

The Earth seen from above

- 05 Preface**
Grégoire POSTEL-VINAY

- 06 Introduction - When the wise man shows the Earth**
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THE ACTORS, THE EARTH SEEN FROM GREATER OR LESSER HEIGHTS

- 08 Satellites**
Valérie FOIX & Jean-Philippe TAISANT

Artificial satellites history starts at the end of the 1960s, in the context of the Cold War. They have gradually covered several civil and military application sectors, such as telecommunications, Earth observation and navigation, to reach around 2,000 objects in orbit at the end of the 2010s. Over the past ten years, technological breakthroughs such as the digitization of payloads, the miniaturization of equipment and satellites as well as the use of commercial components, have accelerated the democratization of Space and the deployment of constellations, modifying the existing eco system and traditional economic models. The increase of Space occupation, following the multiplication of uses and services, in a context of increased commercialization of the orbit, as well as the strengthening of the militarization of the sector, raises the question of the sustainability of its use.

- 18 HAPS (High Altitude Permanent System)**
Michel MASSELIN

Recent technological progress makes it possible to envisage a new capacity based on airborne drones: HAPS (High Altitude Permanent System) such as the Stratobus. Stratobus is a stratospheric airship capable of operating during one year, at an altitude of 19 km, and carrying a payload of 250 kg with a power of 5 kW.

Earth observation applications are complementary to satellite applications, and allow to deploy independent and sovereign means of observation, offering permanent observation and unrivaled optical resolution. In addition, they can be moved above inaccessible areas, or ecologically fragile areas, or following a natural disaster.

The Stratobus project was selected in 2016 as part of the “Nouvelle France Industrielle”, which launched the design phase, then selected as part of the European Defense Fund to produce demonstrators which will fly from 2025 in the stratoport of Canarias.

- 22 Space Launchers' international market**
Hervé GILIBERT

In the last decade, the space transportation domain has been subject to a dramatic transformation, in all its dimensions: launch techniques, launchers technologies, industrial organizations, economic model, association and respective contribu-

tions of public and private sectors... Is this domain on the way toward a classical commercial economy?

This question may have no definitive answer at this stage.

Looking at the fundamentals that have led to the emergence of space transportation 60 years ago, analyzing these 60 years of progress and of successive transformations until the current acceleration, one assesses related stakes: considering together the outstanding perspectives for the 2 next decades, the “capital intensive” aspect of the activity, and its strategic and dual nature, one modestly tries to bring light on this question.

CONTEXT, CROSS-CUTTING ISSUES

28 **Legal aspects: frequencies**

Alexandre MARQUET & Thomas WELTER

Satellite-related needs are tightly linked to their communication needs, that are wireless in nature. In this context, and given the global aspect of these deployments, an important part of the legal matters surrounding spatial services is related to the regulatory aspects of radiocommunications. These are handled by the Radiocommunication sector of the International Telecommunication Union (ITU-R) both on the technical and regulatory levels. ANFR is the unique French point of contact to the ITU-R. In this regard, it is in charge of helping the industries and government agencies to fulfil the necessary space-related processes with the Radiocommunication Bureau of the ITU-R, and also with relevant foreign administrations in the framework of coordination. ANFR is also in charge of the technical studies, as well as of the consolidation and defense of French interests related to spectrum/orbit resources.

34 **Regulation of flying objects: a century-old story at the dawn of the digital revolution**

Louis TEODORO, Pascale ROBERT & Orian DHEU

From the origins of prescriptive international air navigation regulations to innovative aviation, the regulatory foundations of international civil aviation seem to have reached their limits. With the major technical developments that digital technology has been bringing to civil aviation for several years now, profound changes to the various certification and approval processes and, more generally, to aviation law will have to be achieved to ensure that passenger and third-party safety levels are maintained.

40 **The myth of disappearing borders**

Jacques ARNOULD

Seeing the Earth from space: the power of astronautics never ceases to fascinate us. Astronauts, who are probably in the best position among us, repeat that, from up there, almost all terrestrial frontiers disappear: a claim that is no doubt exaggerated. Not only do we need to diversify the way we look at reality and ourselves, but we also need to recognise the existence of necessary boundaries, the need to leave and respect our own place and that of our alter egos.

**43 The legal challenges of Earth observation from space
in the context of the new space economy**
Philippe CLERC

This article puts into perspective the public, private and legal issues that have shaped the construction of Earth observation from space, from its origins in the 1960s to the present day in the era of Big Data. It details the most salient features of its legal framework in order to clarify under what conditions such observation is lawful, how investors or operators can protect the results of their efforts, and how their data should be made available on a competitive market or to the general public.

This reflection takes into account the technical and political upheavals that have affected this activity, on a national, European and international scale, following the rise of the conquest of space, the development of computing, the Internet, mobile applications, the globalized digital economy, and then the advent of New Space. All of this has coincided with the emergence of legislation that, on the one hand, ensures intellectual protection, reservation, control and even exclusivity for the use of space-based data, and on the other, imposes free and unrestricted access (open data), while at the same time preserving certain restrictions.

51 Nanosat: a small-scale revolution
Imane EL KHANTOUTI & Didier DONSEZ

The advent of nanosatellites has transformed and democratized the access to space by offering a more economical and modular option compared to traditional satellites. These compact and standardized satellites are used in various fields, from Earth observation to telecommunications, thereby fueling the dynamics of New Space. The deployment of nanosatellites is carried out by private companies and academic institutions. This approach is characterized by lightweight technologies, short development cycles, project management agility, and increased tolerance for failure, distinguishing it from the more conventional approach of Old Space. The New Space ecosystem encompasses a variety of actors, from equipment manufacturers to carriers, launch providers, government agencies, and universities. Despite the opportunities presented by nanosatellites, challenges persist, including the management of space debris, radio interference in communications, and the threat of cyberattacks.

59 A breakthrough technology for detecting and geolocating ships at sea
Rachid NEDJAR & Maël TORCA

As human activities impact more and more our planet every year, our seas and oceans are more than ever at the center of critical challenges regarding biodiversity protection, global warming, disputes between nations or the multiplication of illegal activities that are difficult to contain.

Despite regulations, quotas and controls, legacy maritime safety systems are showing their limitations, and do not provide an exhaustive view of human activities at sea, and their harmful consequences.

Indeed, the maritime areas to be protected are vast, often far from coasts, and cooperative safety systems (AIS, VMS) can be deactivated or manipulated.

Unseenlabs has developed a space-based radiofrequency detection technology to detect, geolocate and track any vessel at sea, cooperative or not, anytime (night and day), anywhere around the globe, regardless weather conditions.

This capacity, fully operational for 5 years now, provides an innovative solution for oceans protection and global security, and opens new horizons for maritime surveillance from space. The aim of this article is to present the key benefits of space-based RF detection for maritime surveillance by illustrating them through multiple concrete use cases.

APPLICATIONS OF EARTH OBSERVATION

68 Cards to heal the world

Sébastien SORIANO

At a time of major environmental change, maps must become compasses for navigating the Anthropocene and correcting our excesses. A whole area of public policy on data needs to be structured. Providing decision-makers with good maps can help them to be ambitious and even courageous. This mapping revolution is both democratic and technological. Democratic, because we must not just open up the data, we must co-construct it and make it a shared resource with those working on the ground. There is a huge challenge here, which is to “de-silo” the initiatives of players who are often fragmented. Technological, because only AI and digital twins will make it possible to drive the necessary changes in time.

73 High altitude technologies to map the territory

Valérie DERÉGNAUCOURT

Spatial imagery, artificial intelligence, LiDAR technology... To map the territory and make aerial and spatial observations speak for themselves, the IGN is constantly deploying a range of cutting-edge technologies. Here are some explanations.

78 Measuring CO₂ emissions from space and understanding their evolution

Philippe LANDIECH & François Marie BRÉON

CO₂ is the main greenhouse gas whose increasing concentration in the atmosphere is responsible for climate change. The “background” concentration, which is increasing annually by around 2.5 ppm, is measured on the ground with very high precision at around a hundred sites around the world. This concentration shows significant seasonal variations, particularly in the northern hemisphere. These variations are due to natural carbon flows: absorption by plants through the process of photosynthesis, emissions during plant respiration, exchanges with ocean water masses, etc. The principle of these exchanges is well understood, but they are still poorly quantified. In addition to the need to know anthropogenic CO₂ emissions and how they change over time, this better quantification of natural flows requires dense measurement of concentrations both spatially and temporally. Space observation is well suited to this objective.

90 Observing the Earth and its atmosphere to improve weather forecasts

Philippe CHAMBON, Quentin LIBOIS & Bruno PIGUET

Météo-France uses weather forecasts to carry out its missions to protect people and goods. These forecasts are based on numerical models, fed by a variety of observations, most of which come from Earth observation satellites. These satellites are constantly being renewed, thanks to the efforts of space agencies. The EUMETSAT

agency, which operates Europe's operational meteorological satellites, is preparing to launch a new generation of space instruments that will enhance forecasting capabilities. At the same time, Météo-France is carrying out research to improve its models using in situ and space observations. Future advances in weather forecasting will rely on more frequent observations at higher spatial resolution with new generations of satellites, as well as the emergence of technologies such as AI.

100 Using altimetry satellites to measure sea level

Cyril GERMINEAUD, Claire DUFAU & Pierre PRANDI

Since the 1990s, satellite altimetry has revolutionized our understanding of ocean dynamics, providing over 30 years of continuous measurements. Altimeter satellites such as TOPEX/Poseidon, Jason-1, Jason-2, Jason-3, and Sentinel-6 MF have accurately monitored the evolution of the global mean sea level. The SWOT mission, launched in 2022, introduces innovative technology with a KaRIn interferometric radar, allowing spatial resolution ten times higher than classical altimeter satellites. This advance provides an unprecedented view of fine-scale structures in ocean circulation. An increase of about 10 cm has been observed since 1993, with a significant acceleration since the late 2000s. Two main factors contribute to this increase: the thermal expansion of the oceans, which absorb the excess energy (in the form of heat) generated by human activities in the Earth system, and the contribution of melting ice sheets and mountain glaciers. However, this elevation masks very significant regional variations, which can be observed using satellite altimetry. The risk of coastal flooding due to sea level rise is a major economic challenge. Coastal communities around the world face threats that require adaptive solutions. Initiatives such as LITTOSCOPE in France are using satellite data to assess flood risks, anticipate impacts and propose solutions to reduce the vulnerability of coastal areas. In summary, satellite altimetry has been instrumental in understanding ocean dynamics at different spatial and temporal scales, measuring sea level rise, and anticipating flood risks. Technological advances, such as SWOT's KaRIn radar, are opening new perspectives for even more detailed ocean observations, providing critical information to address the challenges posed by climate change.

108 Using satellite data to monitor improvements in farming practices

Antoine LEFEBVRE

Considered an imperative if we are to meet the challenges of the environment and climate change, the transition in agriculture is now being driven by ambitious political objectives and funding programmes. These require the use of measurement solutions that combine objectivity, geographical scope and responsiveness. The satellite analysis products developed by Kermap meet these challenges. They help to consolidate the environmental value chain in the agricultural sector by delivering reliable, enforceable indicators on sustainable agricultural practices: crop diversification, soil cover, grassland management, agro-ecological infrastructure and irrigation. This is a practical way of putting satellite imagery data to work, and echoes the objectives of the France 2030 plan, which aims to create innovative players to harness spatial data for the benefit of the ecological transition.

DEFENCE AND SECURITY**117 Space, a strategic challenge**

Commander Alexandre ARKWRIGHT

Today, space has become the nerve centre for an exponential number of services that are vital to our societies, from GPS and telecommunications to imaging and weather forecasting. This increase in space activity is leading to an increase in risks and the emergence of threats in this environment. The description of this major development, its tangible visible effects and the consequences for the armed forces deserve to be detailed in order to have a realistic vision of space, which is often perceived as remote, inaccessible and peaceful, whereas everything points to the contrary. The Space Command (CDE) embodies France's military space ambitions. It contributes to the definition of military space policy and implements it. It also conducts military space operations. The French Air Force, through the CDE, plays a key role in the development of defence space, so that France can maintain its freedom of action in space in the interests of our strategic autonomy. The challenges ahead are significant but exciting.

122 Harnessing the potential of New Space for foreign intelligence

Nicolas LERNER

The advent of New Space represents a major opportunity for intelligence services. Indeed, constellations of nanosatellites offer unprecedented possibilities for monitoring global telecommunications. However, to fully exploit the potential of this new sensor for intelligence, several significant challenges remain to be addressed:

- we must build close and mutually beneficial partnerships with innovative French companies in the New Space sector, with a dual approach;
- we must prepare to integrate this sensor into a “multi-sensor” strategy, considering it not as a capability merely added alongside historical capabilities, but as a new cog in a multi-faceted intelligence apparatus;
- finally, and this is probably the most significant aspect, we must immediately increase our capacity to process, exploit, and analyze the ever-growing volumes of data we collect on international networks, leveraging artificial intelligence.

127 How hybrid propulsion can help restore French and European sovereignty over access to space

Sylvain BATAILLARD

Since the beginning of the space race, we have been using the same propulsion technology: liquid propulsion. The majority of space industry players are racing on the same track... While some have decided to pave a new path: hybrid propulsion. The promise is simple, a 75% reduction in launch costs, which could even allow us to catch up with the biggest players. However, there is a technological barrier preventing this technology from being used on large vehicles. HyPrSpace, a Bordeaux-based startup, believes they have found a way to bypass this barrier and achieve the holy grail of propulsion.

- 132 Military satellite communications (MilSatCom):
a necessity for the connected soldier**
Vincent SATGE & Grégoire CHAUCHAT

The growing need for connectivity for the armed forces is an ever-increasing reality. In addition to simply increasing connectivity, the SatCom offers incomparable advantages in terms of elongation, making it indispensable in certain use cases. Faced with the development of commercial constellations in low-Earth orbit, the military SatCom must now coexist with its civilian counterpart for the benefit of the military forces. The latter who will benefit from the advantages of the SatCom's diversity (civilian/military duality; geostationary/medium or low-Earth orbit complementarity).

TELECOMS AND SETELLITE POSITIONING

- 138 A tsunami in satellite telecommunications**
Didier LE BOULC'H

The field of communication satellites does not escape from a tsunami of change. The successful arrival of new verticalized actors such as Starlink constellation from Space X, the evolutions in usage through the success of streaming platforms, the fast progress of digitization and virtualization, the convergence with terrestrial standards coming from Mobile World (3GPP standards), the increased interest from terrestrial telecom operators to expand their network through satellite, the change of financing scheme, and finally an increased sensitivity to sustainability and (Life Cycle Assessment reduction) are key factors that are deeply changing the satcom ecosystem. Ongoing heavy developments enable to face those challenges. The commercial space sector used to be somewhat conservative (no easy repair in orbit...) it is now heading a "never seen before" pace of innovation.

- 143 The use of Satcom systems for civil
and government applications**
Hervé POSTEC

Satellite communications systems are essential for both civil and government uses. They rely on satellites in geostationary, medium and low orbit, providing global connectivity. Civilian applications include global telecommunications, satellite television, and bridging the digital divide. Governments use Satcoms for strategic needs, taking advantage of their global reach.

The resilience of Satcoms is crucial in the event of major crises. Satellites provide robust connectivity, even if terrestrial infrastructure is destroyed.

Technological developments, including low-orbit constellations and flexible satellites, are shaping the future of Satcom. In conclusion, these systems play a key role in our technological landscape, requiring constant vigilance in the face of developments.

- 147 Convergence of the Telecommunication systems
with 5G and 6G**
Flavien RONTEIX, Mohamed EL JAAFARI,
Dorin PANAITOPOL & Nicolas CHUBERRE

One observe a profound evolution in the communication networks towards the convergence of access technologies. The integration of satellite access with

terrestrial mobile networks is enabled by the 3GPP Non-Terrestrial Network (NTN). The satellite network component can contribute to the global service continuity and resiliency of mobile systems. Leveraging the terrestrial 5G access technology, a number of solutions mitigating the issues inherent from satellite communications specifics (e.g. Doppler, delay...) have been standardized in Rel-17 of 3GPP under the so called NTN (Non-Terrestrial Network) standard. In the 5G-Advanced (starting from Rel-18), further NTN added value will be unleashed by the usage of regenerative payload architecture and performance optimization enablers. In the ITU IMT-2030's vision, the 6G will bring new network capabilities to support the interactions between the human and its physical environment leveraging real time digital modelling. In particular 6G will see the unification of the TN and NTN into a multi-dimensional architecture enabled by a set of innovative technologies and concept at both radio and network levels.

157 The standardization of networking reaches space

Marc BLANCHET & Vinton G. CERF

Up to now, communications are largely direct between terrestrial infrastructures and devices in space. Parallel to space conquest, the Internet has conquered the Earth and the mobile networks have been deployed. Each of these domains have a standards body. With the major technology innovations and the significant cost reductions, the space conquest brings new providers offering various services in space, starting with Moon and around. A network is currently planned to be deployed insuring optimal utilisation of communications. The standardization of the network technologies is the key to provide interoperability between all future services. This article discusses the standards and provides an overview of the network technologies that will be used not only on Moon and around, but also for Mars and beyond.

Issue editors

Nicolas KUHN and Laurent TOUTAIN