding (fluvial and coastal) | x | | | x | | Limiting access and damage to ground sites required for space operations<br><br>Current coastal launch sites potential at risk of projected sea level rise. |
| **4** | Wildfires | x | | | | x | Limiting access and damage to ground sites required for space operations<br><br>Heavy smoke concentration obscuring images, degrading quality |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5 | Heavy, sustained rainfall | | x | | x | | Increased signal attenuation (>5 GHz at more risk) leading to disruption of data links.<br><br>Launches unable to happen if beyond safe limits |
| 6 | Increased atmospheric carbon dioxide concentration | | | x | | | Change in density of upper atmosphere, impact to orbital dynamics, increase risk of collision |
| **Interdependencies** | | | | | | | |
| 7 | Telecommunications | x | | | x | x | Disruption to management of satellites and access to services |
| 8 | Energy | x | | | x | x | |
| 9 | Global networks | x | x | x | x | x | Disruption to management of satellites and access to services<br><br>Supply chain impacts, interrupting production and replacement of space infrastructure |