

Towards disruptions in Earth observation? New Earth Observation systems and markets evolution: Possible scenarios and impacts[☆]



Gil Denis^{a,*}, Alain Claverie^a, Xavier Pasco^b, Jean-Pierre Darnis^c, Benoît de Maupeou^a, Murielle Lafaye^d, Eric Morel^a

^a Airbus Defence and Space, 31 rue des cosmonautes, 31402 Toulouse, France

^b Fondation pour la Recherche Stratégique, 4 bis rue des pâtures, 75016 Paris, France

^c Istituto Affari Internazionali, Internazionali, Via Angelo Brunetti, 9, 00186 Roma, Italy

^d Centre National d'Etudes Spatiales, 18 avenue Edouard Belin, 31401 Toulouse, France

ARTICLE INFO

Keywords:

Earth Observation
New space
Very high resolution
Revisit
GEOINT
Constellations
Services
Business models

ABSTRACT

This paper reviews the trends in Earth observation (EO) and the possible impacts on markets of the new initiatives, launched either by existing providers of EO data or by new players, privately funded. After a presentation of the existing models, the paper discusses the new approaches, addressing both commercial and institutional markets. New concepts for the very high resolution markets, in Europe and in the US, are the main focus of this analysis. Two complementary perspectives are summarised: on the one hand, the type of system and its operational performance and, on the other, the related business models, concepts of operation and ownership schemes.

Until now, Earth observation systems for the most critical institutional needs are mainly dedicated assets owned and operated by governments or public organisations, often at national level. Even in the case of dual use missions, the governmental and commercial operations are in general fully segregated for the very high resolution satellites.

Recent evolutions could affect this paradigm. Firstly, the increased performance of commercial satellites has a high degree of convergence with defence needs: 25–30 cm resolution is now the benchmark or at least a very short term target for commercial missions. The second evolution is the development of hybrid procurement schemes, combining proprietary missions and data buy framework contracts, partly triggered by the budgetary constraints of public customers, some failures in the execution of large spy satellites contracts and by the willingness to foster the competitiveness of industry on the export market.

New space is another trend, which is more disruptive. This trend begun in the Silicon Valley and spread worldwide, arousing our expectations, sometimes excessively. This new model involves not only start-ups but also big web actors with substantial investment capacity. Both aim to transforming space into a commodity, taking benefit from the convergence between Information technology and EO. Beside the massive constellations for broadband Internet access, some initiatives have been launched for Earth observation markets, targeting high resolution and high revisit. Last but not least, more and more countries, the newcomers, invest in their own EO capacity, confirming the soft power dimension of space but also opening new opportunities for international or regional cooperation.

As many unpredictable events may occur, even in a short time frame, the last part of the paper has a prospective dimension. Based on market trends and industrial stakes, it discusses the realism and likelihood of possible scenarios and identifies their impacts on the EO landscape and the main stakeholders involved, in particular in Europe:

- The governmental and institutional actors, using Earth observation data for their operational missions, with an evolving balance between sovereign assets and external services.
- The commercial operators of very high resolution satellites, with the new market opportunities and the possible emergence of worldwide champions.

[☆] Special thanks to Fabienne Grazzini, Nathalie Pisot, Marie-Christine Delucq, Rob Postma, Laura-Kate Wilson, Magalie Vaissière (ESA), David Hello (Terranis), Lionel Kerrel (GEO4i).

* Corresponding author.

E-mail addresses: gil.denis@airbus.com (G. Denis), alain.claverie@airbus.com (A. Claverie), x.pasco@frstrategie.org (X. Pasco), jp.darnis@iai.it (J.-P. Darnis), benoit.demaupou@airbus.com (B. de Maupeou), murielle.lafaye@cnes.fr (M. Lafaye), eric.morel@airbus.com (E. Morel).

<http://dx.doi.org/10.1016/j.actaastro.2017.04.034>

Received 16 December 2016; Accepted 26 April 2017

Available online 04 May 2017

0094-5765/ © 2017 IAA. Published by Elsevier Ltd. All rights reserved.

- The satellite manufacturers and their competitiveness.
- The role of nations and space agencies, including the non-dependence or national sovereignty and international cooperation dimensions.

Based on the comparison of three “radical” scenarios, the conclusion shows that there are opportunities for service providers and satellite manufacturers. Even without clear answer to the future industrial, technical and political structure of EO systems, relevant indicators to be monitored during the next three-five years are identified. The last section focuses on Europe and the role of institutions in order to support European champions and small and medium companies in the new worldwide competition.

Nomenclature

BA	business Angel	IDIQ	indefinite Delivery Indefinite Quantity
BASIC	broad Area Satellite Imagery Collection	IMINT	image Intelligence
B2B	business to business	IOT	internet Of Things
B2C	business to consumer	IT	information Technologies
B2G	business to government	ITAR	international Traffic in arms Regulations
CAGR	compound annual growth rate	KH	key Hole satellites family
CE90	circular Error at 90% confidence	LBS	location-Based Services
CIBORG	commercial Initiative to Buy Operationally Responsive GEOINT	LEO	low Earth Orbit
CMG	control moment gyroscope	MR	medium Resolution
CNES	centre National d’Etudes Spatiales	MS	member States (Europe)
COTS	commercial-off-the-shelf	MTF	modulation Transfer Function
CRADA	cooperative R&D Agreement	MS	member State
CVC	corporate Venture Capital	NGA	National Geospatial Agency
DAP	direct Access Partner (Digital Globe)	NIIRS	National Imagery Interpretability Rating Scale
DARPA	defense Advanced Research Projects Agency	NIMA	National Imagery and Mapping Agency
DEM	digital Elevation Model	NRO	National reconnaissance office
DGA	délégation Générale pour l’Armement.	NSG	National System for Geospatial Intelligence
DOD	US Department of Defence	NSP	National Security Policy
DRS	direct Receiving Station (Airbus Defence and Space)	NSR	Northern Sky Research
DSP	délégation de Service Public (contractual scheme for the commercial distribution of Pleiades imagery)	NTM	National Technical Means
DTM	digital Terrain Model	PAN	panchromatic imagery
EAR	export Administration Regulations	PDD	Presidential Decision Directive
EARSC	European Association of Remote Sensing Companies	PPP	Public Private Partnership
EC	European Commission	P/F	platform
EDRS	European Data Relay Satellite	R&D	research and development
EO	Earth Observation	SAR	synthetic Aperture Radar
EU	European Union	SLA	service Level Agreement
EUSC	European Union Satellite Centre	SIA	satellite Industry Association
FIA	future imagery Architecture	S/C	spacecraft
G2G	Government to government	SME	small and Medium enterprise
GCP	Ground Control Point	SSO	Sun Synchronous Orbit
GFW	global Forest Watch	UAV	unmanned Aircraft Vehicle
GSD	ground Sampling Distance	VC	venture Capital
HR	high Resolution	VHR	very High Resolution
		WB	World Bank
		WRI	World Research Institute
		XS	multispectral imagery

1. Objectives and structure of the paper

1.1. Overview

This paper reviews the new initiatives and new trends in Earth observation (EO). Addressing both commercial and institutional applications of optical satellites, new systems and concepts for the very high resolution markets are the main focus of this analysis. Earth observation systems for the most critical institutional needs, including the defence intelligence, are mainly dedicated assets owned and operated by governments or public organisations. Recent evolutions, such as the high degree of convergence between the defence needs and the commercial capacities (30-cm resolution is the new benchmark), challenge this paradigm. Three categories of stakeholders are involved: the established commercial operators, the

so-called new space actors, aiming at transforming space as a commodity, and nations with new ambitions in space, as instrument of sovereignty and soft power.

While many papers address the conditions likely to attract private investment and venture capital by imitating the Silicon Valley spirit, our analysis focuses on the market and industrial dimension of Earth Observation imagery and related services. Both for large and small companies, investors or shareholders will support new initiatives if there is a good growth potential. Three “radical” scenarios, with very distinct growth options are analysed. Driving factors are identified as well as the consequences (threats and opportunities) on the stakeholders. One of the key issues addressed is to assess if the current champions can be disrupted by the new players. Some recommendations are also proposed.

1.2. Structure of the paper

Section 2 introduces the current landscape of Earth Observation and the main changes. It also draws an historical perspective, highlighting the evolution of policy context and international environment since the first spy-satellites launched during the cold war. In Section 3, we describe the challenges faced by the data providers and satellites manufacturers: higher resolution and higher revisit, a bit like trying to square the circle. The profile of the main stakeholders is summarised in Section 4, with a specific focus on New Space trends and its actors, often privately funded.

Section 5 describes the recent evolution of the market and the new perspectives in this new context. Scenarios for the future identified as possible evolutions and their consequences on the role and influence of the various stakeholders are presented in Section 6. Section 7 provides a wider perspective of disruptions in GEOINT with some considerations about the strategic scenarios for Europe, where new space actors are currently nearly absent.

2. Setting the scene: historical perspective and new trends

2.1. Introduction

Different types of Earth observation models have been developed over the last forty years bringing significant changes in paradigms:

- Public data with Landsat in the US.
- Development of the commercial market initiated by Spot image (1986) and then by Digital Globe.
- National support to private companies by nations thought anchor tenant contracts: Digital globe backed by the National Geospatial Agency (NGA).
- Development of dual systems (defence and commercial): Cosmo Skymed and Pleiades.
- Purely private investment for SPOT-6 and SPOT-7.
- Development of shared satellites and virtual constellations (DMC, Disaster Monitoring Constellation).
- The so-called “New space” era and the recent development of Earth Observations constellations.

2.2. New space and old recipes: historical perspective, evolution of policy context and international environment

2.2.1. This old good New space

New Space is new, until a newer disruption arrives... Since the launch of Landsat 1 in 1972 and the failed attempt to privatize this programme with EOSAT (Earth Observation Satellite Company), several disruptive events have shape the EO history.

2.2.2. SPOT 1: the advent of commercial era

From this point of view, in 1986, SPOT 1 launch and the decision of the French government and CNES to use a commercial model for image distribution were a revolution.

Two months after this launch, SPOT 1 was tasked to acquire the first 10-meter images after the explosion of reactor n°4 at the Chernobyl nuclear plant in Ukraine (Fig. 1). These images demonstrated the potential role of commercial satellites in support of intelligence missions: no other imagery, either from civil satellites (Landsat resolution was too coarse) or from US spy satellites (the images were classified), was able to witness the reality of the disaster behind the Iron Curtain.

SPOT 1 demonstrated one of the main benefits of commercial remote sensing for intelligence missions: that it can be shared with anyone. The US newspaper “USA today” called SPOT satellite “*The ultimate skycam*”. In the nineties the French took the leading role in this commercial market although the data sales revenues covered only the cost of satellite operations.

2.2.3. Towards US leadership on the commercial market

Already in 1983, Spot Image Corporation was considered by the Wall Street Journal as an “Invader”, illustrating the willingness of the US government to restore the US dominance on this market. In the seventies Carter’s Administration identified the opportunity for the US to develop a commercial market in order to capitalize on the huge investment in space already done.

Taking into account the lessons learnt, successive US Administrations (Reagan, Bush and Clinton) built up the foundation of the US policy on the commercial market expressed in the Clinton Administration Policy on Remote Sensing Licensing and Exports (1994).

An important milestone is undoubtedly the launch of Ikonos-2 in September 1999: Ikonos-2 was the first commercial Earth Observation able to collect images with a ground sampling distance below 1-meter (0.82 m GSD at Nadir in panchromatic mode). US took the lead of the race for higher resolution (ref [1]).

Innovative approaches adopted by NGA, such as Clearview, NextView and Enhanced View, awarded to Digital Globe and Space Imaging in 2003, were the cornerstones for the implementation of the new US policies. They have substantially changed the procurement schemes: instead of relying only on dedicated assets owned and operated by governments, often at national level, these framework programmes were the first Private Public Partnership (PPP) in Earth Observation.

2.2.4. Autonomy or dominance

For security concerns US Administrations for the two last decades have favoured Commercial Services aimed at minimizing the proliferation or the uncontrolled dissemination of very high resolution images. US players, such as Digital Globe, offer the best resolution to deter countries who could plan to acquire their own EO satellites. Robert Cardillo, director of the NGA, recently stated (Ref [2]): “*I recognize that there are two sides to the world’s growing transparency*”.

2.2.5. Google Earth: the beginning of “New Space”

In this context, the introduction of Google Earth in June 2005, based on a virtual globe created by Keyhole Inc., triggered also a disruption, in democratising access to satellite imagery, even if criticisms have been made with respect to the threat to privacy or national security.

Google Earth opened the door to full private investment from non-Space players.

2.2.6. HELIOS, a unique example of cooperation in EO for defence

The implementation of French political decisions to acquire France’s own optical space system (HELIOS 1) in 1984 in support of national sovereignty and nuclear deterrence policy has taken full benefit of the SPOT experience, paving the way of the future duality concept.

HELIOS 1 and SPOT 4 were based on the same platform built by former Matra Espace (now Airbus Defence and Space), the optical



Fig. 1. In 1986, Chernobyl disaster seen by SPOT 1. Copyright CNES - Distribution Airbus DS

instruments for both systems built by former Aérospatiale Cannes (now TAS). CNES expertise on overall system architecture, control ground segment, user ground segment and operations (Spot Image) was key for support the development of the HELIOS ground system and its handover by the military users for the operations and maintenance.

HELIOS remains the unique prototype of international military cooperation in space imagery. Spain, Italy, for HELIOS 1, and then Belgian, Greece, Germany have the right to task HELIOS 2 satellites for their own needs following specific arbitration rules under government to government (G2G) agreements, and to receive and process the corresponding images. As compensation, the national partners fund the participation of their industry to the realization of part of the satellites and the ground segments, or, for Italy and Germany, exchange SAR data, coming from respectively Cosmo Skymed and SAR-Lupe satellites for HELIOS optical data.

2.2.7. Towards dual use and export markets

15 years after HELIOS, the Pleiades system was designed as a full dual system, able to provide imagery to both commercial/civil and military users with appropriate security and priority rules. After 5 years of operations this duality concept is considered as a success. Italy with Cosmo-Skymed implemented the same concept: the satellites are shared between the defence organisation and the commercial ones. This model is an alternative of the US one to respond to the lack of market maturity.

In parallel, in the middle of nineties, France and the United Kingdom developed earth observation satellites for the export market, under ITAR regulation. The rationale of this market is to offer to space as instruments of sovereignty:

- Integrity of the image (no modification by third parties).
- Full access of the satellite resources.
- Confidentiality of national areas of interest.

2.2.8. SPOT-6: when EO satellites are privately funded

Another major innovation occurred in France in 2012 with the launch of SPOT-6, aimed at ensuring the continuity of wide-swath high-resolution observation services provided by the SPOT-5 mission.

In this case, the disruption is the funding model: while the two Pleiades spacecraft were publicly funded, SPOT-6 and SPOT-7 opened a new era: for the first time in the remote-sensing industry, satellite development costs have been funded entirely with private funds provided by Airbus Defence and Space.

2.2.9. Radar case

The commercial High resolution radar satellites emerged in 1995 in Canada with Radarsat-1 operated by MDA. In 2007, Italy launched the first radar constellation of 4 satellites, this system is dual.

The German joint venture between the DLR and Airbus Defence and Space has developed a radar system: TerraSAR-X (2007) and its twin satellite TanDEM-X (2010). The key application is WorldDEM, a worldwide high accuracy Digital Elevation Model (DEM). It is worthwhile mentioning that there is no commercial SAR system in the US.

2.2.10. New space, at the crossroads of space and IT

New Space can be considered as the meeting of the Space world with the IT (Information Technology) one. The first one has developed the relevant concepts with the associated technologies: e-Corve, Rapid Eye, when the second one brings the massive development of the Information technology (big data, analytics) with full private investment. As usual in the IT world, some of these new players will disappear but some of them will survive, supported by the NGA's willingness to consider emerging players to diversify its imagery supply.

Over time, satellite EO-based services were provided towards private customers increasing revenues and competitiveness of services industry. But until recently, acquisition of satellite assets was only

affordable for governments or major economic actors. EO-based services providers were made sustainable mainly through government and public procurement.

In parallel, development of the internet increased mass market interest for geo-information. This context was favourable for cross-fertilizing space EO imagery with digital economy, paving the way to new businesses and services.

2.3. A wind of change in the atmosphere?

The advent of New Space applied to Earth observation is the last and most visible change (Ref [3]), with the first start-ups, such as Skybox Imaging (today Terra Bella), created in 2009, and Planet Labs (today Planet), founded in 2010, proposing constellations of several small or medium and low-cost satellites. Their objective is to propose revolutionary operational and business models with cost effective services combining high resolution and high revisit.

Providing administrations with space imagery and information added-value products on an operational basis promoted development of new companies and employment. The expected development of procurement of geo-information services by US administrations reinforced motivation of entrepreneurs for developing commercial offers using space assets. This impulse at developing new business using satellite EO-based services found a favourable relay towards venture capitalists. Benefiting from first achievements obtained by Space-X and Blue origin, the space sector was identified as a new promising sector for making business.

Last but not least, even if less publicized than the new space ventures, new countries invest in earth observation capacities. Some of them (Russia, India, China, South Korea) are already active and recognised players but show new ambitions. There are also newcomers, buying or building earth observation satellites, as instrument of sovereignty or soft power, to ensure an independent access to imagery or to develop its industry.

For the "Traditional Space" the resolution has been a significant advantage to drive the business within the last 30 years, it moved from 10 m (Spot 1) to 31 cm (Worldview-4). New Space entrepreneurs target the revisit through consequent constellations with medium or high resolution sensors. The change of paradigm is not limited to the New Space initiatives coming from Silicon Valley:

- Airbus Defence & Space for the first time transferred one of its satellite (SPOT 7) to Azerbaijan (Azersky) in the frame of a wider cooperation agreement.
- SSTL has created a new hybrid model with DMC3, a satellite constellation of 3 1 m GSD satellites fully leased by a single company from China (21AT).
- On the export market with PerúSAT-1, Airbus Defence & Space has built up a new type of offer combining services (immediate access to the Airbus fleet of satellites) and classic satellite export.
- Through full ground segment interoperability, both Airbus Defence & Space with Azercosmos and Digital Globe with Taqnia have developed strategic partnerships for the exploitation of satellite constellations.

2.4. Current landscape of Earth Observation

In a nutshell, the current landscape of VHR EO can be summarised through following trends:

2.4.1. Customer needs and technical performance

- The performance of commercial satellites is increasing: high degree of convergence with the defence needs. 25–30 cm resolution is now the benchmark or at least a very short term target for the commercial missions.

- Other performance criteria are becoming more and more important for institutional and commercial operators on top of GSD: volume of acquired surface per day, reactivity and revisit frequency, image freshness, video capability, multispectral capability, automatic processing, delivery mechanisms, etc.
- The performance of ground infrastructures and distribution platforms (data and services) becomes paramount: huge increase of space imagery data to be processed exploited and distributed.
- Satellite lifetime is much longer (10 years) than before, enabling a better business case.

2.4.2. Market and competition

- There is a continuous and worldwide growth of the VHR imagery market.
- Military institutions especially in US are increasingly reliant on VHR commercial imagery providers with appropriate security rules.
- The value chain is shifting from the raw data to services and applications.
- Value for money: there is a strong pressure to reduce infrastructure and operational costs.
- Hybrid procurement schemes, combining proprietary missions and data buy framework contracts, partly triggered by the budgetary constraints of public customers and nations.
- Increasingly, the new comer countries invest in their own EO capacity, confirming the soft power dimension of space but also opening new opportunities for international co-operation or commercial agreements.
- New space and disruptive initiatives are not only developed by start-ups but also by large web actors with a huge investment capacity. Both aim at transforming space as a commodity.
- To complete this global picture, new players are targeting the export market: South Korea, China and Israel.

2.4.3. Regulations

- VHR Imagery remains highly sensitive information and legislation could continue to evolve impacting the new business models.

3. The digital Earth challenge: one Earth, one meter, one day... or more?

3.1. High resolution and high revisit: like squaring the circle around the Earth

Commercial providers of EO imagery are used to say that resolution or Ground Sampling Distance (GSD) is not the sole criterion for choosing a geospatial data source. Depending on the specific application, revisit time, speed of delivery to the customer, radiometric and spectral quality, geolocation accuracy and acquisition capacity (km^2/day) are other key performance factors.

Nevertheless, both for defence and commercial markets, there is a worldwide and continuous race for sharper images and higher revisit (Fig. 2).

For Low Earth Orbit, increasing the resolution of the sensor means that the swath, the area covered by the satellite during its pass over a region, becomes smaller. In the case of polar orbits, it means a longer revisit time for a given area as the satellite orbits the globe (the typical cycle is 14 orbits per day).

In order to serve many applications requiring both data freshness and regular updates (e.g. agriculture, site monitoring for intelligence or geo-marketing).

Basically, swath and number of orbits per day give an indication of the number of satellites needed for a daily coverage of the whole Earth. In their quest for better performance and acquisition capacity, en-

gineers and satellites try to find the smarter trade-off between resolution and revisit for a specific market.

For a given GSD, several solutions can reduce the revisit time and increase the acquisition capacity: steerable mirrors, agility of the platform or multiple satellites, specific orbits (geo-synchronous, inclination), etc. Beyond a single satellite, small or large constellations are popular solutions. While the established data providers rely on small or virtual constellations of agile satellites, new comers seem to bet on a large number of small and low-cost satellites. It is worthwhile recalling a couple of basic rules of physics and space mechanics in order to better understand the current and future initiatives and business cases.

3.2. New space and old physics

10 m, 1 m, 50 cm... 30 cm GSD is the new benchmark for very high resolution satellites.

Commercial and marketing people would like to believe that Moore's law, predicting that the density of integrated circuits doubles approximately every two years, drives also the evolution of the resolution of earth observation satellites.

Unfortunately, system engineers and optical specialists temper their enthusiasm each time they recall that Kepler's law and Rayleigh's Criterion remain applicable. The first one is related to the orbit parameters and the second one to the performance of an earth observation instrument.

In a nutshell, Kepler's law states that a space-borne sensor can't fly at low altitudes and stay stationary over our heads. Roughly speaking, Kepler caps the revisit time and acquisition capacity of a single, nadir-pointing satellite.

Rayleigh's criterion defines the minimum resolvable detail for a specific observation instrument. The resolution of any imaging system is limited by diffraction. For a given wavelength, the angular resolution is inversely proportional to the aperture of the instrument (i.e. the diameter of the main mirror). Other parameters such as the Modular Transfer Function (MTF) are used to specify optical performance but Rayleigh's criterion is very useful for a first and simple estimate.

The aperture of the instrument and the size and mass of the mirror are key difficulties facing the satellite manufacturers. A large telescope needs a large satellite.

Even with the miniaturisation of components, ensuring the accurate and stable but rapid pointing of a large instrument requires a sophisticated platform, with star-trackers, accurate inertial measurement units and control moment gyroscopes (CMG).

This is not always cutting-edge technology but, even with a product approach, that comes at a cost, in particular for the small number of "exquisite satellites" used for reconnaissance or for dual-use applications.

New space actors target less expensive data collection systems, with compromises or new approaches on the image performance features. It



Fig. 2. The Digital Earth challenge, a wealth of pixels.

does not mean poor performance: integration with IT and software open new avenues, such as a new breakdown of functions between space and ground segments or advanced data processing and fusion with GCP/DTM in order to mitigate the reduced stability of smaller platforms (e.g. Blackbridge announced 10 m CE90 accuracy using Landsat GCP, suitable for some applications).

New space actors make the assumption that commercial VHR systems are firstly designed to meet the needs of defence and governmental users.

From their point of view, they are therefore not always well suited for commercial applications (e.g. cost, revisit time, global coverage) and a large proportion of the resource is pre-empted, leaving limited capacity for civilian use. Pleiades dual use model is a notable exception.

It explains also why the new space initiatives shall not be seen as a homogeneous trend. Design choices made by Planet, Terra Bella or UrtheCast, focusing either on resolution or revisit show different visions of business and markets to be addressed.

3.3. Small pixels and big data

An important driver is the volume of data captured each day by the Earth Observation Systems. Even before the era of new space, there were two main approaches:

- Capture every point each day (as meteorological satellites do in LEO such as Metop or Terra).
- Capture any point each day (the operational model for most of the current VHR satellites such as Pleiades or WorldView-3).

The main EO data providers use the second option. Some of the New Space actors have chosen the first solution, possibly limited to land surface area (29% of the Earth’s surface area).

3.3.1. A wealth of pixels

In both cases, a wealth of pixels is acquired by the satellite instrument. The first option is obviously the most challenging one in terms of data volumes: for instance 57 terapixels (tera=10¹²) for a full Earth coverage at 3 m GSD or 5.7 petapixels (peta=10¹⁵) at 30 cm GSD. Focusing on land surfaces only reduces the total volume by a factor of 3.

Even with a very efficient image compression algorithm and a datalink offering a comfortable bandwidth, the transmission time between the spacecraft and the ground remains significant.

As there are only few minutes of visibility between the ground receiving station and the satellites, the number of ground stations shall

fit the total capacity of the system. An alternative is the use of data relay satellites (such as EDRS already implement on some Copernicus satellites).

It is worthwhile mentioning that the performance of the future satellite system will depend increasingly on its ground-based infrastructure.

Last but not least, access to space remains a key issue: new launcher concepts targeting affordable access to space for small or medium-size satellites are emerging but they have still to demonstrate the reliability and their performance. Fig. 3 summarises the “Digital Earth Challenge”.

3.4. The needs of defence and intelligence

It is, of course, not possible to discuss the detailed requirements of the main intelligence missions and to describe the performance of current or planned system. But it is worthwhile having a look on the National Imagery Interpretability Rating Scale (NIIRS) and the main GSD thresholds enabling a particular intelligence task (detection, reconnaissance or identification).

Even if developed in the early seventies, the National Imagery Interpretability Rating Scale remains a very useful scale. Originated in the Intelligence Community, NIIRS is a task-based scale for rating imagery acquired from imaging systems. It was defined in order to predict image interpretability: this analysis cannot be done from simple physical image quality measures (such as GSD or MTF). The NIIRS consists of 10 graduated levels 0–9, with several interpretation tasks or criteria within each level. With a NIIRS 2 panchromatic image, for example, image analysts are able to detect large hangars at an airfield, while on NIIRS 6 imagery they are able to distinguish between models of small/medium helicopters.

Five typical GSD thresholds can be defined with respect to the main geo-intelligence tasks (detection, reconnaissance, identification and description):

- Above 10 m, the detection performance is poor. It reaches only 25% for an image with a 10-m GSD.
- Around 4–5 m, satisfaction rate for detection reaches 50% and first reconnaissance of large assets (buildings, vessels) becomes possible.
- Between 1 and 2 m, the reconnaissance performance increases significantly but identification hit rate remains poor.
- Identification tasks are performed much more efficiently (satisfaction above 50%) with a GSD around 30–40 cm.
- 10–15 cm GSD images enable detailed description.

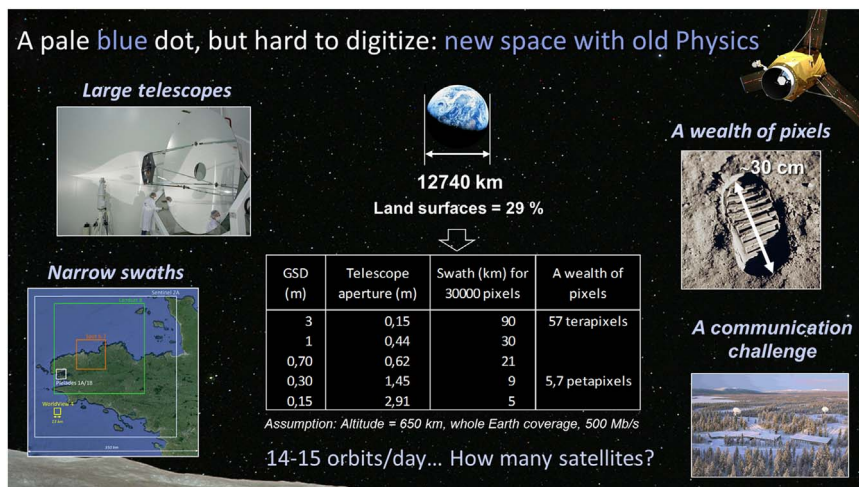


Fig. 3. When New space meets old physics: a pale blue dot, hard to digitize. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article)

The minimal requirements to meet NGA needs with commercial imagery (3 mission layers such as BASIC) can be found in the report of the expert panel chaired by Peter Marino in 2007 (ref [4]).

4. A new game of thrones: the usual suspects, the space invaders and new nations in a worldwide competition

This section gives an overview of the EO imagery landscape in September 2016 with a short presentation of the main providers of EO data and services.

4.1. Main providers of EO data and services

4.1.1. The usual suspects

The two champions are Digital Globe (US) and Airbus Defence and Space (Europe).

DigitalGlobe is today the worldwide leader. It offers today the sharpest imagery (30 cm GSD) with WorldView-3 and WorldView-4 (launched in November 2016). DG's first market is US administration (63.7% in 2015 and 2016) with 55% for NGA as anchor customer (framework contract). In 2015, DigitalGlobe communicated on its "steady business with the U.S. and other governmental customers" compared to disappointing results to the private sector showing the challenge to address both non-governmental customers and a large number of customers (Ref [5]). DigitalGlobe and TAQIA (Saudi Arabia) recently entered a joint venture for a small constellation. Since June 2014, DigitalGlobe is allowed by US government to collect and sell imagery at the best available resolutions (up to 25 cm panchromatic and 1.0 m multispectral GSD). In February 2017, Digital Globe entered into a merger agreement with MacDonald, Dettwiler and Associates Ltd.

Airbus Defence and Space Intelligence division is the second champion and first commercial operator: SPOT 1 operations started in 1986. Its uniqueness is the capacity to offer both VHR optical (Pleiades-1A and Pleiades 1B) and X-band radar imagery (TerraSAR-X and TanDEM-X). Airbus Defence and Space provides also HR / wide swath imagery with SPOT-6 and SPOT-7. There is no major anchor tenancy contract but the twin Pleiades satellites have been funded by the French government, in a dual use scheme.

It was not anymore the case for SPOT 6 and SPOT 7: satellite development costs have been funded entirely by private funds provided by Airbus Defence and Space. The first market is the commercial market. The Geo-intelligence division is backed by Airbus Defence and Space (Space Systems) for the development of new satellites. For Airbus Defence and Space, the next important milestone is the estimated end of life of Pleiades-1A and Pleiades-1B around year 2020 (Pleiades follow-on, end of DSP). Timely and predictable renewal of space assets, performance improvement (resolution and revisit) and continuity of data supply are essential conditions to maintain customers' trust and fidelity. As announced at the World Satellite Business Week by Nicolas Chamussy, Head of the Business Line Space Systems, Airbus Defence and Space is designing and building a new constellation of optical satellites, comprising four identical and very agile sensors delivering very high-resolution imagery.

Despite their differences, DigitalGlobe and Airbus Defence and Space share similar elements of profile: they deliver high quality VHR imagery (up to 30 cm), with a focus on acquisition capacity and powerful distribution services, based on a fleet of agile satellites with large telescopes for VHR imagery, direct receiving stations (DAP or DRS) and networks of distributors. Most of their revenues come from image sales, direct access and delivery services, targeting both domestic and export markets. They propose information services, mainly through vertical markets, including defence.

The other established commercial actors are Imagesat International

(Israel), e-GEOS (Italy). Imagesat International operates the family of EROS satellites. EROS-B delivers 0.7 m GSD at nadir from 510 km. The swath is 7 km. EROS-C is expected to be launched in 2019. It will deliver 0.4 m GSD from 500 km. e-GEOS operates the Cosmo-SkyMed SAR constellation and distributes Digital Globe imagery in Europe.

4.1.2. The space invaders: welcome to the club?

They can also be called "aliens" or "barbarians" (Ref [6]): they do not belong to the regular crowd of the "space club", have their own rules, coming mainly from the IT world and they are fast and agile, with a fresh look on entry barriers.

For a few years, several private companies have emerged in the U.S. with the project to develop and operate space systems on an industrial basis with disruptive commercial objectives.

4.1.3. The rise of New Space

These firms, mainly based in the Silicon Valley or near Seattle, bet on low-cost technology to provide more affordable space systems and services both for earth observation and for telecommunications.

These projects are designed to maximize the benefits reaped from Commercial off-the-shelf technologies, from reduced manufacturing costs as well as from leaner industrial processes. The massive use of high-performance COTS technologies has already proved the feasibility of constellations of several tens of cubesats weighing around 5 kg and costing a few thousands of dollars per unit. But New Space is not always "small is beautiful"-oriented: some initiatives are based on medium-size or even large satellites.

4.1.4. The nations

Whether they are veterans in space activities (China or India) or newcomers deciding to have their own EO capacities, more and more nations are becoming active players in Earth Observation. This affects both the competition and the accessible market.

For example, SI imaging Services (South Korea) distributes since mid-2016 VHR imagery (GSD < 50 cm) acquired by Kompsat-3A. Another example is the drastic reduction of EO data imported by China, since the "Middle Kingdom" operates high and very high resolution satellites. Soon or later, China will enter the worldwide EO market as a new provider.

4.2. Focus on new Space: business not as usual?

4.2.1. New space: the old good recipe of the Silicon Valley

The "new space" trend appeared recently. New private actors are more and more active in the space ecosystem with two different profiles:

- Many start-ups and small and medium size enterprises (SME) are betting on the development of very small satellites, not only for technology testing and education but also for operational missions.
- The big players of the Web sphere are increasingly interested by Space and able to invest massively: Elon Musk with SpaceX is the most famous example but Google and Facebook announced also their own initiatives. Their assumption is the disruption will be triggered by the convergence between advanced information technologies and EO.

The big players with a start-up spirit are very impressive, with a scalable business model able to impact more than one billion customers, aggressive and agile solutions.

They are able to lower or break the entry barriers of the targeted market and have a huge cash capacity. In June 2014, a major announcement was made by Google Inc: an agreement to buy Skybox Imaging for \$500 million in cash. In April 2015, SpaceX announced

court action to open Air force space Launch mission to competition. The most significant initiative is OneWeb with a massive constellation of several hundreds of small LEO satellites providing high speed connectivity.

Either from start-ups or major actors, these initiatives have common features. They are launched by private actors, even when supported by public money or public orders. Even if not based in California, they apply also the Silicon Valley recipe for success. They are fast and agile, proposing scalable systems and are convinced that their dream will become a reality.

The viability of the business plan is perhaps questionable, in particular when one has in mind the attempts to develop the first constellations of satellites (Iridium, Globastar, Teledesic, Celestri) but, as depicted on Fig. 4, the new entrepreneurs are able to raise funds (ref [7]), sign strategic partnerships and, for some of them, build and launch satellites and start their operations.

4.2.2. New Space and Earth observation

In the field of space imagery, many firms have planned to use large constellations of EO satellites. They propose new paradigms and new visions of the value chain:

- Cheaper systems and ground segments.
- Multi sensors ground processing systems.
- Lower cost / reliability and higher replacement rate.
- B2C / Mass market / Vertical integration.
- Data analytics.
- Free of charge imagery to enter new markets.
- New solutions for Capex / Opex optimization.
- And the scalability, i.e. the capacity to start business before the full deployment of the system.

“Democratising” the access to space imagery is usually one key element for their business strategy. Web portals and subscriptions via Internet are commonly referred as preferred marketing tools. However, some of these projects seem to clearly address the usual institutional customer as their reference business partners.

New space in earth observation is mainly an US story, with the exception of Satellogic in Argentina (Ref [8]) and NorStar Space Data in Canada. Most of the investment is from the US, in particular from the Silicon Valley. Other the past ten years, more than 33 projects of EO satellite constellations have been announced. Despite the bloom of new satellite EO constellations, many experts remained sceptical on the capability of all these projects to become operational. On the 33 announcements, today only 9 have actually started and none is fully operational.

In June 2014, when acquiring Skybox Imaging for 500 M\$, Google surprised space remote sensing experts and traditional players. This acquisition highlighted the potential economic value of “low-cost” satellite EO constellations, even if few demonstration satellites have been launched. The potential threat was taken seriously by established providers of EO data and services who started to adapt their offer and their organisation. In 2015, Planet and Urthecast have raised sufficient funding to acquire the space assets of established competitors such as Blackbridge and DEIMOS, re-enforcing their business model with a “traditional” satellite constellation and a client portfolio. These first buybacks are observed with interest by satellite EO experts and venture capitalists to understand the dynamic of this new economic ecosystem. Even if none of the newly announced constellations have reached full capacity, there are already concrete consequences on the market and the existing players: the Rapid Eye (Blackbridge) and Deimos acquisitions give better access to market and a customer base for Planet and UrtheCast but creates an exit strategy for the two former European players.

A new value chain for “low-cost satellite EO” is being developed including satellite and sensor manufacturers, integration and tests providers, communication systems and operations services providers. Downstream services are been developed, aiming at irrigating economic sectors with appropriated analytics for agriculture, resources monitoring, transports, maritime surveillance and many other sectors. If stakeholders agree on the fact that few projects will be operational and that the space EO sector landscape will evolve, no one will make a prognostic in a domain where agility is the rule of the game, and where some players have already change their business model twice.

4.2.3. Presentation of the main initiatives

Planet, (formerly Planet Labs) has put into orbit nearly 150 cubesats. Their GSD is between 3 and 5 m. While modest in terms of pure performance (when compared with 0.30 m resolution from the best commercial satellites), the main feature of these new initiatives is the high number of platforms in orbit. This allows very high revisit rates and makes space sensors much more reactive than when placed on a few satellites only. Other on-going projects plan to make use of somewhat heavier satellites, even if they can still be considered in the class of micro-satellites.

Terra Bella (formerly Skybox Imaging before its acquisition by Google in 2014) has planned to put up in space a constellation of around 24 satellites in the next few years. 7 satellites have already been launched (the last 4 ones in September 2016). The mass is around 100 kg and allow a ground resolution of about 0.90 m as well as producing short videos. Blacksky Global, located in Seattle, plans to put into orbit 60 imaging satellites allowing a performance of around

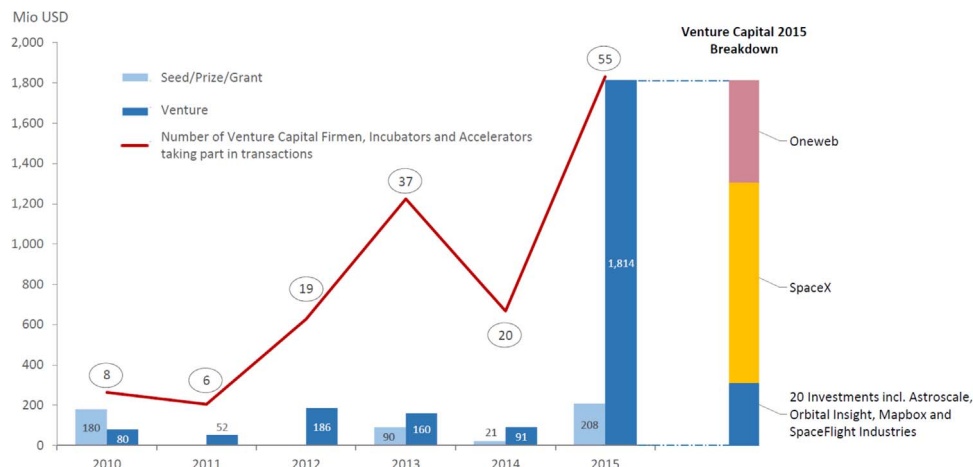


Fig. 4. 2015, a record year for VC investment in space. Source: Spacetec Analysis / Tauri Group data (Ref [7]).

1 m ground resolution (with an additional video capacity) by 2019. Already 6 satellites are under preparation. *UrtheCast*, a Canadian firm based in Vancouver plans to serve the governmental market with its 8 optical and 8 radar satellites in preparation. This firm targets a high-quality phased optical and radar product with 0.50 m and 1–5 m resolution respectively in the optical and radar domains.

Many other projects (Ref [9]) exist as of today, with different mixes regarding the number of satellites, the mass, the complexity and the performances, but with a common objective to reap market shares using innovative dissemination practices. The table in the *Annex* provides a technical overview of the main initiatives. The selection is not exhaustive and focuses mainly on operators who have already launched at least one satellite. Known specifications confirm that there are actually two types of satellites: very small or small ones (less than 50 kg) and medium-size or even large ones (e.g. 670 kg for the *Urthecast* optical satellites).

4.2.4. A vast programme indeed

The pitches and value proposals give an indication of plans, differentiators and ambition of each company. Nearly all promote information freshness, apps or platforms and data analytics tools. *Urthecast* “moves pixels from space to the screen” and states that its “business model borrows more from *DG* than from *Terra Bella*”. *Terra Bella* wants to “empower global businesses to make better decisions with timely, high fidelity imagery and infinite analytics”. Google’s fingerprint is not too far: “Rethinking geospatial data in a bigger way, *Imagery* is only the beginning...”.

Planet’s motto is “See change. Change the World. Anywhere, anytime”. Planet claims to “design, build and launch satellites faster than any company or government in history. We use commodity consumer electronics to build highly capable satellites at drastically lower costs. With the most advanced satellites launching into orbit every 3–4 months, our capabilities are on the cutting edge”.

4.2.5. Some innovative private financing

Most of these firms have been supported by private funds. According to a recent study (ref [10]) performed by Bryce Space and technology (formerly Tauri Group), the space start-ups (all activities included) have raised almost \$13 Billion of private investments between 2000 and 2015. For the sole year 2015, a yearly record of more than \$2.3 Billion has been spent in more than 50 investments in space start-ups in the U.S.

Investments can be of different nature when made by business angels, venture capitalists, or by major industrial groups eager to make acquisitions of strategic nature or simply as space enthusiasts. Obviously, the objectives of those respective types of investors may be very different. Mainly, expectations on the nature and the level of return on investments can be very distinct, business angels being more inclined to support the space activity of a start-up on the mid to long-term while some venture capitalists are more demanding for rapid financial results.

From the standpoint of space imagery activity, venture capitalist financing but also the interest manifested by major groups has formed the bulk of the resources for fresh start-ups. It must be noted that this phenomenon is rather new in a field that had been supported until now by very few private financiers. It must also be noted that such investments can be highly rewarding. The example of *Terra Bella* comes immediately in mind when Google paid more than \$480 Million for acquiring it, while only a total of \$91 Million had been invested in the start-up by a few venture capitalists. The benefits for them were well worth the initial effort. Planet has managed to go through five rounds of investments representing in 2016 about \$206 Million contributed by 17 investors and bought recently *Terra Bella*.

4.2.6. Mixed with some level of government support

Obviously, many questions remain unanswered about the reality and the size of the market for such new economic actors. This explains the importance of initial investments for sustaining the first years of operations.

At a minimum, one can note in the U.S. a real interest from the public institutions for supporting this activity. A bit like in the case of early support for more traditional operators like *Digital Globe* for many years now, the U.S. government through the National Geospatial intelligence Agency (NGA) has declared many times its enthusiasm for the new comers. In 2015, a first initiative known as *NextGen Tasking Initiative* has been announced to sustain these new commercial activities, especially to help for the development of new methods for the collection, processing and dissemination of commercially generated data.

This interest has found its official expression in an agency document titled *Commercial Geoint Strategy* published the same year by the NGA (ref [11]). Six months later, the creation of an “*Outpost Valley*” close to Silicon Valley start-ups was announced via the reinforcement of the NGA Californian Branch.

More recently even, a new *Commercial Initiative to Buy operationally Responsive GEOINT* (CIBORG) has been publicized with the explicit goal to support the new space imagery industry both for federal users (ref [12]). *Terra Bella*, *UrtheCast*, *Planet* and *BlackSky Global* have been identified as the first potential interested parties. The first CIBORG contracts shall be passed early 2017 with an expectedly rising yearly budget over the period 2018–2022.

4.2.7. Beyond Earth Observation

New endeavours beyond the sole imagery may emerge very soon for future commercial constellations. The announcement made in July 2016 about the cooperative venture between *Lockheed Martin* and *HawkEye 360* to develop a small sat constellation for radio-frequency mapping is a good example of possibly evolving missions for small satellites.

If these techniques are deployed operationally, their multi-purpose character can be key to reorganize the missions of each specialized constellation. A possible trend may be to end up with global “space-based utilities” capable of carrying out mixed and adaptable missions.

4.2.8. Other actors

Some start-ups do not plan to fly their own satellites: based in Palo Alto, *Orbital Insights*, for instance, has recently received \$20 Million in new investment, including \$5 Million from In-Q-Tel, the investment arm of the US intelligence community. *Orbital insights* receives its data through contracts with EO data owners. While gathering data on a large scale from external sources, the start-up develops software to extract insights from satellite and aerial imagery. Typical Analytic data products are:

- Counting cars on retail parking lots.
- Gauging the amount of oil stored in tanks (floating lids shadows).
- And a new list of targets: trucks, ships, trains, plants, deforestation (WRI), WB in Sri Lanka.

A second interesting example is *SpaceKnow*, also based in Silicon Valley. Founded in 2013, *SpaceKnow* uses space imagery and other data sources to track global economic trends from space through their Analytics-as-a-Service products (analytics, alerts and indices). They target a wide range of commercial and governmental clients across all major industries. *SpaceKnow SMI* (China Satellite Manufacturing Index) is the first trading index based on satellite data to be featured on the Bloomberg Terminal. *SpaceKnow SMI* for China is based on the monitoring of over 6000 industrial facilities across China to measure

levels of manufacturing activity.

4.3. Time to stop playing? Next steps?

The space activity landscape may radically change in its very nature in the coming years.

New comers from the web and from the information technology world have already contributed to change the balance in a significant manner.

In this respect, it is interesting to compare the current situation with the one that prevailed in the 1990's when initial projects for gigantic telecommunication constellations had been envisioned by some heavy weights of the industry (such as Microsoft) but ultimately failed.

While some people tend to warn about a possible new internet “bubble” that may end with a similar fate, two considerations can be presented to moderate the relevance of this analogy.

First, technology has evolved and new small satellites have improved in terms of performance/cost and performance/size ratios. If not totally overcome, some technological obstacles (not all, as recalled in Section 3) tend to disappear or to be of less crucial importance in the design of the space and ground systems. For example, LEO communication systems can now be developed with a good level of efficiency.

In addition, comparing the support from the web industry in the 1990's and today gives a clear indication of the huge progresses made by this industry and by its financial and industrial strategies regarding its massive needs for broad-band telecommunication and information dissemination worldwide.

The interest of some powerful players (e.g. Google) and the level of their financial capabilities will undoubtedly influence the market landscape.

5. Shifting lines and new boundaries: market evolution and perspectives

5.1. EO value chain: market figures in 2015, main trends and evolution

5.1.1. Overview

Well-known global consulting companies such as Euroconsult, Bryce Space and Technology or Northern Sky Research (NSR) publish regular forecasts and updates. Professional associations such as EARSC or Eurospace provide also comprehensive figures on the health of their respective industry and describe the market trends.

Their assessments of total market value differ but they agree on the main trends and evolutions. Except if specifically stated, the figures used in this section are based on the report “Satellite-based Earth Observation, Market Prospects to 2025” released by Euroconsult (Refs [13,14]).

Commercial data market reached \$1.7 billion in 2015 (6% growth on

2014), largely driven by defence and IMINT (\$1.1 billion). All other market shares are below 10%. According to Euroconsult, Optical data represented 84% of the market. SAR data (16%) has not experienced the same ramp-up, except in maritime surveillance. Value-added services market reached \$3.2 billion in 2015 (Fig. 5). In 2016, new entrants continue to raise capital, develop satellites and deploy initial constellations.

5.1.2. Market trends and drivers

From a very broad perspective, EO development is closely linked to the worldwide digitalisation of our societies, with endless appetite for information, increasing number of data sources and need for interoperability, finance and economics, interconnected ecosystems (governments, industry, commerce) and last but not least security issues, national prestige and soft power.

In a nutshell, the global EO landscape is as follows:

- More and more commercial EO satellites, both for governments and private companies, will be launched over the next decade: over 400 satellites (> 50 kg) compared to 163 over 2006–2015, from 35 countries.
- In addition 1200 small satellites (< 50 kg) could be launched with the growth of constellations.
- 50 countries are now investing in EO programmes.
- Environmental monitoring, food security and climate change are top priorities in political agendas. Border monitoring and Eastern tensions are major trends.
- In 2025, the market for commercial EO data is expected to reach \$3 billion (6% CAGR over 2015–2025). Current market forecast for value-added services is \$5.3 billion for 2025 (5% CAGR).
- Regionally, North America will remain the first market (forecast > \$1 billion in 2024). Asian markets, Latin America (forecast: \$350 million in 2024) and Africa (\$65 million in 2024) are expected to have strong growth profiles. Natural resources management, engineering and infrastructure, LBS and Non-US defence are the main activities supporting growth.
- The number of commercial satellites is expected to increase significantly, fostered by the growing demand and the number of new entrants in the commercial market. Business and environmental intelligence are their new Eldorado.
- New regulations and evolution of ITAR restrictions (supporting the competitiveness of US industry and services) will boost the VHR data market. More operators will try to address this market.

One shall add the free and open data sets delivered under Copernicus programme, providing a wealth of environmental data likely to catalyse added-value services and data analytics, but also with a possible impact on the sales of medium-resolution data. Here, the two key questions are:

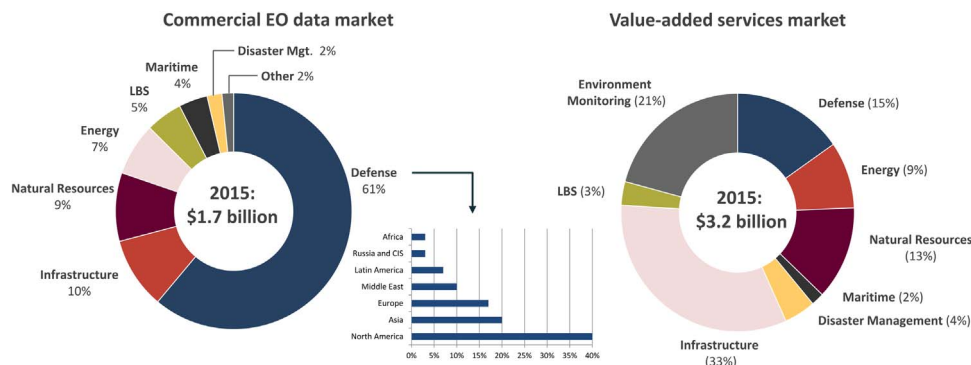


Fig. 5. Commercial EO data market 2015 and Value-added services market 2015 (source: Euroconsult, ref [13]).

- Will the development of added-services compensate the drop of imagery sales at least for medium and high resolution)?
- Who will be the main beneficiaries of this evolution?

New Space adds a new dimensions and potential game changers with new entrants from ICT domains, a platform-based economy and shorter mission cycles.

5.1.3. Structure of the value chain, evolution of prices and market demand

Three risks associated to these growth prospects can affect the main data providers:

- The evolution of prices, influenced by increased availability of VHR/HR, impact of free imagery and the redistribution of value between the data and the services.
- The evolution of international demand, when small and large countries invest in their own EO capacities, while they were accounted so far as major commercial opportunities.
- The increasing number of suppliers.

Until now, data prices are mainly driven by « image quality ». GSD is important but geolocation accuracy, image freshness and radiometric accuracy are also part of the criterions. The usual model (except for direct reception of telemetry) is the price per square kilometre or the price per image.

5.1.4. From scarcity to abundance

In this context, standard imagery prices could drop drastically. A typical example is the evolution of the EO sales in China. Until recently, China was buying imagery from foreign suppliers. Since 2011, the volume of medium-resolution data acquired by Chinese satellites exceeds the imported share and China meets its needs independently (Ref [15]).

A similar move affects the higher resolution products. The strategy of the various suppliers to mitigate this risk depends on their profile. There are two main, non-exclusive options (Fig. 6).

The “high end approach”: the usual suspects will seek to secure their revenues with differentiated products, taking advantage of their existing or future high end assets, i.e. in further increasing imagery resolution and targeting customers needing these new VHR data and acknowledging their value.

They will also develop the use of new IT platforms and service hosting, at least for their main vertical markets. The key criteria in this scenario: a significant percentage of total value comes from EO image value.

The “service-based strategy” of the new entrants: it is not only a low-cost approach: it makes the assumption that the EO will become a commodity and that the value of their products will be the information and the services created from the EO data and from other data sources.

5.1.5. B2G, B2B or B2C: B2C rules applied to B2B

The pricing is thus based on service value. The global value increases because the volume of services and the number of customers increase. The challenge is to propose as far as possible standardized products. The feasibility and the benefits of an evolution towards more “horizontal markets” have to be demonstrated. In this situation the customer becomes a consumer.

In both cases, the specific solution for the optimization of CAPEX and operational costs will determine the strategy of each operator.

5.2. Shifting lines and new boundaries: position in the value chain, resolution and revisit, data, services and information

5.2.1. Focus on EO data

Fig. 7 is a tentative representation of the commercial EO data market evolution, with two types of changes. On the horizontal axis, there is a shift between the resolution boundaries, from the right side to the left side, corresponding to the trend toward higher resolution. On the vertical axis, the vertical arrows show the factors driving the growth or the contraction of a specific segment.

One tricky question is the appropriate number of segments to consider in the analysis of EO data. Apart from the core military needs, three segments are usually defined by the commercial operators: medium resolution, high resolution and very high resolution.

The segmentation is mainly based on the offer and does not necessarily fit the actual demand. Market evolutions, growth perspectives and interactions between segments could justify a finer-grained analysis, in particular for orphan segments or overlaps between different offers.

In particular, a narrower definition of VHR (for instance < 30–40 cm) could open a new avenue for “less high VHR” (e.g. between 50 cm and 1 m), if its price is attractive compared to the one of the sharpest imagery. Beyond GSD, similar trade-offs can be made with other performance parameters (geolocation accuracy, spectral resolution, etc).

It could mean that a “high-end” option could find its own niche, even is this market segment is mainly addressed by “low-cost” products. Table 1 summarises, in a nutshell, the shifting factors and growth drivers.

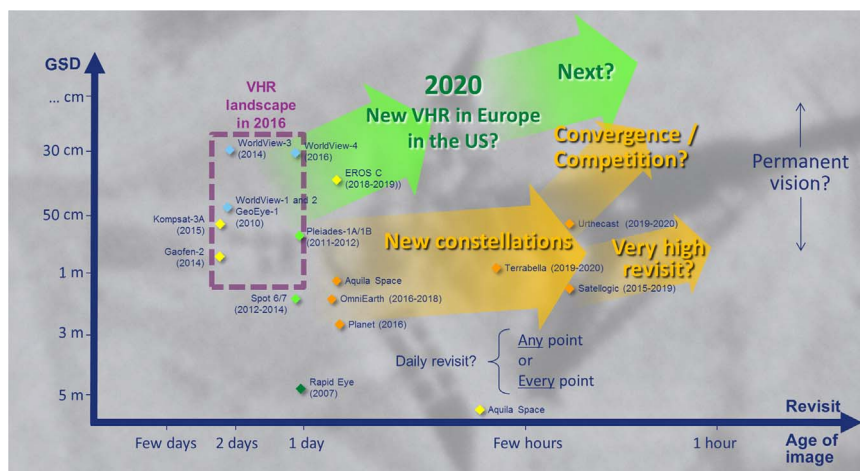


Fig. 6. Trends in commercial imagery - Resolution versus revisit, two strategies.

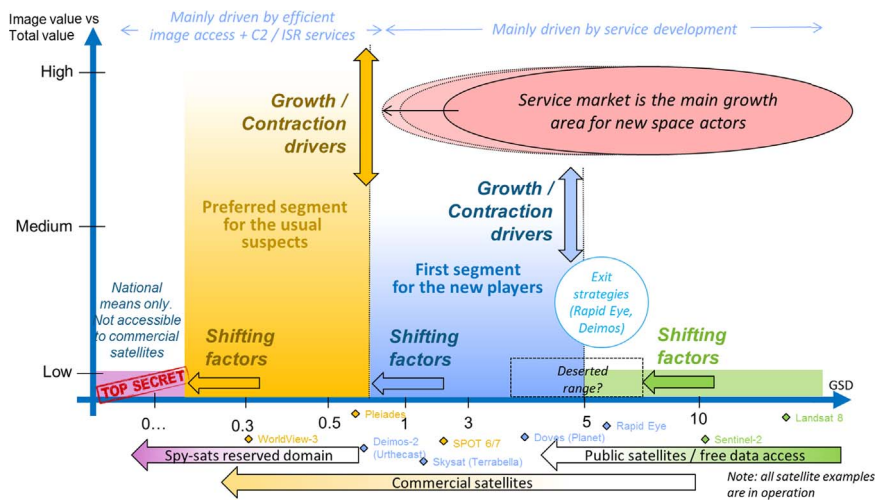


Fig. 7. Shifting lines and new boundaries; evolution of EO data supply.

5.2.2. Typology of information services and customers

In all areas, service market is the main (or first) growth opportunity for the new operators. From satellite manufacturing to service delivery to the end user, the EO value chain is usually structured in tiers with the upstream, midstream and downstream layers, as depicted on Fig. 8.

The main components of a generic service chain based on EO data are:

- EO Imagery and other data sources.
- Processing and access middleware.
- Mid-stream and downstream infrastructure (algorithms, cloud, analytics, etc.)
- Service providers, with possible hosting in mid-stream infrastructures or as external components.

One can identify several types of services: depending on the weight of image data compared to other data (data-agnostic services), there may be opportunities for EO data owners or satellite operators, EO data brokers or for pure service players.

Another important factor is the level of automation (processing, advanced analytics, role of models) and the need for human expertise in the information production process.

Both for institutional and private customers, the need to integrate customer data in service production can raise security and confidentiality issues and justify sometimes a local implementation of the service.

Table 1 Evolution of the EO data landscape. Shifting factors and growth/contraction drivers.

	Very high resolution	High resolution	Medium resolution
<i>Shifting factors</i>	<ul style="list-style-type: none"> ● Increased use of commercial data in IMINT (+). ● More monitoring needs (+). ● Budgetary constraints and impact on national means (+) ● Regulations and export rules (-) 	<ul style="list-style-type: none"> ● High competition (+) ● Success of services offers (+) ● Regulation and dissemination control (-) 	<ul style="list-style-type: none"> ● Success of the commercial and institutional service offers using this range of data. Evolution towards higher-end (+). ● Evolution of public missions such as Copernicus NG / Copernicus Security (+)
<i>Growth or contraction drivers</i>	<ul style="list-style-type: none"> ● Increasing use of commercial satellites (+) ● Increased capacity (+) ● Increased competition and newcomers (-) ● New national missions (-) ● Competition from aerial market and other sources (-) ● One size fits all impact on customer base (-) 	<ul style="list-style-type: none"> ● Quantitative development of services with lower costs (+) ● New national mission (-) ● Market saturation or competition with open data (-). 	Not applicable

For activities which are usually implemented directly by the customer (GEOINT, Insurance, etc.), the readiness to outsource the service production is obviously a critical point. Typical markets and maturity (use of EO data and services) are presented in Tables 2, 3.

6. Food for thought: scenarios for the future

6.1. Introduction

This part of the paper has a prospective dimension. It discusses the realism and likelihood of possible scenarios of market development and identifies their impacts on the EO landscape and the main stakeholders involved. Three main scenarios have been identified as “extreme options”.

It would probably not be realistic to expect that one of these scenarios may actually happen but this tool is useful to forecast market evolutions and interactions between market segments. These scenarios are not necessarily exclusive. This section provides also a first review of the driving factors and possible consequences (threats and opportunities) on the main actors.



Fig. 8. EO services – Structure of the value chain. Background image: Ricardo Liberato (Licensed under CC-BY-SA).

6.2. Between business as usual and market disruptions: some science fiction

6.2.1. Scenario 1: solid revenues from the VHR data for the intelligence community

This scenario is based on a steady continuity of the VHR market, with a sustainable or growing demand of the defence and IC for high-end products.

In parallel, a significant market share comes from commercial customers (domestic and export markets), ready to pay a premium for high-class imagery. The main driving factors are:

- Evolution of defence and commercial markets using VHR imagery.
- Regulations and export control rules, also depending on dissemination policies implemented by new countries (e.g. China).
- The availability of high performance online distribution systems (e.g. OneAtlas by Airbus Defence and Space).

Main opportunities are related to the evolution of the global threats and instability (increasing needs for GEOINT) and the sustained demand for accurate geo-information in the main vertical markets.

The threats are linked to the evolution of intelligence needs (other priorities such as cybersecurity, ELINT), the use of other sensors (UAVs, HAPS or ground-based assets) and the obstinacy of competitors (commercial companies or new countries) to enter this market beside their initial business. Another risk is the possible gap between intelligence needs and commercial needs. The needs of some commercial customers could be met with lower resolution (50 cm to 1 m) data, with a direct impact on price sensitivity.

Service development opportunities for GEOINT missions are not obvious, as long as the readiness to outsource remains low. The

Table 2
Types of services.

« Image + » services	Specialised services and niches markets	Vertical markets	Horizontal approach
“Image-only” services (real time, time series, etc.) Automated processing	Thematic or Geographic specialisation High Expertise Customer intimacy	Defence, agriculture, oil and gas, assurance, etc.	Geo-marketing, geo-analytics, monitoring, LBS
B2B or B2G rules	B2B or B2G rules	B2B or B2G rules	B2C or B2B2C rules applied to B2B or B2G
Close link with the satellite owner	Tailor-made solutions. Fragmented ecosystem of VAC and SME	Ready-to-wear. Standard product portfolio for families of customers	One size fits all. Customer = consumer. Main target for new space actors

Table 3
Types of customers.

	Defence	Civil institutional	Commercial	Consumer market
Typical activities	Mapping Intelligence C2-ISR	Cartography Environmental monitoring	Agriculture, oil and gas, insurance, etc.	Mapping, LBS, etc. for web actors
Maturity	High	High	Variable	Low
Growth potential	Medium	High	High	High
Customers	100	100-1000s	1000s	Millions

institutional human resources constraints can trigger innovative schemes with private providers with two conditions:

- Ensure sensitive data integrity and confidentiality and system security.
- Define new governance rules.

6.2.2. Scenario 2: a new Eldorado with EO-based services for commercial applications

Convert promises into tangible achievements... The expected explosive growth in geo-information services and applications materialises. This success depends on:

- The actual implementation of some of the planned constellations.
- The confirmation of commercial demand in key sectors.
- The public demand and the readiness of the public sector to outsource this activity.

- The demonstration of EO data value in the information production and the benefits of platform-based analytics.

Main opportunities are:

- The development of new services for new markets with game changers on demand side, related either to global environmental issues (adaptation to climate change, water and food security, insurance, etc.) or to new commercial usages (geo-marketing, mapping and LBS, etc.)
- Successful implementation of services in areas where space data plays a major role and can't be substituted.

The main threat is the “hype effect” with the collapse of new initiatives due to lack of funding or a viable business models. Data-agnostic services (terrestrial networks of sensors, IOT, crowd-based sensing) pose another threat (see scenario 3).

6.2.3. Scenario 3: EO becomes a commodity («banalization») and strong competition with other sources of information

“There is really not that much demand”: even if only two or three new initiatives succeed, there is a risk of oversupplying the market. This scenario is roughly a nightmare variant of scenario 2. The main unknown is the actual role of space data in a big data world.

The wealth of data will also come from other information sources (drones and HAPS, crowd-based and in situ in a connected world). In particular, in the case of high revisit, the need for real time information is often linked to tactical needs and direct action / response with security forces, first responders, troops, etc. In this case, in-field operators carry sensors (e.g. police helicopters, short range UAVs) and this model can be very efficient. Crowd-sourcing is another trend, possibly fostered by the development of mobile devices and networks (incl. IOT). If EO data become really a commodity with huge competition between data and satellite owners, there is an opportunity for pure content aggregators or data brokers, without investment in proprietary data collection systems. An evolution towards source-agnostic service provision is also credible: most of end users (GEOINT can be an exception) are sensor/data agnostic: they want the information not the data.

6.3. Consequences and impacts: focus on Europe

In a worldwide competition where the disruptive offers are mainly initiated in the US, the accessible market share for European actors is a strategic issue, with commercial consequences but also stakes in relation with sovereignty and non-dependence. This section reviews the possible consequences and impacts on the main stakeholders:

- GEOINT community.
- EO data and services providers.
- Satellites manufacturers.
- Nations and institutions.

6.3.1. GEOINT community

The United States have adopted a well-publicized policy that is intended to make the best use of future constellations for government and intelligence needs. Mid-2015, a so-called “NextGen Tasking Initiative” has been launched by the *National Geospatial Intelligence Agency* (NGA) with the goal to develop new methods for collecting, processing and disseminating commercially generated information for intelligence purposes.

Web and cloud-based solutions have been particularly highlighted at this occasion. Even more recently, the head of NGA has confirmed an effort to devote several tens of million dollars from the FY 2017 budget to directly feed up the most prominent start-ups of the domain. More generally, these declarations are fully in line with a “Commercial

GeoInt Strategy” published in October 2015 (ref [11]): NGA makes no secret of the relevance of future commercial constellations for the U.S. government.

In the European Union, it seems that some Member States have also expressed interest in these developments. In France for example, a recent report mandated by the French Government (ref [16]) has insisted on the changes induced by the rise of the new commercial space sector and the need to adapt the institutional practices and procedures to nurture these evolutions. Similar studies have been commissioned in Germany. However, the level of governmental involvement is far below what can be seen in the U.S. in the rise of the security and defence-oriented utilizations of the New Space. It is highly likely that a number of obstacles linked to real-world intelligence and defence issues, such as data policy and security or public-private relationships will remain to be overcome for some time before it becomes a new standard for the practitioners.

Since the end of the cold war, the defence budgets have significantly and regularly decreased in Europe. In countries such as France, Germany or Italy, the priority to space have been more or less assured due to instable geostrategic situation, but not enough to enable the implementation of robust and consistent military space capacities (equipment, human resources to operate and exploit, training, etc).

As an example, Europe has no space early warning capacity to face increasing threats coming from some rogue countries equipped with ballistic missiles. We can assume the following trends in the coming years:

- **More and more dual systems** especially in the field of hybrid security/defence needs: maritime, borders and critical sites surveillance, control of inter-national treaties, etc. with funding shared between defence and civil entities or even private operators.
- **More civil space assets owned and operated by private companies** assuring guaranteed and secured access of data to military customers.
- **Limitation of state owned systems to those strictly connected to national security and sovereignty:** identification optical systems, SIGINT space systems, etc.
- **More and enlarged cooperation and sharing processes between European partners.** The current SAR/optical data sharing implemented between France, Germany and Italy is a virtuous process which shall be reinforced and enlarged in the future.
- **More synergies with civil IT technologies** (big data, cloud, automatization of processes, fusion of data, etc.) in ground segment and operations in order to follow the rapid evolution of technology and the exponentially increasing amount of space data to be processed by the military operational users.

In brief, the objective of defence actors will be to use more space assets with less or same amount of money and people. Moreover this growing and strategic use of space capacities and data either for military, dual or civil uses stresses the importance of the security of these capacities which are today vulnerable to external threats. A specific effort is required at the level of major European space countries.

6.3.2. European space ecosystem: from satellites to services

The service ecosystem is heterogeneous with various profiles: SMEs, large web actors, large GIS actors.

According to a study prepared by EARSC (European Association of Remote Sensing Companies) on the State and Health of the European EO Services Industry (ref [17]), 451 companies were active in the domain of EO services in Europe (and Canada) in 2014. The majority of companies (63%) have less than 10 employees (95% < 50 people). The

total sector employment is 6811 persons in 2014. The total revenues for the EO Services sector in 2014 reached €910 million (€786 million in 2012) and is growing at a rate of around 7.6% p.a.

The new space context means new opportunities (with new EO data sources) but also more competition and a risk of information dominance by a small number of worldwide champions (monopoly) or global service providers backed by the large web actors.

The priority support action should be to secure the market position of the commercial VHR data providers. Market analysis confirms that the public sector has a key role in helping its European champions: even if a European NGA will not be easily implemented, anchor-tenant contracts can be developed by a public sector in its customer role with a new balance between patrimonial assets or in-house activities and external services. In her report on “open space” (Ref [16]), Genevieve Fioraso recommends a “Buy European Act”.

The value-adding EO services in Europe are in an emerging state and delivered by a very fragmented base of suppliers. The consolidation of this supply chain (through mergers or strategic agreements) leading to European champions is an option but this fragmentation is not necessarily a weakness. It can mean a closer link with the final customers and a solid territorial footprint.

In this case, the main need is to strengthen networking between local commercial actors. This assumption is the rationale behind Eugenius, A European Group of Enterprises for a Network of Information Using Space, an initiative started by Terranis, a French SME, in cooperation with a core team of European service providers.

Targeting the development of Copernicus downstream services, the objective is to federate and transform isolated SMEs into a powerful network of expert partners serving their proximity customers. Eugenius concept is based on three foundations: the regional hubs (geo-information service platforms), the applicative tools (thematic software suites for specific needs such as agriculture, risk assessment, coastline monitoring) and a set of organisational and commercial rules between Eugenius partners. GEO4i is another good example: this French SME combines the expertise of image analysts and geomatics skills from the Ministry of Defence. GEO4i emphasises its close relation with the final customer and its capacity to propose ad hoc solutions.

Fig. 9 highlights the potential use of medium resolution data as information source for added-value services. A coherence map of two radar images (Sentinel-1) reveals the activity detected between the 8th March 2016 and the 20th March 2016. It allowed detecting many passages of vehicles and showed intense activity. This suspicious activity is confirmed by the optical image (Sentinel-2) acquired March, 11th.

6.3.3. Opportunities for satellite manufacturers

Market forecasts predict \$39 billion in manufacturing revenues over the period 2015–2024, an 80% increase over that of the previous decade. It is obviously an opportunity for European satellite manufacturers and the related supply chain, if they are competitive on the worldwide market and sometimes ready to invest as partners in new ventures. Recent successes in the telecommunication domain (OneWeb or O3B) show that European space industry was able to play the game. The support of space agencies is key, for the preparation of the future (non-dependence and critical technologies, disruptive technologies, etc.) and a contribution to “de-risking” activities (ref [18]).

The relation between space industry and space agencies could evolve from a customer / supplier relationship to a cooperation / co-development approach (“together in the driver’s seat”). The situation is much more complex for the IT component, as there is no European champion, able to compete with Google or Amazon on the mid-stream segment. Being able to change this situation is questionable, even if it raises serious issues with respect to security and sovereignty.

6.3.4. Between sovereignty and dominance

Governments are responsible for regulations (including export control

and data policies) but these regulations can also become incentives for the development of services and infrastructures. Governments have also a significant role to play in agreements between governments (G2G) and support to export activities, both for infrastructures and services: one can anticipate an evolution of the concept of sovereignty, with hybrid procurement schemes, between full ownership (e.g. PerùSAT-1) and guaranteed access to information, helping to mitigate a risk of information dominance by a single country. In a world of continental states, these recommendations apply also to Europe and its 28 Member States. Lessons learnt from Copernicus implementation (ref [19]) could help to define an innovative and efficient scheme for a new generation of Copernicus with a security component.

6.3.5. The cost of non-Europe

Towards a more coordinated approach between Member States in Europe for GEOINT missions? Or even shared capacities? Is it realistic? The European Union Satellite Centre remains the main focal point in Europe for imagery and GEOINT sharing. Its functioning is based on the fair exchange of information between all member States as soon as it has been produced by the centre on request of one or several member States. In this context, high performance commercial imagery has been playing a key role, allowing the dissemination of homogeneous information among the member States in a context when national intelligence procedures might have impeded the sharing of intelligence generated by national systems. It is clear that such regional arrangements can provide avenues for commercial systems to become key providers of sensitive but sharable data on a collective basis.

6.4. GEOINT disruptions: considerations about the strategic scenario for Europe

The “New space” paradigm represents a mix of visionary entrepreneurial operations bonding with a large amount of investments coming for a very proactive venture capitalist ground. Main IT players are investing in the EO sector in order to be able to offer an always more

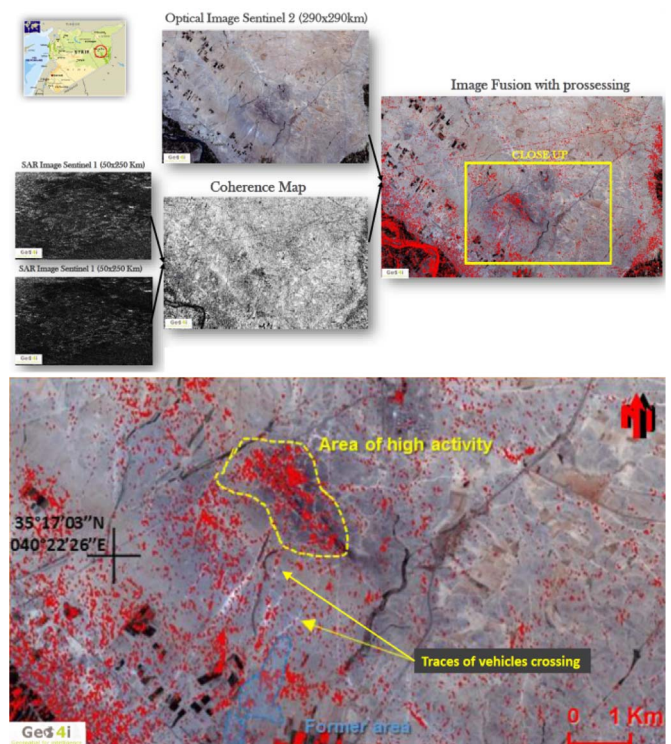


Fig. 9. Added value services for GEOINT, derived from Sentinel imagery. Clandestine refineries in Deir ez Zor (Syria). Credit: GEO4i.

integrated set of services, based on worldwide data retrieving, transmission and processing (Ref [20]).

This is indeed an incredible boost for the EO and GEOINT sector which, for a long time, was linked to institutional markets, both in the US and in Europe. But furthermore, this vision to provide an “all inclusive” value added service chain on Earth is sometimes presented as propaedeutic for space exploration and human colonization of planet Mars. Even if Elon Musk or Jeff Bezos have to be considered very seriously, also observing their achievements in the launching activities, this grand vision has to be scrutinized in order to draft scenarios and recommendations for EU GEOINT sector.

In a pure market logic, the consequences could be highly disruptive: the integration of EO space based capabilities within an IT commercial offer, integrated in apps developed by Alphabet or other Silicon Valley champions, seems able to wipe out the EU industrial and technological effort, based on a long term investment, often triggered by technology push, relying on a public demand. On the other hand, new constellations can potentially provide better performances than existing EU systems, relying on a more frequent revisiting time, a factor paving the way for a set of new applications able to push on the side the technical performances of institutional systems such as defence ones. This type of thinking pushes the European space champions to try to position themselves inside a renewed chain of added value in order to stay in the game. This calls for offers of services such as agreements or sub contracts with IT companies willing to produce and launch satellites, or the development of European IT clusters in order to valorise existing data gathering capabilities through processing and service development. It is a mix of response between collaboration and competition with the main US initiatives. But on another hand a resilient scenario shall be taken into consideration: European capabilities in terms of EO and GEOINT are developed by companies which are also strategic, both at national and EU level.

If we have in mind the French, German and Italian cases, we can observe a mix where States partially own some key companies (directly or sometimes through public agencies), companies able to produce an applied technology which can serve the national security interests of those states.

In a nutshell, those companies are strategic not only in terms of products and applications to be used for national security purposes, but also because they represent a specific know-how and capability which shall be maintained in order to keep a reasonable level of independence.

6.4.1. Independence and interdependence

This question of independence is a key issue. IT companies are often (and rightly) perceived as highly pervasive, with huge risks on individual rights, rule of law and democracy. The growing control of the information chain by a few multinational US based companies has to be carefully monitored in order to avoid some totalitarian effect based on the capacity to retrieve and process all kind of data. Europe hasn't developed such an integrated company. Space capabilities however represent a sector where Europe has always kept a decent level of technology, with some fields of excellence. The fact that Europe is able to master the technologies of the entire space chain represents an asset for today and tomorrow.

It is a key feature in terms of autonomy, but it is now an asset for EU independence in terms of information gathering and processing. If we take for granted a huge development of GEOINT capabilities following the “new space” boost, there is a danger to loose some pieces of the chain if the “Alphabet” or “Amazon” market driven trend pushes the EU products out of the market. Loosing such capacities would also be synonym of the loss of an autonomous and reliable information gathering. For example one can be cautious in terms of defence and security decisions based on US IT gathering and processing, also because huge IT companies can have objectives rather different than the ones of EU governments. Let's recall that France has been the first country to invest in defence EO satellite, a decision reinforced by the difficulties in obtaining satellite intelligence from the US ally during the Balkans conflicts. The main EU countries (Italy, Germany) have followed, considering that they shall reach some autonomous capabilities. GEOINT capabilities shall be considered as a key feature of an EU resilient capability. And this is the reason why public R & D projects but also public demand shall sustain the space EO sector, in order to avoid that important pieces of technologies or companies finished completely preyed by some Silicon Valley money drop.

This trend also calls for a major awareness at MS and EU levels, a priority agenda to be translated in EU cooperation frameworks such as Copernicus or the bilateral agreements between the main European countries. These strategic considerations shall lead to a quite conservative but also resilient paradigm: in order to maintain the control over the GEOINT chain, Europe shall pursue its current programme in order to maintain know how but also autonomous capabilities.

Some thinking shall also be made to understand whether there is an optimum for the size of the market. In Europe over the last decades, the paths between Europeanisation trends and national ones were diver-



Fig. 10. EO services – A new gold rush... and opportunities for Europe structure of the value chain.

ging. Often, Europe is presented as a minimum size market in order to ensure the sustainability and the growth of European industrial capabilities. This analysis is based on the concept of minimum level of concentration for technology and capital.

This logic was also present when the supply side has been pooled, meaning the creation of EADS (today Airbus) on one side and the merging of Alcatel Space and Alenia Space on another hand. If we take for granted the progressive integration of the EU market, those industrial mergers follow that trend. But we have also noticed contradictory elements, such as the correspondence between public programmes and national champions: it is easier to provide public support on a national basis than on a pan European one. Furthermore today's technical disruption involves small teams of engineers and technicians.

After many years with pressure to always think bigger, we can observe some prudence towards the MS level which represents often a guarantee in terms of continuity and has the advantage of a "natural" ground of expertise from academia to industry. Furthermore countries such as France, Germany or Italy are today relying on regional technological clusters, a relatively small dimension which is synonym of a virtuous mix with research and development capabilities.

Those clusters can also foster the development of smaller companies able to make their way in the application market, the key driver for the commercialization of technologies. The space sector in general, and specifically in Europe, does not rely on a huge organisation, but rather extremely qualified middle-size entities. The growth or at least the preservation of this system could be identified as a strategic goal for Europe. If US IT companies penetrate and conquer the EO sector through their holistic applications, this could threaten the very existence of the EU producers. The relations between Space EO industries and IT applications oriented service providers is a very touchy issue, that shall be dealt with a cautious, if not resilient, approach.

7. Conclusions: and the winner is?

"Predictions can be very difficult - especially about the future."
(Niels Bohr, attributed).

7.1. Trends to watch...

Who will be the winner?

Can European industry secure its role and competitiveness with respect to the growing influence of the large US actors, the New Space dynamism in the Silicon Valley? And will the promise of a huge growth of the geoinformation market fostered by the convergence between IT and EO become a reality?

It is too early to answer. The next three or five years will be very interesting with trends and key indicators to be monitored:

- Actual implementation of the new space initiatives and consolidation of the landscape.

- Evolution of the market of the VHR (all market segments between 30 cm and 1 m) and respective shares of Digital Globe, Airbus Defence and Space and potential newcomers.
- Actual development of the EO services and profile of the top winners (SME, web actors, midstream actors), level of outsourcing by public sector and degree of consolidation of the service supply chain.
- Evolution of the defence market and governmental policies. European perspective (mutualisation, capacity sharing, European policies).
- New space countries investing in their own capacities and/or acting as new providers (e.g. China).

Will we see new and hybrid service schemes instead of black or white options (including data policies) and new dimensions of dual use between Public and Private, Civil and Defence, National sovereignty and collective instruments (e.g. capacity sharing)?

Even if it does not provide a clear answer to the future industrial, technical and political structure of EO systems, this study shows that the EO markets and related industrial landscape can evolve significantly or even be disrupted in the coming years.

The consequences of the possible scenarios can affect the main stakeholders involved, in particular in Europe (Fig. 10).

7.2. A new gold rush?

The current situation is similar to California Gold rush in 1849 with lot of gold miners. Beside the development of service companies, satellite manufacturers can find their way and become the new shovel sellers.

Small is beautiful and Silicon Valley entrepreneurs, often space enthusiasts, are very active. But one can observe that European champions, both big companies and SMEs, have already demonstrated their agility and ability to stay ahead and propose competitive products and solutions. OneWeb is a typical example in telecommunication. PerúSAT-1, built in less than 24 months in Airbus Defence and Space "Projects Factory©" is another one in Earth Observation.

Despite the increasing influence of the private investment, public sector support for commercial initiatives, not only via policy-making, regulations and preparation of the future (R & D) but also as customer, plays a key role to fostering the development of its world-class champions and its ecosystem of SMEs. There are obviously opportunities in Europe:

- Strengthen the European champions: accompany R & D, involvement in risk sharing and develop anchor tenancies.
- Stimulate and support an ecosystem of innovative SMEs in EO-based services for defence, institutional and commercial applications.
- Foster European space and defence policy/market (capacity sharing / mutualisation).
- And some open questions such as the dependence on mid-stream infrastructure built outside Europe.

Annexure. New constellations for Earth Observation (non-exhaustive list, green part: at least one satellite in operation in orbit)

<i>Name</i>	<i>System overview</i>	<i>Performance indicators</i>	<i>Status</i>
Terrabella (former Skybox, 2009)	24 satellites constellation. 110 kg. 1.1m video (30 fps).	PAN: 90 cm GSD XS : 2 m GSD Swath: 8 km	7 satellites in orbit: 3 first Skysat in operation launched in Nov 2013, July 2014 and June 2016. 4 new satellites launched in September 2016 by Vega (VV07). Bought by Planet in February 2017.
UrtheCast (2010)	Initially, operation of 2 sensors on the ISS Deimos-1 and Deimos-2 Optisar: 16 satellites (8 pairs optical + SAR) on 2 orbital planes (SSO + inclined). SAR: 1400 kg, Optical: 670 kg UrtheDaily: 8 satellites constellation	Theia on ISS: 5 m + video IRIS HRC on ISS : 1 m Deimos-1: 22 m imagery 650 km swath Deimos-2: 0.75 m PAN, 12 km swath. 2-days revisit OptiSAR: SAR : 1m X-band + 5m L-band Optical : 0.5m Video: 0.5 m color video, 30fps. UrtheDaily: 5 m, 145 Mkm ² /day	Acquired Deimos in 2015 (\$80M) OptiSAR: Full deployment planned in 2020. Built by SSTL. Ground segment by Elecnor Deimos. Analytics platform: UrthePlatform CRADA (Cooperative R&D agreement) with NGA
Planet (former Planet Labs, 2010)	Rapid Eye. 5 satellites Large constellation of “Doves”	Rapid Eye: 6.5 m GSD. 5 bands. 77 km swath. 5 million km ² /day Doves: 3-5 m GSD, Image size 12x8.5 km. 3 bands. Targets daily Earth coverage with medium resolution	Focus on data freshness. Launched 14 times from 4 different countries, totalling 179 satellites (145 successfully reached space). Last launch with 12 Doves put in SSO orbit (PSLV). Purchased Blackbridge Rapid Eye (and its global imagery archive) in July 2015 and Terrabella in February 2017.
Jilin (China)	60 satellites by 2020. 138 small satellites by 2030. Mass between 95 and 420 kg.	72-cm GSD. UHD video capability. Ambition: all-weather coverage of any point on Earth, at 10 minute intervals	Constellation sponsored by the Jilin Provincial government. First 4 satellites launched in October 2015. Plan to have 16 satellites in orbit by 2019.
Satellogic (2010)	300 satellites (35 kg). 20 ground stations (own and partners).	Revisit time 5 minutes: 1 m meter multispectral. First constellation: 2 h revisit.	2 satellites, Fresco and Batata, launched in May 2016 (Chang Zheng-4B, Taiyuan space base) 16 satellites to launch in 2017.
Aquila Space / Astro Digital (2014/2015)	30 satellites. 10 Landmapper-BC for broad coverage (10 kg). 20 Landmapper-HD for High definition (20 kg)	Daily multi-spectral imaging of arable and coastal areas worldwide with 22 m GSD. Multi-spectral, 2.5 m GSD imagery of Earth’s arable and urban areas every 4 days.	Focus on monitoring agricultural land. Astro Digital: platform for data access. Uses also sentinel-2 data.
Blacksky Global	60 satellites (50 kg).	One-meter resolution. Focus on revisit time or “persistence”	Assumption that low cost launchers will become available. Technology validation on two Pathfinder satellite (Pathfinder 1 launched 26 th September 2016 on PSLV)
OmniEarth	18 satellites in 10:30 AM SSO (3on-orbit spares). Altitude : 680 km.	GSD: 2m panchro + 5m XS Swath : 180 km 6 channels (Pan + 5 MSI)	First launch planned in 2018.
Hera Systems (2013)	48 satellites (12U, 22 kg). SSO + inclined, varying time during day. First constellation: 9 satellites. Second generation : 2HOPSat	1-m GSD imagery. Video mode 48-sats: nearly hourly updates.	Non-Reimbursable Space Act Agreement (NRSAA) with NASA for upgraded satellite design.

References

- [1] “Alternative Futures: United States Commercial Satellite Imagery in 2020”, Report prepared for the Department of Commerce by Robert A. Weber and Kevin M. O’Connell, Innovative Analytics and Training, November 2011. See (https://gis.idaho.gov/pdf/Framework/Imagery/IAT_DoC_Alternative_Futures_Commercial_Satellite_Imagery.pdf).
- [2] “Team GEOINT: This is Our Moment”, Remarks as prepared for Robert Cardillo, Director, National Geospatial-Intelligence Agency, US Geospatial Intelligence Forum GEOINT Symposium, Washington, June 2015. See (https://www.nga.mil/MediaRoom/SpeechesRemarks/Documents/2015/20150623_GEOINT_As_Delivered.pdf).
- [3] “EO embracing the new space environment: the significance of EO smallsat constellations”, Earth imaging Journal, July 2015, Euroconsult, Canada, Adam Keith. See (<http://ejournal.com/print/articles/earth-observation-embracing-the-new-space-environment-the-significance-of-geo-smallsat-constellations>).
- [4] “Independent Study of the roles of commercial remote sensing in the future national system (NSG)”, Final report of the panel chaired by Pete Marino, July 2007.
- [5] “See a Better World”, 2015, annual report, Digital Globe.
- [6] “Des Aliens et des barbares : une révolution dans l’observation de la Terre”, Thierry Rousselin, Revue Prospective Stratégique, n°45, 1st trimestre 2016.
- [7] “Financial landscape for space-related ventures in Europe”, Spaceteq Partners, slides presented during the workshop Access to Finance for European space industry, European Commission, DG GROW Brussels, 3 May 2016.
- [8] “Satellogic on its way to launching 300 satellite constellation for Earth Observation”. Satellitetoday, Caleb Henry, March 2016.
- [9] “2016: State of the Satellite Industry Report”, prepared by Bryce Space and Technology (formerly The Tauri Group) for Satellite Industry Association, June 2016. See: (https://bryceteq.com/downloads/SIA_SSIR_2016.zip).
- [10] “Start-Up Space: Rising Investment in Commercial Space Ventures”, Bryce Space and Technology (formerly The Tauri Group), January 2016. See: (https://bryceteq.com/downloads/Start_Up_Space.zip).
- [11] “Commercial GEOINT Strategy”, National Geospatial- Intelligence Agency, October 2015, 15 p. See: (https://www.nga.mil/MediaRoom/PressReleases/Documents/2015/NGA_Commercial_GEOINT_Strategy.pdf).
- [12] “CIBORG Introductory Industry Day”, Slides presented by NGA, 16 June 2026. (<https://interact.gsa.gov/sites/default/files/CIBORG%20IndustryDay16Jun2016FINAL%2016-493%20Release%20%281%29.pdf>).
- [13] “Satellite-Based Earth Observation: Market Prospects to 2025”. Report prepared by Euroconsult, 9th edition, September 2016.
- [14] “Earth Observation: state of play and future prospects”, presented by Adam Keith, Managing Director, Euroconsult Canada. Summit on Earth Observation Business, 15th September 2016.
- [15] “China Launches High-resolution Commercial Imaging Satellite”, Peter de Selding, Space News, October 2015. See: (<http://spacenews.com/china-launches-high-resolution-commercial-imaging-satellite>).
- [16] “Open Space, l’ouverture comme réponse aux défis de la filière spatiale”, Fioraso Geneviève, Rapport au premier Ministre, Paris, France, July 2016, 170 p. See: (<http://www.gouvernement.fr/sites/default/files/liseuse/7791/master/index.htm>).
- [17] “A survey into the state and health of the European EO services industry”, Study prepared by EARSC. September 2015. See: (http://earsc.org/file_download/265/EO+industry+survey+september+2015+vf.pdf).
- [18] “The challenge of future space systems and services in Europe: Industrial competitiveness without a level-playing field”, Gil Denis (Airbus Defence and Space) and Xavier Pasco (Fondation pour la Recherche Stratégique). Presented at IAC 2013 (Pekin). Published in New Space (Vol. 3, No. 1) March 2015. DOI: 10.1089/space.2013.0034.
- [19] “GMES and the development of Earth observation services: threats and opportunities for the service industry”, Gil Denis (Airbus Defence and Space), Toulouse Space Show 2010, Space ECO workshop.
- [20] “NewSpace: New business models at the interface of the space industry and digital economy. Opportunities for Germany in a connected world”. Study prepared for the German Federal Ministry for Economic Affairs and Energy by SpaceTec Partners and BHO Legal. See: (https://www.bmwi.de/Redaktion/DE/Publikationen/Studien/bmwi-new-space-geschaeftsmodelle-an-der-schnittstelle-von-raumfahrt-und-digitaler-wirtschaft.pdf?__blob=publicationFile&v=7).