Christian Brünner · Georg Königsberger
Hannes Mayer · Anita Rinner *Editors*

Satellite-Based Earth Observation

Trends and Challenges for Economy and Society

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Foreword I

When distinguished space exploration experts meet for a major symposium at the Styrian Economic Chamber, they have good reason to do so. After all, as the 'company of entrepreneurs', it is the ideal venue for an exchange between the scientific and business communities. After all, satellite-based earth observation is becoming increasingly significant in many areas of business and daily life. From navigation and weather forecasting to investigation of soil properties and the satellite data needed for autonomous driving, working with space data is essential in many fields of business and research. Promoting the transfer of technology from space science to industrial fields and thus to new applications contributes significantly towards a region's attractiveness—and this is especially true for Styria. An R&D quota of 5, 16%, one of the highest in Europe, is testimony to the fact that research and development play a prominent role in Styria. The mobility cluster, which includes the major area of space technology, has an R&D quota of almost 12%. And the significance for our companies of research conducted at Styrian institutions of higher education, is illustrated by another, equally impressive, figure: 186 million euros in third-party funds has recently been poured into Styrian universities and institutions of higher education. This is money invested in the region by companies in order to achieve success nationally and internationally through innovation. And, in doing so, these companies are clearly stating their commitment to Styria as a business location, by creating and maintaining jobs and thereby guaranteeing the region's prosperity.

Steiermark, Austria

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Josef Herk has been the President of the Styrian Economic Chamber since 2011, and, in this capacity, represents about 74,000 companies in the Austrian province of Styria.

He also runs a medium-sized automobile body and paint shop, a family business now in its second generation.

Foreword II

In 2017, we celebrated the 60th anniversary of the launch of *Sputnik*. *Sputnik* was the first human-made object in orbit. Shortly afterwards, when the first cameras were put on satellites, earth observation from space was born. The concept of giving eyes to satellites was mainly inspired by the dramatic ‘space race’ between the USSR and the US during the Cold War. In the beginning of the 1970s, the transition from purely military use of earth observation technology to the civilian domain was marked by the science-driven *Landsat* program. *Landsat* served the emerging demand for comprehensive information on the planet’s environmental health. Although earth observation, or at least a significant part of it, had now left the realm of defence, it was still the domain of an exclusive circle of scientists and ‘nerds’.

2017 also saw the 40th anniversary of the launch of *Meteosat*. *Meteosat* was the first fully operational earth observation satellite built as a joint European project. A new era of weather and climate forecast was dawning and brought observational data about the earth into people’s minds and living rooms. A typical weather forecast at the end of the news now included animations tracing the formation and movements of clouds in the diurnal cycle, featuring photos of continents rather than schematic graphics. *Meteosat* was followed by the first European Radar Satellites ERS-1 and -2 and ENVISAT, all three truly European endeavours. These steps culminated in the European earth observation programme *Copernicus,* which has been operational since 2014. *Copernicus* provides a comprehensive system of space infrastructure and offers sustainable services and information products for monitoring the environment and supporting civil security. With *Copernicus*, earth observation crossed the threshold to benefiting the public, evolving into an indispensable tool for tackling grand societal challenges.

At the same time, the entire space sector is facing a giant leap in evolution both in economic and institutional terms, often referred to as *New Space* or *Space 4.0*. More and more stakeholders are active in space, the private and commercial sectors are ramping up and space is increasingly becoming a ‘normal’ business, like the automotive sector, for example. The earth observation sector is more attractive than ever. In the coming years thousands of—predominantly small—satellites will be launched, based on digital technologies and facilitating new digital business models.

This is why the book ‘Trends and Challenges of Satellite-based Earth Observation for Economics and Society’ comes exactly at the right time. The editors *Christian Brünner, Georg Königsberger, Hannes Mayer* and *Anita Rinner* and all the contributors succeed in addressing the right questions and discussing appropriate issues. Earth observation systems such as *Copernicus* were designed and created by scientists and engineers. A particular asset of this book is seeing earth observation from a multitude of perspectives, not only from the technical side.

Wien, Austria

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Thomas Geist started working for the Aeronautics and Space Agency (ALR) within the Austrian Research Promotion Agency (FFG) in 2007.

As an expert for Earth Observation (EO) Thomas is the Copernicus contact point in the agency and responsible for the coordination of EO projects in the national R&D funding programme ASAP (Austrian Space Applications Programme). Thomas represents Austria in the ESA Programme Board for Earth Observation (PB-EO) and since 2017 he is the Chairman of the Data and Operations Scientifical and Technical Advisory Group (DOSTAG) at ESA. Furthermore, he is delegate in the Horizon 2020 Space Programme Committee and the Copernicus Committee.

Before joining FFG, Thomas worked as a senior researcher at the University of Innsbruck. He holds a Master’s degree in Physical Geography from the University of Munich, and a Ph.D. degree from the University of Innsbruck (Faculty of Geo- and Atmospheric Sciences).

Preface

Outer Space is not only fascinating but—since the first launch of a satellite, the Russian Sputnik in 1957—has become an ever more attracting target and object of activities. Apart from the exploration of outer space, the utilization of outer space for different purposes has been in the centre of interest from the very beginning. In fact, 'outer space' has meanwhile turned into one of the most important—and most indispensable—fields of human activities, of society and of politics. The main applications are communication, navigation and Earth observation, furthermore in the near future probably the exploitation of natural resources ('space mining').

Nowadays the results of space science, space activities and space technology are applied in countless areas of everyday life to such a degree that mankind is depending on them. Each of us uses at least 20 different satellite applications everyday, this especially in the fields of weather forecast, navigation and communication; less visible—but likewise important—are, for e.g. applications for steering systems in transformer stations for electricity.

Furthermore, the importance of space applications for bridging the digital divide in order to enhance economic and societal development throughout the world has to be mentioned. 54% of the world population does not have access to Internet; the respective figures for Africa and for Europe are 75%(!) and 21%.

And yet, the strategic as well as operational importance of outer space has not reached its top, it is incessantly growing. Keywords—especially in the context of commercialization of outer space—are 'New Space', 'Astropreneurship' or 'Space 4.0', connected with new models of Public–Private Partnership. Parallel to this development, there is a growing need for an effective political, societal, legal, but also ethical framework, this on an international as well as on a national level.

An important task in this context is the education, information and participation of a broad public in order to raise awareness of the importance of exploration and utilization of outer space ('Outreach').

Numerous organizations and institutions are active for and in outer space. Besides governmental ones—for e.g. the United Nations with several space-related programs and the Committee on the Peaceful Uses of Outer Space (UNCOPUOS) with its two Subcommittees (the Legal one and the Scientific and Technical one);

the European Space Agency (ESA); (National) Space Agencies—nongovernmental organizations, private companies, experts, etc., play an important part in order to shape the above mentioned framework.

Among the nongovernmental organizations are the International Astronautical Federation (IAF), the International Academy of Astronautics (IAA) and the International Institute of Space Law (IISL). They are the organizers/co-organizers of the annual International Astronautical Congress (IAC). Furthermore, the European Centre for Space Law (ECSL) has to be mentioned. I have the privilege to be a member of IAA, IISL and ECSL.

The ECSL was founded 1989 by Gabriel Lafferanderie, a pioneer of space law, within the organizational frame of ESA. Among the most important activities of ECSL count the annual Summer Course on Space Law and Space Policy, which is usually held in different countries and in cooperation with one of the ECSL National Points of Contact (NPOC), as well as the regular organization of the Practitioner's Forum and recently the Young Lawyer Symposium (YLS).

On a national level, the work of ECSL is supported by the National Points Of Contact (NPOC). In 2001, I established the Austrian NPOC at the University of Graz which was possible due to the continuing affords of the ECSL's former chairman Gabriel Lafferanderie and the support from Eva-Maria Schmitzer, at the time Head of the Space Research Division at the Federal Ministry for Transport, Innovation and Technology. An important contribution to the implementation of this idea came also from Leopold Summerer, who had presented a report on the dissemination of Austrian expertise in the field of space law in 2001.

I founded NPOC Subpoints at the Austrian universities Linz, Salzburg, Innsbruck, Wien, at the Danube University Krems and the Vienna University of Economics and Business. I headed the NPOC Austria until 2009, when I handed it over to the University of Vienna. Since then the University of Graz is a Subpoint of ECSL/NPOC Austria, which we call 'Competence Centre for Space Law and Space Policy (CC)'. The Subpoint, respectively, the CC do not have an organizational basis, but a personal one, including Georg Königsberger, Hannes Mayer, Anita Rinner and Katharina Zollner.

By the way, my curiosity about matters of outer space was wakened in 1991. As a member of the Austrian Parliament and as the spokesman for academic affairs of the Austrian People's Party (ÖVP), I had the possibility to watch the launch of the Sojus—Rocket from the Cosmodrome in Baikonur, Kazakhstan, with the Austrian astronaut Franz Viehböck on board.

Since its founding, the NPOC Austria and/or the Subpoint Graz, respectively, made it its business to promote teaching and research in the field of space law and space policy. A Seminar on Space Law and Space Policy is held annually within the diploma program of law. Master's and doctoral theses are supervised.

Moreover, every year since its founding, the NPOC could offer several students of Austrian universities the possibility to take part in the ECSL Summer Course on Space Law and Policy as well as in other space-related events. Due to an agreement with the former head of the Bureau of International Law within the former Federal Ministry for Foreign Affairs, Ambassador Dr. Hans Winkler, students can participate as part of the Austrian delegation to the meetings of the Legal Subcommittee of UNCOPOUS.

Furthermore, it is an important task to circulate information on space (law) topics and events among a broad public. Awareness of the importance of space exploration and space utilization for everyday life has to be raised.

My approach is an interdisciplinary one. Not only legal and political perspectives are reflected, but also societal, cultural, economic, technical and ethical ones.

Several symposia have been organized since 2005. The recent symposium 'Trends and Challenges of Satellite Based Earth Observation for Economy and Society' was organized by the NPOC Subpoint Graz, respectively, by the Competence Centre for Space Law and Space Policy.

The symposium consisted of two parts: The presentations by lecturers and moderators and their professional contributions to the topic 'Satellite-Based Earth Observation' (see the program under the link https://homepage.uni-graz.at/de/christian.bruenner/. Remark: Not all lecturers were able to deliver the written version of their papers. Fortunately Silke Migdall, Lena Brüggemann and Heike Bach, and Michael Wurm filled in the gap). And: 'Space Art & Space Technology', an exhibition of paintings of selected artists and of a model of the nanosatellite OPS-SAT took place, furthermore the video 'ART_SAT' was presented (see the contribution of Richard Kriesche and my introduction page xxi).

Important support came from the Styria Economic Chamber (WKO/Steiermark) and its President Ing. Josef Herk. Furthermore, the symposium, respectively, the publication was sponsored by Austrospace, the FFG/NPOC Austria, the BMVIT, the University of Graz, the Government of Styria, the City of Graz and the Bankhaus Krentschker. The lecturers and the moderators contributed substantially to the success of the symposium.

Help came also from the students of the 2017 Seminar on Space Law and Space Policy (see the list of the students https://homepage.uni-graz.at/de/christian.bruenner/). Furthermore, the members of the NPOC Subpoint Graz, respectively, the Competence Centre did a great job.

All actors and sponsors deserve my sincere thanks.

Last but not least, I want to thank the publishing house Springer Wien New York and its representative, Ms. Silvia Schilgerius, Senior Editor Applied Sciences. The kindness and cooperation have been outstanding.

Graz, Austria Christian Brünner

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ECSL
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National Point of Contact Austria
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Christian Brünner is Professor Emeritus of Public Law at the University of Graz. He is also a Lecturer of Space Law and Space Policy at the University of Graz, the ECSL Summer Courses and the ISU Space Studies Program.

He was Rector of the University of Graz, Chairman of the Austrian Rector's Conference, Member of the Austrian National Parliament and of the Styrian Regional Parliament.

He is founder of the Austrian National Point of Contact (NPOC), ECSL/ESA, which he chaired for several years. Furthermore, he is member of the ECSL Board, the IISL, the International Academy of Astronautics and the Austrian Delegation to UNCOPUOS.

Besides publications in the fields of education(al law), university management, control, parliamentarianism and religious and ethnical minorities, he has authored and/or edited several publications in space law, including the book (as Co-Editor) Outer Space in Society, Politics and Law which was awarded the Social Sciences Book Award of the International Academy of Astronautics 2012. Furthermore, he was awarded the Polarstern Award 2015 by the Austrian Space Forum (Österreichisches Weltraum Forum).

He is active in various fields to raise public awareness of space, space law and space policy.

Georg Königsberger is Legal Officer at the Styrian Economic Chamber's labour and social law desk. Among his earlier career steps was a stint as scientific project contributor at the Institute of Austrian, European and Comparative Public Law, Political Science and Administrative Studies at Karl-Franzens-University Graz. He is a contributor of the Competence Centre for Space Law and Space Policy at Karl-Franzens-University Graz. He studied law and history at Karl-Franzens-University Graz and Charles University Prague. Publications in the fields of labour law; teacher in adult vocational training.

Hannes Mayer works at the Competence Centre for Space Law and Space Policy as well as the Institute of Canon Law of Karl-Franzens-University Graz. He serves as a member of the Austrian delegation to the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS). He is a member of the European Centre for Space Law, the Space Generation Advisory Council's Space Law and Policy Project Group, the Austrian Space Forum and the History Committee of the International Academy of Astronautics (IAA). He is a board member of the Diocesan Committee of Catholic Organizations Styria and a member of the European Academy of Religion. He has (co-)authored several publications on outer space and is a member of the editorial staff of the Theologicum Magazine.

Anita Rinner is a Trainee Lawyer (with bar examination) at Muhri & Werschitz Attorneys, Graz; Lecturer in Space Law and Policy, University of Graz; Member, Competence Centre for Space Policy and Space Law, Graz; Member, European Centre for Space Law (ECSL); Member, Austrian Space Forum, and Member, International Institute of Space Law (IISL). Austrian Delegate, United Nations Committee on the Peaceful Uses of Outer Space Legal Subcommittee, Vienna; Alumna, European Centre for Space Law Summer Course (ECSL), Rijeka; Tutor, ECSL Pafos; Alumna, International Space University Space Studies Program, Strasbourg; Oral and written Presentations at the International Astronautical Congress in Beijing, Toronto and Jerusalem; Presentations at various space-related symposia in Graz, Vienna, Berlin and Rom; Participant of ESA/CNES Parabolic Flight Campaign, Bordeaux.

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Introduction

For as long as humankind has existed, men and women have looked at the sky. With respect and highly fascinated, they have watched the rising and setting of the sun and of the moon and the stars glittering in the dark sky.

Looking at the sky, their thoughts have circled questions like: Where do the celestial bodies come from? Is there an entity—God or whatever names were given to the unknown—which has created all this and has implemented the rhythm which we can experience in our lives and nature? Or: Do the sun, the moon and the stars influence our lives? Or: Who am I in this immense and unknown universe?

In the ancient Egyptian, Greek and Roman mythologies the celestial bodies were seen as Gods. Astrology, which is 5000 years old, teaches that the planets including the sun and the moon are symbols representing certain aspects of human's personality. For Hermes Trismegistos, a philosopher in ancient Egypt, it was a 'natural law' that how it is aloft, so it is beneath.

The celestial bodies, especially the sun and the moon, have been early objects of astronomical calculation. For millennia, astronomers, astrologers and philosophers have been developing theories attempting to explain the material world, based upon astronomical calculations. They were also used for practical terrestrial needs, for instance for navigation on the seas.

The early space-oriented activities already show the two main views, when we talk about space: on the one hand, the view from Earth 'outside' with the objective of exploring the universe, and, on the other hand, the view towards Earth to observe the place where we live, an observation that serves manifold purposes.

Besides navigation, telecommunication and the recently planned exploitation of natural resources on the moon and asteroids ('space mining') earth observation is the largest sector of space applications. Around 30% of the whole budget of ESA, the European Space Agency, is spent for Earth observation activities. Furthermore, the objectives of earth observation are multifold. In a list of space applications meeting societal needs ESPI, the European Space Policy Institute, mentions several objectives, for instance food management, land management, urban planning, preserving archeological sites, forest management, monitoring of freshwater, assessing the risks of natural disasters, search and rescue, national security, etc.

An important aspect of the framework of earth observation is how the access to gained and generated data is regulated. For example, the data which are gained by the EU-Project Copernicus are freely accessible and without costs.

Earth observation's genius loci is Wilhelm Nordberg. He was born in Fehring and has studied physics at the University of Graz. After his studies, he emigrated to the USA, where he served as NASA's Director for Space Applications for 2 years. In 1955, he was the first to publish his conviction that weather forecast via satellites must be possible. This hypothesis was realized by the weather-satellite TIROS I. Consequently, he turned towards earth observation. A result was the satellite LANDSAT 1. Due to these activities, it is appropriate to consider Willi Nordberg the father of earth observation. The symposium was honoured by the presence of Kurt Nordberg, Willi Nordberg's brother.

With the symposium, we pursued three objectives:

1. We want to give information to a broad public concerning different applications of earth observation data in economy and society and concerning its political, economic and legal framework, this also on the level of the EU (Part I-V).
2. The Outer Space Treaty of 1967 lays down the purpose of space activities. According to Article I par 1, the exploration and use of outer space, including the Moon and the celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind.
   The provision is the starting point for a multidimensional view of space activities. In 'Space Art & Space Technology', an exhibition of paintings and installations by Edith Temmel, Petra dieHolasek, Hannes Scheucher, Josef Bramer und Günther Friesinger, the nanosatellite OPS-SAT, respectively, TUGSAT-1/BRITE-Austria and the presentation of the video clip ART_SAT we outline the cultural/artistic and technical dimension (Part VII).
   A few words concerning ART_SAT (for more information see the contribution of Richard Kriesche in this volume): ART_SAT was—besides 15 scientific experiments—an artistic experiment within the project AUSTROMIR, the mission of an Austrian astronaut to the Russian Space Station MIR. It was carried out in cooperation between Richard Kriesche, the designer and operator in the ground station, and Franz Viehböck, the Austrian astronaut on board of MIR.
3. As university teacher, it is important for me to fill young people and students with enthusiasm for outer space in young people and students and to instruct them properly. Anita Rinner, space law lecturer in the Seminar on Space Law and Space Policy which is held annually at the University of Graz, proposed to invite the students of the 2017 seminar to draw up posters and present them in a poster session during the symposium (see Part VI).

Part VIII of this volume is dedicated to my 75th birthday. The part is based upon a proposal of my co-workers at the Subpoint Graz/Competence Centre for Space Law and Space Policy. Initially I hesitated, but then I agreed, and now I am grateful for this Part.

Christian Brünner

Part I
Earth Observation and Its Multidimensional Application

The European Space Agency's Earth Observation Programme

Wolfgang Rathgeber

1 Introduction

The European Space Agency (ESA) has been managing an Earth Observation Programme since the launch of its first Meteosat meteorological satellite in 1977. Following the success of this first mission, a subsequent series of Meteosat satellites, two Earth Remote Sensing satellites (ERS-1, ERS-2), and the Envisat mission provided a wealth of valuable data about Earth, its climate and changing environment. As a result, ESA has become a major provider of Earth observation data and stimulated the build-up of the Earth science community and beyond.

Started in the mid-1990s, the ESA's Living Planet Program heralded a new approach to satellite observations for Earth science with focused missions defined, developed, and operated in close cooperation with the worldwide scientific community. As time progressed, three main categories of ESA Earth observing missions have emerged: Earth Explorer, Earth Watch, and Copernicus (formerly GMES) Sentinel missions.

ESA also distributes satellite data from international partner agencies, so called Third Party Missions (TPM). The data from these missions are distributed under specific agreements with the owners or operators of those missions, which can be either public or private entities outside or within Europe.

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2 ERS and Envisat

Both these missions addressed a wide range of environmental questions and predate the formal establishment of the Earth Explorer and Sentinel missions. The first European Remote Sensing Satellite (ERS-1) was launched in 1991. It was ESA's first sun-synchronous polar-orbiting remote sensing mission. ERS-1 carried a comprehensive payload including an imaging Synthetic Aperture Radar (SAR), radar altimeter, and other instruments to measure ocean surface temperature and winds. In March 2000, nine years after launch, a computer and gyro control failure led to ERS-1 finally ending its operations after far exceeding its planned lifetime.

ERS-2, which overlapped with ERS-1, was launched in 1995 with an additional sensor for atmospheric ozone research. Both satellites collected a wealth of valuable data on Earth's land surfaces, oceans, and polar regions that were used to monitor natural disasters such as severe flooding and earthquakes in remote areas of the world. Shortly after the launch of ERS-2 in 1995, ESA operated the two satellites in the first 'tandem' mission mode, which lasted for nine months. Beyond the sheer increase in revisiting the same site, this tandem operations boosted SAR-interferometry applications particularly for the generation of digital terrain models (DTMs). In July 2011, ERS-2 was retired and the process of de-orbiting the satellite began.

The giant Environmental Satellite (Envisat) was launched in 2002. The largest Earth observing satellite ever built by any space agency, it was an advanced polar-orbiting satellite that provided measurements of the atmosphere, ocean, land, and ice for over 10 years, double its initially planned lifetime. Envisat's ambitious and innovative payload provided new Earth science data and also ensured the continuity of the data from the two ERS satellites. Exceeding its predicted lifetime by a factor of 3, the end still was sudden. In April 2012, contact with Envisat was lost without warning, likely as a consequence of a failure in the power-regulator or a short-circuit. However, ten years of Envisat's archived data continue to be exploited for studying our planet with demand remaining very high even today.

3 Earth Explorer Missions

The Earth Explorers are research missions designed to address key scientific challenges identified by the science community, while demonstrating breakthrough technology in observing techniques. These missions involve the science community right from the beginning in the definition of new missions followed by a peer-reviewed selection process ensuring that the resulting mission is developed efficiently, and provides the data required by the user. This approach also gives Europe an excellent opportunity for international cooperation with the global scientific community and in the area of technological development. It should be added that some Earth Explorer missions also feature an operational perspective.

GOCE: Launched in 2009, the Gravity field and steady-state Ocean Circulation Explorer (GOCE) mission was the first of the Earth Explorers. GOCE was designed to provide information for understanding critical Earth system variables, such as ocean circulation, sea-level change and variations in ice cover driven by the Earth's gravitational field. The gravitational gradients were measured by a set of six three-axis accelerometers. GOCE provided data to accurately determine global and regional models of Earth's gravity field and geoid, the shape that the surface of the oceans would take under the influence of Earth's gravitation and rotation alone. This advanced research in areas of ocean circulation and ocean dynamics, physics of Earth's interior, geodesy and surveying, and sea-level change.

All mission requirements had been met by the end of 2012. GOCE went on to map gravity signals significantly beyond its original goal of 100 km altitude resolution. The advance meant that for the first time, global ocean currents could be extracted directly from satellite altimetry data. At the end of January 2012, GOCE's orbit was lowered to 235 km, increasing the accuracy and resolution of the measurements to 80 km and improving GOCE's view of smaller ocean dynamics. The satellite was further lowered to 225 km at the end of May 2013 and re-entered Earth's atmosphere in November 2013.

SMOS: Also launched in 2009, the Soil Moisture and Ocean Salinity (SMOS) mission is making global observations of soil moisture and ocean salinity using a unique L-Band Radiometer Microwave Imaging Radiometer with Aperture Synthesis (MIRAS). Soil moisture data are required for hydrological studies and ocean salinity data are vital for improving our understanding of ocean circulation patterns. SMOS completed its nominal three-year mission lifetime in November 2012, but continues to provide valuable results to this day, also beyond its initial mission objectives measuring ice thickness and wind speed.

CryoSat-2: In 2010, Europe's first ice mission CryoSat-2 was launched. Its principal instrument is the Synthetic Aperture Radar/Interferometric Radar Altimeter is designed to measure centimetre-scale changes in thickness of ice floating in the oceans and the ice sheet thickness that blanket Greenland and Antarctica. When combined with other satellite data, analyses showing how the volume of Earth's ice is changing leads to a better understanding of the relationship between ice and the Earth's climate. Cryosat-2 is providing accurate, synoptic, Arctic measurements of ice thickness and column in unprecedented detail.

Swarm: Launched in 2013, Swarm is a constellation of three satellites that provide high-precision and high-resolution measurements of the strength and direction of the Earth's magnetic field using an advanced magnetometer, an accelerometer and an electric field instrument. The geomagnetic field models resulting from the Swarm mission enable new insights into the Earth's interior. They further our understanding of atmospheric processes related to climate and weather, and have practical applications in many different areas such as space weather and radiation hazards.

Aeolus: With a target launch date in 2018, the Atmospheric Dynamic Mission Aeolus will advance global wind profile observations and provide much-needed information to improve weather forecasting. Aeolus will orbit in a Sun-synchronous, dusk/dawn orbit at 408 km and employ a highly sophisticated Doppler wind lidar with a large telescope that collects light backscattered from gas, dust, and droplets of water in the atmosphere. Data from Aeolus are expected to pave the way for future operational meteorological satellites dedicated to measuring Earth's wind fields.

EarthCARE: With a target launch date in 2019, the Earth Clouds Aerosols and Radiation Explorer (EarthCARE) mission is being implemented in cooperation with the Japanese Aerospace Exploration Agency (JAXA). Its aim is to improve the representation and understanding of Earth's radiative balance in climate and numerical weather forecast models. This will be achieved by global measurements of the vertical structure and horizontal distribution of cloud and aerosol fields together with outgoing radiation. The payload comprises two active instruments: a high-resolution atmospheric lidar and radar, and two passive instruments: a multispectral imager and a broadband radiometer. EarthCARE will orbit in an early afternoon sun-synchronous orbit at 393 km.

Biomass: This mission will employ a novel P-band synthetic aperture polarimetric radar operating at 435 and 6 MHz bandwidth. The satellite flies at 637–666 km in a near polar sun-synchronous orbit, and will address one of the most fundamental questions in our understanding of the land component in the Earth system, namely the status and the dynamics of forests, as represented by the distribution of biomass and how it is changing. Biomass will greatly improve our knowledge about the terrestrial carbon pool and fluxes. In addition, the mission responds to the pressing need for biomass observations in support of global treaties such as the United Nations Framework Convention on Climate Change initiative for the Reduction of Emissions due to Deforestation and Forest Degradation.

FLEX: In November 2015 ESA Member States selected the Fluorescence Explorer (FLEX) as the eighth Earth Explorer, following a User Consultation Meeting in September 2015. FLEX is a three-year mission slated for launch in 2022. It will globally monitor the steady-state chlorophyll fluorescence in terrestrial vegetation. FLEX includes three instruments to measure the interrelated features of fluorescence, hyperspectral reflectance, and canopy temperature. FLEX will orbit in tandem with one of the Copernicus Sentinel-3 satellites.

Earth Explorers 9 and 10: For Earth Explorer 9, a call for proposals was published in 2016. Out of the 13 concepts received, two candidates were selected to enter a competitive feasibility phase. These two candidates will spend the next two years being studied thoroughly. In 2019, a User Consultation Meeting will be held, after which a decision will be taken by ESA's Member States as to which of the two contenders will be implemented. Earth Explorer 9 is foreseen to be launched in 2025. A Call for Mission Ideas, initiating the process for Earth Explorer 10, was released in September 2017. The launch of Earth Explorer 10 is foreseen for 2027/28.

4 Earth Watch Missions

The Earth Watch missions are designed to provide Earth observation data for services, including those of the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), whose main purpose is to deliver operational weather and climate-related satellite data, images, and products to the European National Meteorological Services as well as to other users worldwide. The ESA-EUMETSAT partnership was established in 1986 and was implemented with a series of geostationary (Meteosat) and polar orbiting (MetOp) satellites, where ESA builds the satellites that are then operated by EUMETSAT.

Meteosat Second Generation (MSG) is a significantly enhanced, follow-on system to the first generation of Meteosat (MFG). MSG consists of a series of four geostationary meteorological satellites, along with a ground-based infrastructure, that will operate consecutively until 2020. The last MSG satellite, MSG 4, was launched in July 2015. The MSG satellites carry two instruments. The Spinning Enhanced Visible and InfraRed Imager (SEVIRI), which has the capacity to observe the Earth in 12 spectral channels and provide image data that are core to operational forecasting needs, and the Geostationary Earth Radiation Budget (GERB) instrument supports climate studies.

The Meteosat Third Generation (MTG) satellite programme will bring a step change in capability for operational meteorology. The programme will guarantee access to space-acquired meteorological data until, at least, the late 2030s. MTG will continue visible and infrared imagery and infrared and ultraviolet/near infrared sounding observations from geostationary orbit that will result in three-dimensional information on humidity, temperature, and wind to support Nowcasting.

The series will comprise six satellites: four MTG-I imaging and two MTG-S sounding satellites. The two types will be positioned over the same longitude in their geostationary orbits. The sounding element will also host the Copernicus Sentinel-4 air quality observatory (see below). The first MTG satellite is planned to be launched around 2020.

The EUMETSAT Polar System (EPS) is Europe's first polar-orbiting operational meteorological satellite system, and it is the European contribution to the Initial Joint Polar-orbiting Operational Satellite System (IJPS), a joint effort between EUMETSAT and NOAA. EUMETSAT's polar-orbiting satellites (i.e. MetOp satellites) carry a set of state-of-the-art sounding and imaging instruments that offer improved atmospheric sounding capabilities to both meteorologists and climatologists.

The EPS Space Segment includes three successive MetOp satellites and is being developed and procured in cooperation between ESA and EUMETSAT. MetOp-A was launched in 2006 and MetOp-B in September 2012. In April 2013, MetOp-B replaced MetOp-A as the EUMETSAT prime operational polar-orbiting satellite, following the end of its commissioning period. The combination of instruments onboard MetOp satellites have remote sensing capabilities to observe the Earth during day- and night-time hours, as well as under cloudy conditions.

The follow-on EUMETSAT Polar System is now under way to replace the current satellite system in the 2020 timeframe and to contribute to the IJPS. Started in 2005 under the name of Post-EPS, the activities have been endorsed in 2012 under a new programme called MetOp Second Generation (MetOp-SG). Comprising six MetOp Second Generation satellites in total, this programme is based on pairs of satellites that carry different packages to deliver complementary meteorological information. The A series of satellites will be equipped with atmospheric sounders as well as optical and infrared imagers, while the B series focuses on microwave sensors. In addition, the A series will carry the Copernicus Sentinel-5 instrument on behalf of the European Commission. Each satellite will be launched separately. It is envisaged that the first A satellite will be launched in 2021, followed by the first B satellite in 2022.

5 The Sentinel Missions

Copernicus is the world's most ambitious Earth observation programme. It is Europe's answer to global needs, allowing to manage the environment, to mitigate the effects of climate change and to ensure civil security Copernicus is led by the European Union, with ESA being the coordinator of the space component. The Sentinels form the dedicated part of the Copernicus Space Component. The Sentinel missions feature constellations of two satellites to provide robust datasets for operational services.

Sentinel-1 This is a polar-orbiting, all-weather, day-and-night mission featuring a C-band Synthetic Aperture Radar (SAR) supporting Copernicus operational services for land, marine, and risk monitoring. The first satellite, Sentinel-1A, was launched in April 2014, and Sentinel-1B in April 2016.

Sentinel-2 This is a polar-orbiting, multispectral high-resolution imaging mission for Copernicus land monitoring to provide imagery of vegetation, soil and water cover, inland waterways, and coastal areas. Sentinel-2 will also provide information for emergency services. The first satellite, Sentinel-2A, was launched in June 2015, and Sentinel-2B in March 2017.

Sentinel-3 This mission is composed of two operational satellites with a one day (land) and a two day (ocean) revisit time. Each satellite will carry an Ocean and Land Colour Instrument (OLCI), a Sea and Land Surface Temperature Radiometer (SLSTR) and a microwave payload including a SAR Radar Altimeter (SRAL) and a two frequency Microwave Radiometer (MWR). This mission will support activities in the field of topography, sea and land surface temperature, ocean carbon, and land colour. The first satellite, Sentinel-3A, was launched in February 2016. Sentinel-3B will be launched in 2018.

Sentinel-4 is a payload devoted to atmospheric monitoring that will be embarked on an MTG-S satellite. Ultraviolet and near infrared spectrometers will be used to continuously monitor air pollution and its precursors from North Africa to northern Europe at a $6 \times 6\ \mathrm{km}^2$ spatial and one hour temporal resolutions.

Sentinel-5 Precursor is a polar sun-synchronous mission scheduled to launch in 2015 to reduce data gaps between Envisat and Sentinel-5 for global atmospheric composition measurements including ozone, aerosols and atmospheric pollution precursors. The instrument is a follow-on to the Ozone Monitoring Instrument (OMI) flying on the NASA's Aura satellite with additional channels in the near infrared. Sentinel-5P was launched 13 October 2017.

Sentinel-5 is a payload that will monitor the atmosphere from polar orbit aboard a MetOp-SG A satellite. It will continue the atmospheric composition data collected from Envisat and employ ultraviolet and infrared spectrometers that will the measure profiles and column amounts of trace gases and aerosols important in atmospheric chemistry and climate.

Sentinel-6 carries a radar altimeter to provide high-precision and timely observations of the topography of the global ocean. This information is essential for the continued monitoring of changes in sea level, a key indicator of climate change. It is also essential for operational oceanography. Sentinel-6 builds on heritage from the Jason series of ocean topography satellites and from ESA's CryoSat mission. Sentinel-6 is designed to complement ocean information from Sentinel-3.

6 Outlook

ESA's Earth science program has been steadily growing since the 1990's. Distributing high-quality data and building on continuous technological progress driven by the computer and internet revolution, the "free & open" data policy has been the ultimate accelerator in guaranteeing the maximum exploitation of ESA data.

Copernicus has kicked off a new era of operational Earth observation, leaving the initial "pure science and technology" phase behind and meeting with huge user interest: By November 2017, more than 109.000 users have registered on the Copernicus open access hub, and more than 40 PB of Copernicus data have been downloaded.

Currently Earth Observation is experiencing major trends and paradigm shifts, such as exponential growth in availability of data, the impact of big data and cloud processing, the entrance of new private and institutional actors into the field, the multiplication of national initiatives in Earth Observation, as well as the emergence of venture-capital funded micro-satellite constellations. In addition, advances in on-board technologies are constantly improving spatial resolution and measurement accuracies.

ESA is taking adequate measures to stay on top of these developments. With its suite of missions and programmes, ESA is devoted to bringing the benefits of space based Earth observation to citizens in Europe and worldwide.