Global Future Council on Space

Space for Net Zero

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Executive summary

Satellites are critical to monitoring greenhouse gas emissions. A new way of analysing and displaying all the data in one place is vital to helping the global community deal with climate change.

Climate change is one of the greatest global challenges facing humanity. Achieving net-zero greenhouse gas (GHG) emissions has been recognized as critical to mitigating some of climate change's worst impacts.

Remote sensing satellites have increased the fidelity of people's understanding of Earth system science and the evolution of the planet's climate, helping to measure different climate change indicators. Satellite measurements of air and sea surface temperatures and of sea levels, as well as other space-based observations, reveal important consequences of a warming, changing world.

A key measure of anthropogenic sources of climate change is the emission of GHGs. Of all the long-lived GHGs from human activities, carbon dioxide and methane have the largest impact on the climate. Satellites are critical to monitoring atmospheric concentration of both gases, and new satellites are planned in the near future.

While satellites provide vital data, gaps remain in modelling, mitigation and coordination. Currently, five satellites (Greenhouse Gases Observing Satellite (GOSAT), GOSAT-2, Orbiting Carbon Observatory (OCO)-2, OCO-3 and Sentinel-5P) measure these gases with the precision, accuracy, resolution and coverage needed to track GHG emissions globally. Improved understanding and response can result from a holistic analytic approach that, for example, facilitates integrating space, airborne and ground-based observations, combining civil and commercial capabilities, and managing markets for emission data.

Hundreds of organizations conduct research into relevant climate change processes, but an organization has yet to be established that is dedicated to the continual and integrated development of the two core modelling fields – Earth systems modelling and economic engineering modelling – and to embedding their results in a physical visualization environment that can inform and shape decision-making. The time has come to build a new type of decision-support facility: an Earth Operations Centre that leverages space data and expertise to conduct multidisciplinary science and engineering research, and to successfully manage and coordinate net-zero efforts.

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1 The net-zero challenge

Achieving a balance between anthropogenic GHG emissions produced and removed from the atmosphere would be a critical milestone in mitigating the worst impacts of climate change.

> To achieve long-term temperature goals, a limited global "GHG budget" of allowable cumulative emissions must be respected to avoid overshooting 2˚C and destabilizing the global climate.

The World Economic Forum has called climate change "one of the greatest global challenges the world has ever faced".[1] For the last three years, climate threats have occupied the top three spots of the World Economic Forum *Global Risks Report* as the most likely risks facing humanity within the next decade.[2] The Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6) in 2021 has made the significant extent of that risk clearer than ever.[3]

Achieving a balance between anthropogenic greenhouse gas (GHG) emissions produced and removed from the atmosphere (net zero) has been recognized as a critical milestone in mitigating the worst impacts of climate change. Until that milestone is reached, each year will see yet more GHG emissions, which will further heat the planet and increase the potential for climate shifts with catastrophic human consequences.

The consensus, reinforced by the Paris Agreement, is that global warming needs to be limited to well below 2˚C, preferably to 1.5˚C, compared to pre-industrial levels, and to achieve carbon neutrality (net-zero emissions) by mid-century. The state of global warming reports from 2020 (by NASA Goddard Institute for Space Studies, National Oceanic and Atmospheric Administration [NOAA], Copernicus Climate Change Service, Berkeley Earth) show a median increase of 1.2˚C today. The science has made it clear not only that anthropogenic sources of GHGs dominate the increasing changes in climate, but also that some warming and sea-level rise is, at this point, inevitable.[4]

To achieve long-term temperature goals, a limited global "GHG budget" of allowable cumulative emissions must be respected to avoid overshooting 2˚C and destabilizing the global climate.

The IPCC concluded in 2018 that for a reasonable chance of limiting warming to 1.5˚C by 2030, the world must halve GHG emissions and reach the net-zero goal by mid-century. Current national pledges – even the most ambitious established through the Paris Agreement, which may or may not be realized – are not on track to achieve this. Further, the recently published AR6 provides new estimates regarding the chances of crossing the global warming level of 1.5˚C in the next decades, and finds that "unless there are immediate, rapid and large-scale reductions in GHG emissions, limiting warming to close to 1.5˚C or even 2˚C will be beyond reach […] This assessment is based on improved observational data sets to assess historical warming, as well as progress in scientific understanding of the response of the climate system to human-caused greenhouse gas emissions".[5] Humanity is, in short, a long way away from controlling the rise in global temperature and it is necessary to move rapidly towards achieving net-zero global emissions.

The World Economic Forum is fostering pathways for a future zero-carbon economy through participation in the Mission Possible Partnership, an alliance of climate leaders focused on decarbonization of high-emitting industries. Through this and other initiatives, the Forum aims to improve the state of the world by integrating global efforts that range from action on climate change to transition to safer and cleaner transportation.[6]

The Forum recognizes that space technologies play a critical and increasingly visible role in supporting the planetary management of climate change and achieving and maintaining global net-zero emissions. This paper, produced by the World Economic Forum Global Future Council on Space, describes the contribution of space-based observations to the discipline of Earth system sciences and to the monitoring of essential climate variables, and describes some of the gaps in modelling, mitigation and coordination. The paper explores the potential for an Earth Operations Centre to address those gaps and improve progress towards net zero, assisting with systems trade-offs at a global level and becoming a decision-making platform for world leaders.

Below: @sergeyxsp/Gettyimages

2 The role of space technologies in getting to net zero

More than 50% of essential climate variables are measurable only from space.

Space science has played a foundational role in understanding the processes of global climate change. Earth science missions and remote sensing satellites have provided much of the baseline data that have allowed the monitoring and an understanding of the evolution of Earth's climate. More than 50% of essential climate variables (Table 1) are measurable only from space.[7] Many satellites[8] measure different weather, climate change and other properties of Earth, providing data on GHG emissions and insight into the consequences for all aspects of climate.

TABLE 1 **Essential climate variables measurable from space**

Domain	Essential climate variables
Atmospheric	Surface wind speed and direction; precipitation; upper-air temperature; upper-air wind speed and direction; water vapour; cloud properties; Earth radiation budget; carbon dioxide, methane, and other long-lived GHGs; ozone and aerosol properties
Oceanic	Sea-surface temperature; sea-surface salinity; sea level; sea state; sea ice; ocean colour
Terrestrial	Lakes; snow cover; glaciers and ice caps; ice sheets; albedo; land cover; fraction of absorbed photosynthetically active radiation; leaf area index; above-ground biomass; fire disturbance; soil moisture

Source: Global Climate Observing System, *Systematic Observation Requirements for Satellite-Based Data Products for Climate 2011*

2.1 Seeing earth as a system from space

In the 1980s, as part of its Earth science space programmes, the National Aeronautics and Space Administration (NASA) of the United States developed a new model of Earth as an integrated system-of-systems. The model, named the Bretherton Diagram for its primary architect, Francis Bretherton, described Earth as a system, with inputs and outputs as well as interactions among all its elements: liquid water, ice, clouds, solar radiation, energy, biomass, GHGs and human activity. Building on this foundation through the 1990s and 2000s, a new discipline of science emerged – not just the study of the oceans or atmospheric chemistry, or of solar radiance and reflection, but the integrated study of the interaction and relationship between all these elements: the discipline of Earth system science.

“ Satellites provide a critical perspective to Earth system science that can help in understanding Earth's integrated system-of-systems and the consequences of not getting to net zero.

Since then, Earth science satellites from space agencies around the world have, mission by mission and year by year, increased the fidelity of our understanding of Earth system science. The satellites have led to the realization, with increasing certainty, of both the risks that increased GHGs in the atmosphere represent and the necessity for getting to net-zero GHG emissions to stabilize the climate.

The next five years are vitally important for the future of Earth system science. New, pioneering missions are in preparation for launch. At NASA, four important new Earth science missions arising from the 2007 Earth Science and Applications from Space (ESAS) decadal survey are set to launch before 2025. These missions will measure various aspects of climate change:

– **The Surface Water Ocean Topography mission**, scheduled for launch in 2022, will provide fundamental worldwide observations of changing water levels, slopes and flood extents in rivers, lakes and floodplains.

– **NISAR (NASA-Indian Space Research Organization Synthetic Aperture Radar)**, formerly DESDynI, is a collaborative NASA-Indian Space Research Organization radar satellite mission scheduled for 2022 that will "determine the contribution of Earth's most variable biomass to the global carbon budget and characterize ecosystem disturbance and impacts on biodiversity".[9]

– **The Climate Absolute Radiance and Refractivity Observatory (CLARREO) Pathfinder Mission**, scheduled for launch to the International Space Station (ISS) in fiscal year 2023, will help prepare for the foundational CLARREO mission that will provide vital calibration of solar radiance measurements, a primary input into climate models.

– **The Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission**, set for launch in 2024, will improve understanding of how the ocean and atmosphere exchange carbon dioxide, including through algal blooms.[10]

Beyond these, what can be expected from future NASA Earth science missions? The current Earth science decadal survey[11] (ESAS 2017-2027) recommended continued support to these and other programmes of record, and designated five priority areas for targeted observations: aerosols; clouds, convection and precipitation; mass change; surface biology and geology; and surface deformation and change.[12] In May 2021, the US White House announced a new concept for a NASA Earth System Observatory to address the five areas of focus established by ESAS 2017.[13] Beyond these top priorities, ESAS 2017 recommended the creation of Earth System Explorer, a new line of missions within NASA's Earth Science Division consisting of three missions focused on one or more of the following areas: atmospheric winds, GHGs, ice elevation, ocean surface winds, ozone and trace gases, snow depth and amount, and land ecosystems.[14]

Other agencies, such as the Japan Aerospace Exploration Agency (JAXA) and the European Space Agency (ESA), have also been active in the field of Earth science satellites. JAXA's GOSAT-2 mission was launched in 2018, a follow-on to GOSAT from 2009. JAXA's next generation greenhouse gas-monitoring mission, GOSAT-GW, is scheduled for 2023. ESA launched the Copernicus Sentinel-5 Precursor mission in 2017, carrying the TROPOspheric Monitoring Instrument (TROPOMI). ESA is also planning the Copernicus Carbon Dioxide Monitoring mission (CO2M).

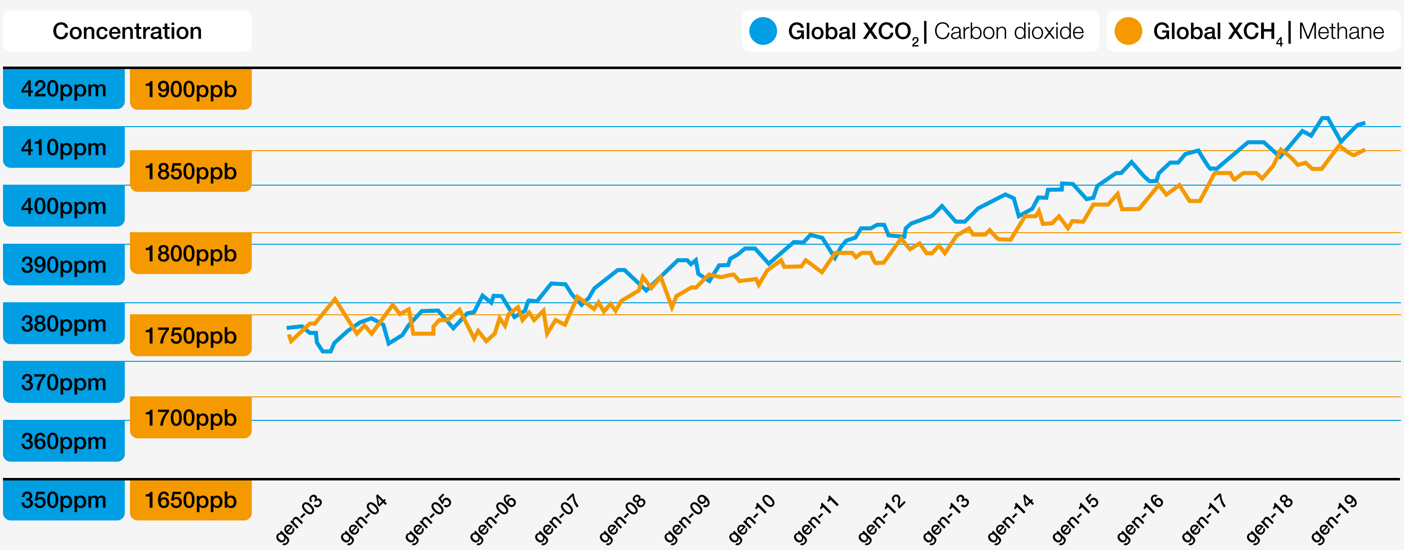
The Copernicus programme has also helped provide continuous monitoring of sea levels since 1992 with the Topex-Poseidon satellite, followed by the Jason/Sentinel satellite series, which saw its most recent satellite launched in 2020 with another scheduled for launch in 2025. Currently under development in China, the LIBRA Earth observation satellite project exemplifies how the world is moving to global coordination in response to the critical importance of climate change science observations.

Satellites provide a critical perspective to Earth system science that can help in understanding Earth's integrated system-of-systems and the consequences of not getting to net zero. They are also one of the most important tools for directly measuring GHG emissions.

2.2 The importance of monitoring GHG emissions

Continuous, high-resolution global measurements of GHGs are critical for understanding climate change. GHG emissions began rising dramatically in the 1800s due to the Industrial Revolution and changes in land use.[15] Anthropogenic sources of GHGs include combustion of fossil fuels, deforestation, fertilizers, livestock farming and landfills. According to Copernicus, the European Union's (EU) Earth Observation Programme, "of all the long-lived greenhouse gases emitted by human activities, the ones that have the largest climate impact are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)".[16] Satellite data (Figure 1) show that atmospheric concentrations of CO_2 and CH_4 are increasing at annual average rates of 0.6% and 0.4%, respectively. Satellites cannot currently measure N_2O as accurately.[17]

FIGURE 1 **Global carbon dioxide and methane, 2003-2019**



Note: ppm = parts per million; ppb = parts per billion
Source: European Space Agency, ESA climate office, "Climate Change: The Evidence from Space: Satellites provide critical lines of evidence for climate change", https://climate.esa.int/en/evidence/observations-change (accessed 23 August 2021)

CO_2 Carbon dioxide

CO_2 is a naturally occurring gas important for life on Earth. Sharp increases or decreases, however, can influence its atmospheric balance and alter the global climate. The Earth system maintains a check and balance on CO_2 through the carbon cycle, the process in which large fluxes of CO_2 travel between the atmosphere, land biosphere and oceans through sources and sinks. The fraction of anthropogenic carbon release not reabsorbed by the Earth system has increased concentration of atmospheric CO_2 by more than 50% above pre-industrial levels of 280 ppm.[18] According to NOAA measurements, the global average atmospheric CO_2 concentration in 2020 was 412.5 ppm, an increase of 2.6 ppm compared to 2019.[19] Increased levels of anthropogenic CO_2 are widely believed to be the primary driver of climate change.[20] While other gases such as methane have more potent heat-trapping ability on a molecule-by-molecule basis, they are far less abundant and have a shorter lifetime in the atmosphere, so they have a smaller impact on the climate.

The carbon cycle is complex, with many natural sources of CO_2 including oceans, decomposing biomass and venting volcanoes. These are offset by sinks like photosynthesis and ocean absorption. Carbon exchange varies seasonally; net carbon uptake by plants occurs during spring and summer, while in the fall and winter, photosynthesis declines in the middle and upper latitudes, and plant respiration exceeds photosynthesis, returning CO_2 to the atmosphere.

While Earth can cycle through naturally occurring CO_2, it cannot fully absorb all the additional carbon dioxide build-up generated by human activities since the Industrial Revolution. According to an article published in *Science*: "The uptake of CO_2 from the atmosphere into the land and oceans constitutes between 20 and 80% of CO_2 emissions from fossil fuel and land use change and is ~50% on average. […] Measurements of the increasing inventory of carbon in seawater indicate that almost a quarter of the CO_2 emitted by human activities is being absorbed by the ocean, where it contributes to ocean acidification. […] another quarter of the CO_2 emitted by human activities is absorbed by processes on land."[21]

The article continues: "The efficiency of these natural land and ocean sinks also appears to vary dramatically from year to year. Because the identity, location, and processes controlling these natural sinks are not well constrained, it is not clear how they will respond in the future."[22] As a result, it is critical to have a holistic view of how carbon content is increasing in the atmosphere, how much is due to human activities relative to the natural cycle, and how the carbon cycle may amplify or mitigate future climate change.

Today, an international network of ground-based GHG measurement stations in the World Meteorological Organization's Global Atmospheric Watch and the Total Carbon Column Observing Network provide precise measurements of atmospheric CO_2 concentration from over a hundred locations. Their coverage, however, is too limited to provide a complete global picture. Observations from various satellite instruments have been analysed to estimate the abundance of atmospheric CO_2. These estimates are not as accurate as those from the ground-based network but complement those data with much greater special resolution and coverage. Efforts that combine data from satellites and the ground-based network could provide the global, multi-variable, interlinked system for monitoring GHG emissions and attributing their origins.

CH_4 Methane

As noted, methane is a more potent per-molecule GHG than CO_2 (84 times more potent over a 20-year period), with a shorter atmospheric residence time. Reducing methane emissions can have a greater short-term impact on warming, as work continues to find longer-term solutions to reducing CO_2.

According to the International Energy Agency, a 75% reduction in methane emissions from the energy sector would be possible if all options for methane emissions abatement were deployed across the oil and gas sectors.[23] (Satellite observations have been made of methane from US energy-producing regions; see Figure 2.) Instead, however, an unexpected increase in methane concentrations has occurred since 2007.[24] Three main interrelated causes have been proposed:

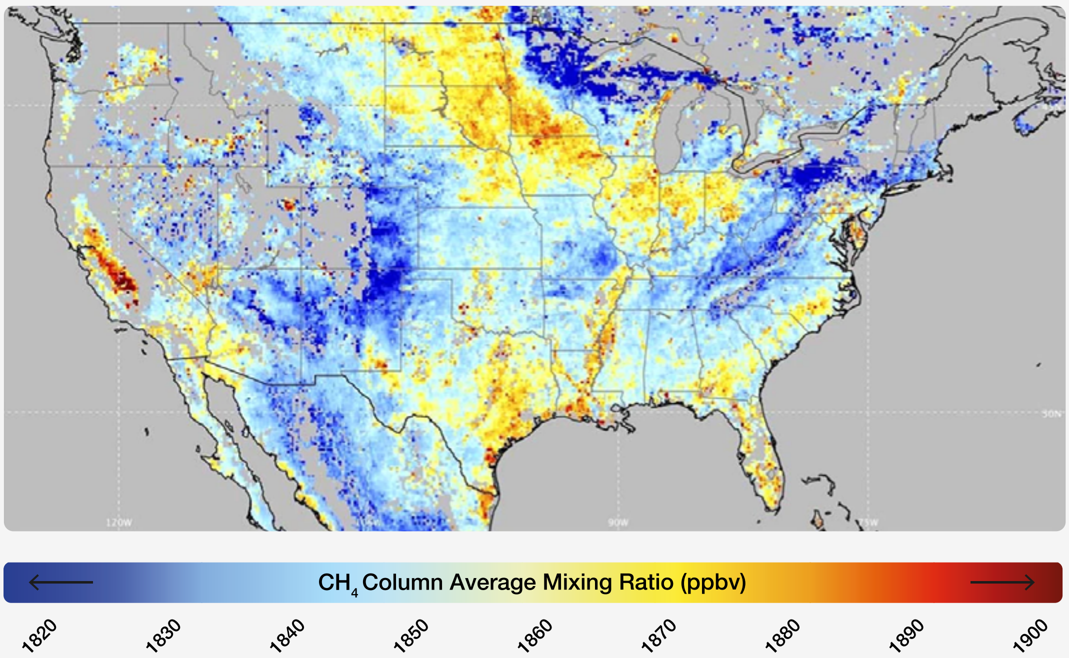
- **Increased anthropogenic emissions** primarily from the fossil fuel industry, likely due to rapid growth in fracking and deregulated emissions in the United States and to coal mining in China[25]
- **Increased natural emissions** from melting permafrost, wetlands and flood zones
- **Reduced capacity of methane sinks**: "Changing hydroxyl radical (OH) concentration in the atmosphere, caused by other atmospheric pollutants, means that natural sinks may not be as efficient at breaking down atmospheric methane."[26]

As a result, the number of satellites focused on methane measurements has risen in recent years, and many are planned in the near future.

Public-sector satellites, such as Japan's GOSAT and GOSAT-2, and the Copernicus Sentinel-5 Precursor TROMPI, are focusing on regional-scale global measurements. Private-sector efforts are focused on surveying "super-emitters", which are responsible for an outsized share of total emissions. In 2017, the Environmental Defense Fund (EDF) measured methane emissions, comparing top-down (airborne measurements of ambient concentrations) with bottom-up (ground-based emissions inventory) estimates. The EDF found that "1% of natural gas production sites accounted for 44% of total emissions from all sites, or 10% of sites 80% of emissions".[27] These super-emitters therefore represent the easy targets that the GHG observation community can initially prioritize for monitoring. Satellites have the potential to support a holistic picture of these super-emitters, which are typically coal mine vents, abandoned natural gas wells and gas distribution networks.

FIGURE 2

Daily satellite observations of methane from US oil and gas production regions
1 December 2018-31 March 2019



From TROPOMI sensors over the United States

Note: ppbv = parts per billion by volume

Source: de Gouw, Joost A., et al., "Daily Satellite Observations of Methane from Oil and Gas Production Regions in the United States", *Scientific Reports*, vol. 10, no. 1379, 2020, https://www.nature.com/articles/s41598-020-57678-4 (accessed 21 August 2021)

2.3 Satellites that monitor GHG emissions

The first space-based sensor that was sensitive to CO_2 and CH_4 near the surface, where most sources and sinks are located, was the ESA Envisat SCIAMACHY instrument, which operated between 2002 and 2012. The first dedicated space-based GHG sensors were Japan's GOSAT, launched in 2009, and NASA's OCO-2 launched in 2014. These sensors were followed by GOSAT-2 in 2018 and OCO-3 in 2019.

The OCO-2 satellite collects global measurements with the needed precision, coverage and resolution to help resolve CO_2 sources and sinks on regional to global scales. Estimates of atmospheric CO_2 concentrations derived from OCO-2 measurements have been validated against ground-based measurements and used to derive estimates of CO_2 emissions. As sunlight passes through the atmosphere and is reflected back to the satellite, CO_2 and other gases absorb a distinct set of frequencies or colours of this light, which provides an identification fingerprint for each gas. The OCO-2 sensor measures the sunlight's intensity at the frequencies partially absorbed by CO_2 and molecular oxygen. This information is analysed to estimate the concentration of CO_2 and its variations with location and time.

Both human activities and natural processes can change atmospheric CO_2 concentrations over the daily cycle. OCO-3 addresses an important measurement gap by exploring, for the first time, daily variations in the release and uptake of CO_2 by human activities in large urban areas and by the natural biosphere, in areas including the major carbon systems of tropical rain forests of South America, Africa and South-East Asia, providing crucial data for explaining global variations in atmospheric carbon dioxide levels.

> These satellites will help to differentiate human-produced emissions of CO_2 from those originating from natural processes.

China's first GHG satellite, TanSat, was launched in 2016 to provide space-based estimates of the CO_2 distribution and its variation on seasonal time scales. Europe's Sentinel-5 Precursor, launched in 2017, measures several atmospheric trace gases, including methane. It will be followed by Sentinel-5A in 2023. These two Sentinels and the three-satellite CO_2 Monitoring (CO2M) constellation in 2025 will support the EU's Copernicus Atmosphere Monitoring Service, which estimates net fluxes of CO_2, N_2O and CH_4 on Earth's surface, as well as GHG emissions from biomass burning and wildfires. These satellites will help to differentiate human-produced emissions of CO_2 from those originating from natural processes, with the goal of helping EU Member States and other countries track progress in achieving the Paris Agreement and other decisions regarding the CO_2 budget. With its high spatial resolution (2 km by 2 km) and global coverage, CO2M will allow scientists to pinpoint the exact source of emissions.

The Geostationary Carbon Cycle Observatory (GeoCarb) mission is scheduled to launch around 2024. From geostationary orbit (GEO), GeoCarb will monitor CO_2, carbon monoxide (CO) and CH_4, as well as plant health and vegetation stress across North, Central and South America, and will analyse the natural sources, sinks and exchange processes in the atmosphere. The NASA-funded instrument, to be launched on a yet-to-be-determined platform, will collect 10 million observations a day.[28] As a geostationary observatory, GeoCarb will complement measurements by existing carbon-measuring instruments in low Earth orbit (LEO) by filling in data gaps in time and space.[29] While satellites in low Earth orbits provide global coverage, they have long revisit times, large gaps in coverage, and usually observe the landscape at a fixed time of day.[30] By remaining over the same spot on Earth's surface, GeoCarb will enable observations of ecosystem transitions and biogenic processes that LEO satellites may otherwise miss, addressing certain unanswered questions in carbon cycle science, with a focus on the Americas.

Most GHG monitoring satellites have sensing capabilities over large areas, but limited resolution at the local level. The Canadian company GHGSat and the American non-profit Carbon Mapper aim to monitor GHGs at resolutions high enough to attribute emissions directly to individual facilities around the world. In 2016, GHGSat launched Claire, the first of a small satellite constellation dedicated to monitoring GHGs at resolutions of 25 m^2. GHGSat has three satellites in orbit and plans to have a constellation of ten by 2023. Carbon Mapper and its partners – the State of California, NASA's Jet Propulsion Laboratory, Planet, University of Arizona, Arizona State University, High Tide Foundation, and RMI – are developing a constellation of satellites with 30-metre resolution and daily revisit times, expected to be operational by 2025.

MethaneSAT, a subsidiary of the EDF, plans to launch an Earth observation satellite in 2022 that aims to fill a gap between point source and global mapping satellites. It will detect high-emitting point sources over a 200-km view path at a 400 x 130 m^2 resolution, covering a larger proportion of emissions but with less spatial granularity than point-source detectors.

These commercial and non-governmental GHG satellites (see list, Table 2) complement the observations made by satellites being deployed by public-sector space agencies. Government missions aim at long-term observations and creating baseline data on a global scale, and must meet the challenges of future verification of national reporting. Commercial observations, in contrast, generally aim at more specific markets, such as gas or mining companies requiring leak control, with business opportunities to commercialize relevant data products. Given government organizations' focus on global climate science and the carbon balance and analysis of large data sets, their instruments generally have coarse spatial resolution (for example, ESA's TROPOMI and Japan's GOSAT-2 at 7 km x 7 km and 10 km diameter, respectively) but much higher sensitivity. To achieve the high-resolution, high-revisit measurements needed to identify individual facilities, privately funded satellites offer finer resolutions but lower sensitivity to GHG concentrations (as mentioned, of note are GHGSat [25 x 25 m^2 resolution] and MethaneSAT [400 x 130 m^2 resolution]).

Below: @Art Wager/ Gettyimages

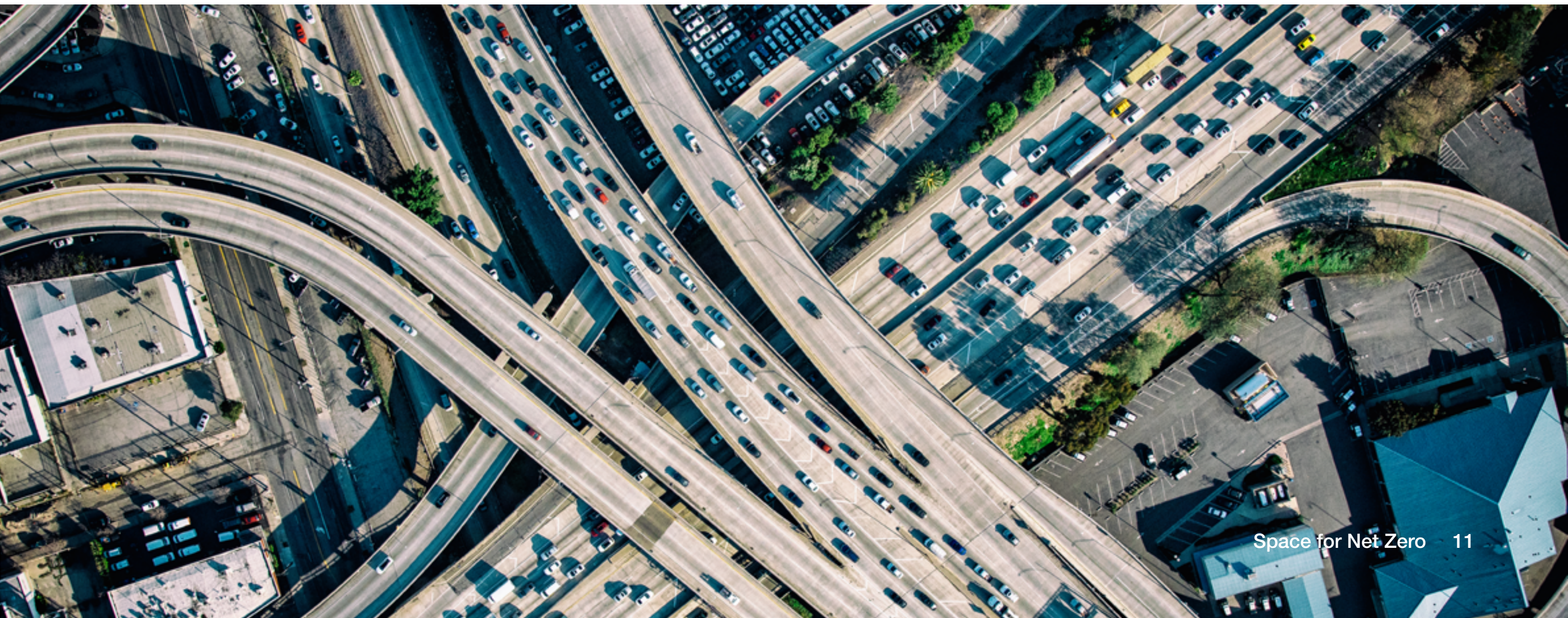


TABLE 2 | **Selected GHG monitoring satellites**

Satellite/instrument	Primary institution(s)	GHG-related measurements	Orbit	Launch date
GOSAT/Thermal And Near-infrared Sensor for carbon Observation-Fourier Transform Spectrometer (TANSO-FTS)	JAXA, Ministry of the Environment (MOE), National Institute for Environmental Studies (NIES) (Japan)	CO_2, CH_4	LEO/Sun-synchronous orbit (SSO)	2009
OCO-2	NASA (USA)	CO_2	LEO/SSO	2014
TanSat (CarbonSat)	Chinese Academy of Sciences (China)	CO_2	LEO/SSO	2016-2018
Sentinel-5P/ TROPOMI	ESA, Netherlands Space Office (Netherlands)	CO, CH_4, O_3, NO_2	LEO/SSO	2017
GHGSat	GHGSat (Canada)	CH_4	LEO/SSO	Constellation build-out expected 2016-2023
GOSAT-2/TANSO-FTS	JAXA, MOE, NIES (Japan)	CO, CO_2, CH_4, H_2O, O_3	LEO/SSO	2018
OCO-3	NASA (USA)	CO_2	LEO/ISS	2019
MethaneSAT	EDF (USA)	CH_4	LEO/SSO	Expected 2022
Meteorological Operational Satellite-Second Generation A (MetOp-SG A)/ Sentinel-5	ESA (Europe)	CO, CH_4, NO_2, O_3, SO_2	LEO/SSO	Expected 2023
Carbon Mapper	State of California, NASA, Planet, University of Arizona, Arizona State University, High Tide Foundation, RMI (USA)	CO_2, CH_4	LEO/SSO	Constellation build-out expected 2023-2025
GeoCarb	NASA, Lockheed Martin, University of Oklahoma (USA)	CO, CO_2, CH_4	GEO	Expected 2024

Source: BryceTech

Companies and space agencies around the world continue to invest in new operational systems to enable the global tracking from space of CO_2 and CH_4 emissions.

2.4 What satellites communicate about climate

> While satellites continue to demonstrate their critical value for tracking GHG emissions, the use of satellites can be far more effective in the future.

The combination of satellites measuring GHG concentration with other Earth-observation satellites and data sources has enabled scientists to monitor effects on climate. This helps to understand the consequences of not getting to net zero and to track the impacts of continued warming.

Satellite measurements of air and sea surface temperatures, sea levels and other space-based observations reveal a warming, changing world.[31] Many of the key observations from space used for constraining the weather system, such as the NASA Earth Observing System Aqua satellite, the Soumi-National Polar-orbiting Partnership satellite, the operational NOAA Joint Polar Satellite System and MetOp satellites, provide key climate quality data sets. Some of these satellites also host a Clouds and the Earth's Radiant Energy System (CERES) sensor, which is important for understanding the radiative balance of the climate system, and will soon be followed by the more accurate CLARREO-Pathfinder sensor to operate from the ISS. The equilibrium climate sensitivity (which is an estimate of how sensitive the overall climate is to a doubling of carbon dioxide) and the predicted sea-level rise for given levels of warming (of which the predicted extent of ice-sheet melting remains the largest uncertainty) are two vital Earth system science questions with direct implications for consequences of continued climate change.

Surges in atmospheric CO_2 and other GHGs have long been recognized as producing a warming effect; when combined, satellite records indeed show an upward trend in temperatures of the lower atmosphere, referred to as "global warming".[32] Temperature increases, in turn, contribute to sea level rise through melting ice and thermal expansion of water. As previously mentioned, continuous monitoring of sea levels has been enabled by the Copernicus programme's satellites since 1992. According to the director of NASA's Earth Science Division, "When we combine the data from instruments like the altimeter on Sentinel-6 Michael Freilich with data from other satellites like GRACE-FO and IceSat-2, we can tell how much of the sea level rise is due to melting ice and how much is due to expansion as the oceans warm."[33]

Satellites have provided a consistent microwave record of polar sea ice since the late 1970s. In the Arctic, this record shows an accelerating downward trend in sea ice extents that was apparent by the end of the 20th century and has accelerated since then.[34] Likewise, the global sea level rose approximately 20 centimetres in the last century and this rate is accelerating slightly every year.[35] As such, the first consequences which affect the climate are just beginning to be seen, since the mass of the atmosphere is more than 1,000 times smaller than that of the oceans.

During the COVID-19 pandemic, space agencies (NASA, ESA and JAXA) came together and built an Earth Observing Dashboard,[36] which included the impact of the COVID-19 pandemic on atmospheric CO_2. The data indicates that lockdowns and other social distancing measures implemented in response to the pandemic have led to temporary reductions in CO_2 emissions from human activities. It was also noted, however, that "initial studies suggest that although COVID-19-related CO_2 emission reductions are expected to slow the speed at which CO_2 accumulates in the atmosphere, they will not reduce the overall atmospheric concentration of CO_2".[37]

While satellites continue to demonstrate their critical value for tracking GHG emissions, achieving net zero and managing climate change, the use of satellites can be far more effective in the future.

2.5 Gaps in understanding and opportunities for more effective mitigation

> In the United States, no single organization can provide the US president with reliable insight into the complete system of emissions and mitigation.

Though satellites are critical to understanding and addressing GHG emissions and climate change, satellite data alone are not sufficient, and the use of data to drive insight and action remains inadequate. Gaps in modelling, mitigation and coordination are still struggling points.

In the United States, for example, no single organization can provide the US president with reliable insight into the complete system of emissions and mitigation, and reliably model where to shift the system to drive better outcomes. Globally, determining the distance to net zero is difficult. Current calculations for large fossil fuel extraction and transportation processes often rely on self-reporting and are not performed at a global level in a consistent manner; direct measurement provides better insight on the state of net emissions. The integrated use of existing data, additional sensors and the coordination of that global net-zero accounting function can provide information on where the world stands against the goal.

> A tiered remote sensing approach using satellite, airborne and ground-based sensors can improve local, regional and international understanding of GHG emission sources.

Where to find the worst offenders is not always clear. A holistic view of GHG emissions from multiple sensors can help to target the best uses of mitigation resources. A tiered remote sensing approach using satellite, airborne and ground-based sensors can improve local, regional and international understanding of GHG emission sources. Ideally, aircraft would be ready to perform detailed regional studies when satellites detect a particular event, with those measurements complementing in-situ readings on the ground, which provide constant localized coverage but are only useful if placed directly within a plume. Airborne and in-situ measurements can also provide readings during night-time, since satellite platforms relying on shortwave infrared sensors require sunlight to collect their measurements.

One example is an initiative to understand methane emissions from certain oil fields in Kern County, San Joaquin Valley, California. Detailed observations of three oil fields via this tiered process found that fields were leaking high levels of methane. Some steam injection wells (to enable fracking) were leaking at rates in excess of 200,000% above EPA estimates for the average leak rate of a gas well in the western United States.[38]

Integrating different sensor types can help operators globally find leaks, prioritize enforcement and consider mitigation for wells leaking at high rates; this can have a big impact. When oil or gas wells reach the end of their useful productive life, operators in California, for example, are required to decommission and plug wells according to state plug and abandonment regulations. When operators in financial difficulty have abandoned their oil and gas assets, the responsibility to plug these orphan wells has fallen to the state. According to a 2017 study by the California Council on Science and Technology, about 122,000 of the state's approximately 229,000 oil and gas wells have already been plugged. The Council's 2018 report estimates that roughly 5,540 wells could already be at risk of becoming orphaned, and another "69,425 economically marginal and idle could become orphan wells in the future as their production declines and/or as they are acquired by financially weaker operators".[39] Extrapolating from California's experience of methane super-emitters and leaking wells suggests the potential for meaningful mitigation by focusing on the worst sources in other areas as well.

Similarly, a tiered approach to sensor data among satellite types can increase efficiencies. For instance, observations can start to look for super-emitters at the regional level through kilometre resolution instruments (typically government systems), and then home in on individual facilities through finer resolution instruments (potentially offered commercially).

Another opportunity for improvement comes with managing market dynamics to incorporate commercial data into policy decisions. Given the diverse actors engaged in building GHG satellites, their approaches to data policy vary. Government-funded missions, such as TROPOMI and GOSAT-2, already offer free and open data to the public. Carbon Mapper, as a dedicated non-profit, will also make the methane data produced by its new constellation of satellites, built by Planet, available free to the public, as will MethaneSAT, given its sponsorship by the non-profit EDF. GHGSat and Bluefield, the two main commercial entities currently pursuing LEO constellations, intend to make their data available to paid subscribers. GHGSat, however, imposes additional constraints on data usage, restricting subscribers' ability to publicly identify individual emitters. Market demand for GHG measurements spurred these players to innovate at the sensor level and pursue GHG measurement through privately owned satellites and constellations.

A key policy issue is how governments can continue to incentivize the development of GHG measuring instruments and satellites. A number of approaches should be explored, ranging from non-dilutive grants to private non-profits and companies committed to providing open and transparent data, to guarantees where governments can be buyers of last resort of this data.

Given innovations in instruments and other areas, striking a balance between maintaining government programmes and helping to shape a market for GHG emission data can be in the public interest. As additional organizations enter the marketplace, the price of emissions data will gradually drop, and the fidelity of insights that can be gained from integrating all GHG measurements will increase. This is particularly important to ensure any forthcoming regulations mandating the use of GHG measurements from orbit will not penalize smaller players and asymmetrically advantage larger corporations capable of affording their own constellations or securing access to high-priced data.

Satellite internet of things (IoT) constellations can be a significant enabler in this area too, with emissions data able to be collected by sensors on the ground and transmitted globally. Communications satellites can help to actively monitor and reduce emissions by allowing real-time access for numerous business and consumer IoT applications for the purposes of increasing operational efficiency and minimizing energy and fuel consumption.

To identify effective mitigation approaches using a full range of policy, economic, market, technology and science tools, a focal point is needed for coordinating local, regional, national and international action. Better integrating different data sources, different mission types and different organizations is needed. A way to align plans and policies, to coordinate programmes and to get the best results out of mitigation actions is also needed.

To close these gaps, this paper proposes a new type of climate change organization – one that builds on the iconic moonshot success of the past.

Below: @Phil McCarten/Reuters

3 Earth Operations Centre

Building an EOC may be one of the most important contributions the global space community can make to achieving net-zero GHG emissions.

NASA's Mission Control Center was a product of one of the greatest challenges of the 20th century – sending humans to the surface of the Moon. The challenge of getting to net zero is far greater and far more complex, and calls for a global commitment in the 21st century. Space-based technologies will play a key role in reaching net zero. The development of a new type of decision-support facility by space agencies and the global space industry – an Earth Operations Centre (EOC) – would be a physical and functional expression of the willingness to make that commitment. If a global campaign to get to net-zero GHG emissions is to succeed, building an EOC may be one of the most important contributions made by the global space community.

While the processes of climate change will clearly unfold over decades and perhaps even centuries, not enough has been done to establish institutions that can operate and evolve over those time periods as well. While hundreds of organizations around the world conduct vital research into understanding and modelling the relevant processes, an organization has yet to be established that is dedicated to the continual and integrated development of the two core modelling fields – Earth systems modelling and economic engineering modelling – and to embedding results in a physical visualization environment that can inform and shape decision-making.

“ To successfully manage and coordinate the net-zero efforts on “spaceship Earth”, the time has come to build a sort of distributed operations centre to help manage our “spaceship”.

To successfully manage and coordinate the net-zero efforts on “spaceship Earth”, the time has come to build a sort of distributed operations centre to help manage our “spaceship”. It would be a science and engineering research facility that could serve as a focal point for the coordinated collection of global Earth science and socio-economic information relevant for ensuring long-term planetary sustainability and for the assessment of the options to achieve net zero. This facility's construction would provide a powerful symbol of the commitment to address these challenges today, and to serve as the Earth's caretakers on behalf of future generations. The purpose of an Earth Operations Centre would be to conduct multidisciplinary Earth system science and engineering economic analysis to assess policy and investment options for getting to global net-zero GHG emissions.

The EOC vision seeks to support and leverage the benefits of the many global initiatives focused on curbing GHG emissions, such as Caring for Climate, Climate TRACE, the GHG Management Institute, the Integrated Global Greenhouse Gas Information System, the Low-Carbon Emitting Technologies initiative, and the Mission Possible Partnership. The concept of the Centre is to facilitate collaboration between different organizations by providing a facility where various participants can access a data set, shape future data collection and share data analysis. The Centre will add value to other efforts by promoting a holistic approach to decision-making, and by integrating data and expertise from both Earth system and economic engineering fields.

The Centre would support international commitments to the Paris Agreement and serve as a permanent research environment for a world-class cadre of scientists and analysts, and as a data-visualization environment in support of decision-making by world leaders. The EOC would superficially resemble a traditional spacecraft operations centre, such as NASA's Mission Control Center at Johnson Space Center in Houston, Texas (USA), with rows of computers and rows of dedicated technical experts, large data visualization screens displaying relevant technical data, and a viewing area for senior decision-makers to monitor developments and witness important simulations and events.

But whereas a spacecraft operations centre has developed this type of facility and physical layout to centralize operational control of orbiting spacecraft, an EOC would adapt it to create a new type of research and operations facility. The Centre could serve to develop, debate and coordinate national and international projects and programmes designed to achieve net-zero emissions. Indeed, considering the scale and complexity of the future global challenge, achieving success without a Centre would be hard to imagine.

The EOC initiative is envisioned as a multidisciplinary research and development project dedicated to understanding the ecological state of the planet and the options available for ensuring planetary sustainability. As such, it will require the participation of world-class experts in Earth system science, social sciences and engineering – namely, in physics, chemistry, biology, geology and oceanography; in politics, economics, sociology and psychology; and in industrial engineering, aerospace engineering, energy systems and agricultural engineering. These multidisciplinary experts would work together to identify potential improvements in modelling and data-gaps (and options for bridging the latter), including incorporating the many relevant sources of private-sector capabilities and data, and evaluating and modelling potential technological and non-technological solutions to getting to net zero. The Centre will also integrate Earth science space satellite data and models, operational space-based GHG monitoring, and Earth applications software.

While the development of an EOC would be a milestone project in integrating Earth systems, economic modelling and data visualization, it would only be the beginning. Once one operational EOC has been successfully developed, a blueprint would be available that could, in principle, also scale to a network of EOCs around the world. The challenge of getting to net zero will require coordination and contributions from every region and every country.

One EOC is not enough; many are needed, in fact dozens around the world engaged in the great scientific and technological research challenges related to successfully managing the planet so that everyone on it can thrive. Each country serious about contributing to a sustainable future for humanity could have its own EOC – its own team of experts analysing options for getting to net zero, ensuring planetary sustainability, collaborating with colleagues around the globe, serving as a focal point for analysis and enabling political decision-making within their nation and region.

Globalization – in terms of the extensive and rapid flows of goods, information and people around the world – and the scale of the climate-change challenge ahead have led to a phase of social development that suggests the need for new global institutions. In this context, the development of a global EOC network is an important step if all people, not just a privileged few, are to thrive and meet the myriad challenges of the centuries ahead. New generations would then be able to grow up participating in, and learning from, the development of the EOC, and creating a pioneering global institution of practical planetary stewardship in the process.

This vision has been inspired by the planetary perspective of the global space community and presents a new opportunity for space technology to address the most pressing planetary challenge of the century. It would provide global leaders with the knowledge, technologies and community of experts needed to build a thriving future for the planet. It is worth insisting that failure is not an option for the life support system of spaceship Earth; people must commit to understanding, articulating and enabling the political and industrial strategies that can achieve net-zero emissions and help manage planetary civilization sustainably.

Below: @temizyurek/ Gettyimages

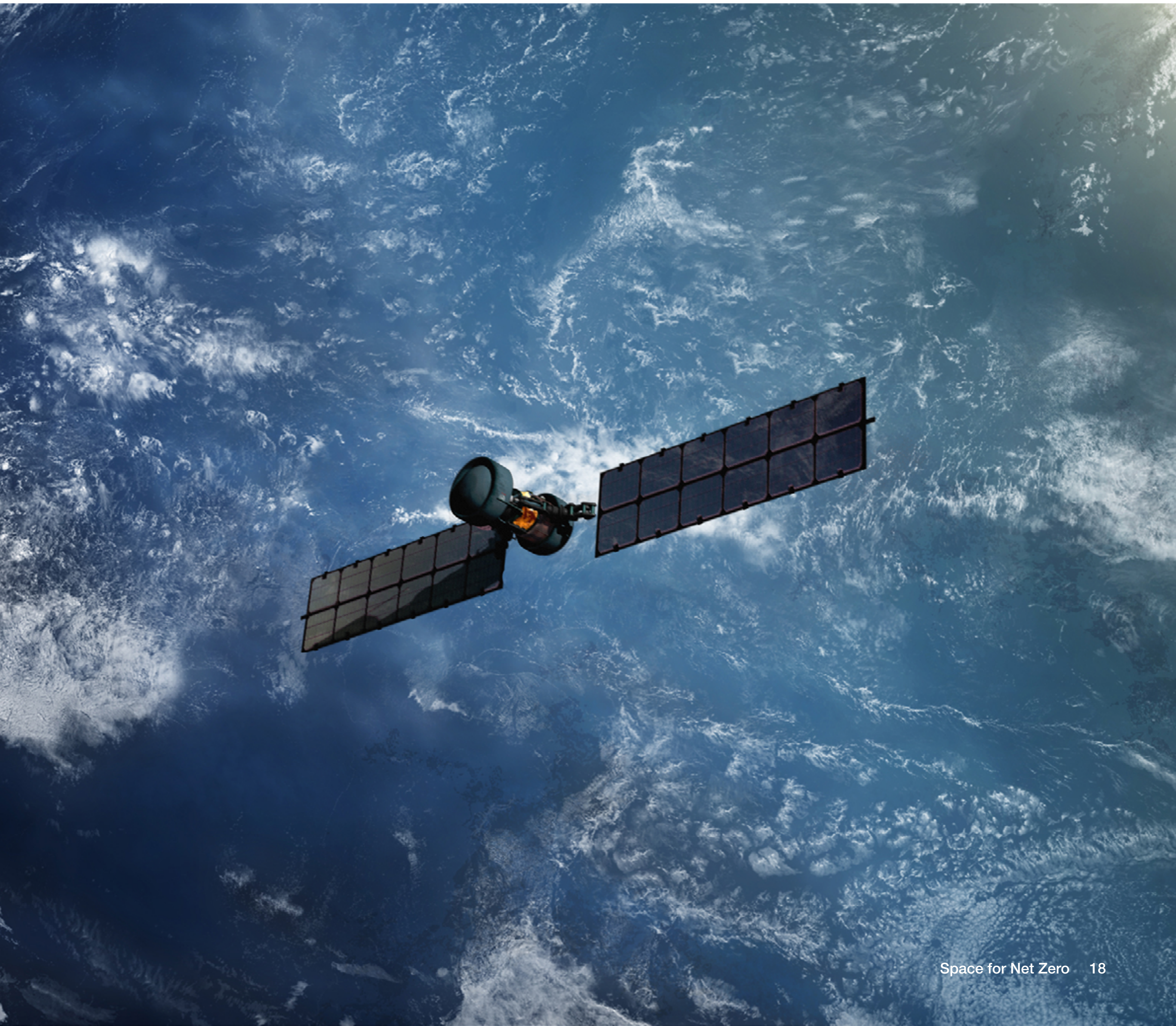
Conclusion

The global community is faced with an unprecedented crisis: GHG emissions have caused the Earth to warm, threatening the sustainability of life unless the move to net-zero emissions is achieved. The space sector has played a critical role in demonstrating that climate change is occurring, and gathering data to help countries become more resilient to the effects of the already significant rise of atmospheric CO_2. The space sector now has a vital role to play as the world moves towards net-zero emissions.

The space sector is developing the tools to provide comprehensive global sensing of CO_2 and CH_4, and the scientific expertise to extract the human signal from natural variations in these GHGs. Data from satellites capable of measuring atmospheric GHGs, or other global surface features, can be used to identify the sources of emissions or sinks and contribute to tracking compliance with commitments. This will be critical as the global community endeavours to hold warming to under 2°C.

Beyond that, this paper advocates that space data and expertise be used to create an Earth Operations Centre. The climate crisis threatens the Earth's sustainability, and the planet requires a decision-support facility. Planet Earth is analogous to a spaceship: a lack of understanding and monitoring of its life support systems has led to the current crisis. An Earth Operations Centre would gather multidisciplinary experts to use cutting-edge technology and data to gain predictability and test solutions for the Earth's sustainability.

Below: @yalax/Gettyimages



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Endnotes

1. World Economic Forum, "Forum's Climate Initiatives are accelerating action on climate change", 20 January 2021, https://www.weforum.org/our-impact/the-one-essential-element-needed-to-accelerate-action-on-climate-change (accessed 21 August 2021).
2. World Economic Forum, *The Global Risks Report 2021: 16th Edition*, 2021, http://www3.weforum.org/docs/WEF_The_Global_Risks_Report_2021.pdf (accessed 18 August 2021).
3. Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2021: The Physical Science Basis*, 2021, https://www.ipcc.ch/report/ar6/wg1/#FullReport (accessed 18 August 2021).
4. Ibid.
5. IPCC, "Climate change widespread rapid, and intensifying – IPCC", Press release, 9 August 2021, https://www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr (accessed 19 August 2021).
6. The Forum also actively promotes a sustainable space environment though the Space Sustainability Rating initiative, launched in 2019 in collaboration with the Space Enabled Research Group, the University of Texas, BryceTech and the European Space Agency.
7. World Economic Forum, "Six ways space technologies benefit life on Earth", Briefing Paper, September 2020, http://www3.weforum.org/docs/WEF_GFC_Six_ways_space_technologies_2020.pdf (accessed 20 August 2021).
8. The non-profit Committee on Earth Observation Satellites (CEOS) lists 172 satellites from dozens of member agencies contributing to knowledge in the field.
9. NASA Jet Propulsion Laboratory, NISAR (NASA-Indian Space Research Organization Synthetic Aperture Radar) mission, "Ecosystems", 2016, https://nisar.jpl.nasa.gov/science/ecosystems (accessed 19 August 2021).
10. PACE was listed as an additional mission in the 2010 Climate-Centric Architecture Plan, which provided further guidance for implementing the ESAS 2007 survey in a manner sensitive to anticipated budget levels. See National Research Council, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*, 2007, https://www.nap.edu/catalog/11820/earth-science-and-applications-from-space-national-imperatives-for-the (accessed 19 August 2021).
11. Decadal survey reports elicit insight from leading scientists to help set 10-year national priorities in key science disciplines.
12. Showstack, Randy, "Report Recommends Priorities for Earth Observations from Space", *Eos*, 26 January 2018, https://eos.org/articles/report-recommends-priorities-for-earth-observations-from-space (accessed 19 August 2021).
13. The White House, "FACT SHEET: Biden Administration Invests $1 Billion To Protect Communities, Families, and Businesses Before Disaster Strikes", 24 May 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/05/24/fact-sheet-biden-administration-invests-1-billion-to-protect-communities-families-and-businesses-before-disaster-strikes (accessed 20 August 2021).
14. The National Academies of Sciences, Engineering, and Medicine, *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space*, The National Academies Press, 2018, https://www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth (accessed 19 August 2021).
15. United Nations Framework Convention on Climate Change (UNFCCC), Information Unit for Conventions (IUC), United Nations Environment Programme, "Climate Change Information Sheet 22", updated 19 July 2000, https://unfccc.int/cop3/fccc/climate/fact22.htm (accessed 19 August 2021).
16. Copernicus, "Greenhouse Gases", 2018, https://climate.copernicus.eu/greenhouse-gases (accessed 19 August 2021).
17. Ibid.
18. Prentice, I.C., et al., "The Carbon Cycle and Atmospheric Carbon Dioxide", *TAR Climate Change 2001: The Scientific Basis*, https://www.ipcc.ch/site/assets/uploads/2018/02/TAR-03.pdf (accessed 23 August 2021).
19. NOAA Research News, "Despite pandemic shutdowns, carbon dioxide and methane surged in 2020", 7 April 2021, https://research.noaa.gov/article/ArtMID/587/ArticleID/2742/Despite-pandemic-shutdowns-carbon-dioxide-and-methane-surged-in-2020 (accessed 23 August 2021).
20. Union of Concerned Scientists, "Why Does CO_2 get Most of the Attention When There are so Many Other Heat-Trapping Gases?", 6 June 2009/updated 3 August 2017, https://www.ucsusa.org/resources/why-does-co2-get-more-attention-other-gases (accessed 20 August 2021).
21. Eldering, A., et al., "The Orbiting Carbon Observatory-2 early science investigations of regional carbon dioxide fluxes", *Science*, vol. 358, issue 6360, 13 October 2017, https://science.sciencemag.org/content/358/6360/eaam5745.full (accessed 19 August 2021).
22. Ibid.
23. International Energy Agency, "Methane Tracker 2020: Methane abatement options", https://www.iea.org/reports/methane-tracker-2020/methane-abatement-options (accessed 20 August 2021).
24. Voiland, Adam, "Methane Matters", NASA, 8 March 2016, https://earthobservatory.nasa.gov/features/MethaneMatters (accessed 20 August 2021).

Endnotes

25. CICERO Center for Climate Research, “Methane: a climate blind spot?”, 25 March 2019, https://cicero.oslo.no/no/posts/klima/methane-a-climate-blind-spot? (accessed 19 August 2021).
26. Ibid.
27. Zavala-Araiza, Daniel, “Super-emitters Are Real: Here Are Three Things We Know”, Environmental Defense Fund, 16 January 2017, http://blogs.edf.org/energyexchange/2017/01/16/super-emitters-are-real-here-are-three-things-we-know (accessed 19 August 2021).
28. NASA, “GeoCarb: A New View of Carbon Over the Americas”, 11 January 2018, https://www.nasa.gov/feature/jpl/geocarb-a-new-view-of-carbon-over-the-americas (accessed 19 August 2021).
29. Ibid.
30. Ibid.
31. NASA, “2020 Tied for Warmest Year on Record, NASA Analysis Shows”, 14 January 2021, https://www.nasa.gov/press-release/2020-tied-for-warmest-year-on-record-nasa-analysis-shows (accessed 20 August 2021).
32. Parkinson, Claire L., “Satellite Contributions to Climate Change Studies”, *Proceedings of the American Philosophical Society*, vol. 161, no. 3, September 2017, https://www.amphilsoc.org/sites/default/files/2017-12/attachments/Parkinson.pdf (accessed 20 August 2021).
33. NASA, “NASA, US, European Partner Satellite Returns First Sea Level Measurements”, 10 December 2020, https://climate.nasa.gov/news/3052/nasa-us-european-partner-satellite-returns-first-sea-level-measurements (accessed 19 August 2021).
34. Parkinson, “Satellite Contributions to Climate Change Studies”, op. cit.
35. NASA, “Climate Change: How Do We Know?”, https://climate.nasa.gov/evidence (accessed 20 August 2021).
36. “Earth Observing Dashboard”, https://eodashboard.org (accessed 20 August 2021).
37. Smith, Lilly, “The view from space: See how dramatically COVID-19 changed the world”, *Fast Company*, 29 June 2020, https://www.fastcompany.com/90521893/the-view-from-space-see-how-dramatically-covid-19-changed-the-world (accessed 19 August 2021).
38. Jones, Karen L., and David M. Tratt, *Mapping methane super-emitters in oil and gas fields: A tiered remote sensing strategy*, The Aerospace Corporation, Center for Space Policy and Strategy, June 2020, p. 4, https://aerospace.org/sites/default/files/2020-06/Jones-Tratt_Methane_20200617.pdf (accessed 21 September 2021).
39. Boomhower, Judson, et al., *Orphan Wells in California: An Initial Assessment of the State’s Potential Liabilities to Plug and Decommission Orphan Oil and Gas Wells*, California Council on Science and Technology, November 2018, https://ccst.us/reports/orphan-wells-in-california (accessed 20 August 2021).

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