GLOBAL OUTLOOK 2018: SPATIAL INFORMATION INDUSTRY

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ABOUT THIS REPORT

This report is a compilation of published material covering technology developments that relate directly to spatial technologies or that operate in support of spatial technologies. The intended audience is anyone with an interest in the progressive development of spatial technologies.

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ACRONYMS

4IR	FOURTH INDUSTRIAL REVOLUTION
ACMA	AUSTRALIAN COMMUNICATIONS AND MEDIA AUTHORITY
ACSGN	AUSTRALIAN CYBER SECURITY GROWTH NETWORK
AGDC	AUSTRALIAN GEOSCIENCE DATACUBE
AI	ARTIFICIAL INTELLIGENCE
ANCLIC	AUSTRALIA NEW ZEALAND LAND INFORMATION COUNCIL
AR	AUGMENTED REALITY
BIM	BUILDING INFORMATION MODELING
BTBI	BRAIN TO BRAIN INTERFACES
CAD	COMPUTER AIDED DESIGN
CAGR	COMPOUNDED ANNUAL GROWTH RATE
CASA	CIVIL AVIATION SAFTEY AUTHORITY
CDMA	CODE DIVISION MULTIPLE ACCESS
CEOS	COMMITTEE ON EARTH OBSERVATION SATELLITES
CI CERT	CRITICAL INFRASTRUCTURE COMPUTER EMERGENCY RESPONSE TEAM
CME	CORONAL MASS EJECTION
CORS	CONTINUOUSLY OPERATING REFERENCE STATIONS
COTS	COMMERCIAL OFF THE SHELF
CRCSI	COOPERATIVE RESEARCH CENTRE FOR SPATIAL INFORMATION
CSIRO	COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANISATION
DAA	DETECT AND AVOID
DARPA	DEFENSE ADVANCED RESEARCH PROJECTS AGENCY
DBRPAAS	DATA BROKER PLATFORM AS A SERVICE
DDOS	DISTRIBUTED DENIAL OF SERVICE
DEA	DIGITAL EARTH AUSTRALIA
DGPS	DIFFERENTIAL GLOBAL POSITIONING SYSTEM
DSTO	DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
EEG	ELECTROENCEPHALOGRAM
EO	EARTH OBSERVATION
ESA	EUROPEAN SPACE AGENCY
FDMA	FREQUENCY DIVISION MULTIPLE ACCESS
FSDF	FOUNDATION SPATIAL DATA FRAMEWORK
FSS	FIXED SATELLITE SERVICES
FTE	FULL TIME EQUIVALENT
GA	GEOSCIENCE AUSTRALIA
GDP	GROSS DOMESTIC PRODUCT

ACRONYMS (CONT)

GDPR	GENERAL DATA PROTECTION REGULATION
GIC	GEOMAGNETICALLY INDUCED CURRENTS
GII	GLOBAL INNOVATION INDEX
GIS	GEOGRAPHIC INFORMATION SYSTEM
GITA	GEOSPATIAL INDUSTRY TECHNOLOGY ASSOCIATION
GNSS	GLOBAL NAVIGATION SATELLITE SYSTEM
GODI	GLOBAL OPEN DATA INDEX
GPL	GENERAL PUBLIC LICENCE
IADC	INTER AGENCY SPACE DEBRIS COORDINATION COMMITTEE
IMF	INTERPLANETARY MAGNETIC FIELD
IOT	INTERNET OF THINGS
ISA	INNOVATION AND SCIENCE AUSTRALIA
ISS	INTERNATIONAL SPACE STATION
ITS	INTELLIGENT TRANSPORT SYSTEMS
JORN	JINDALEE OPERATIONAL RADAR NETWORK
LBS	LOCATION BASED SERVICES
LEO	LEO EARTH ORBIT
LF/HC	LOW FREQUENCY/ HIGH CONSEQUENCE EVENT
LIDAR	LIGHT DETECTION AND RANGING
LPWAN	LOW POWER WIDE AREA NETWORKS
M2M	MACHINE TO MACHINE
MASA	MASH APP AND SERVICES ARCHITECTURE
NASA	NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
NBN	NATIONAL BROADBAND NETWORK
NCI	NATIONAL COMPUTATIONAL INFRASTRUCTURE
NFC	NEAR FIELD COMMUNICATION
NISA	NATIONAL INNOVATION AND SCIENCE AGENDA
NORAD	NORTH AMERICAN AEROSPACE DEFENSE COMMAND
NPI	NATIONAL POSITIONING INFRASTRUCTURE
NSDI	NATION WIDE SINGLE DATA INFRASTRUCTURE
ODC	OPEN DATA CUBE
OECD	ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT
OST	OUTER SPACE TREATY
OWA	OPEN WEB ANALYTICS
PNT	POSITIONING, NAVIGATION AND TIMING
PPP	PRECISE POINT POSITIONING

ACRONYMS (CONT)

RF	RADIO FREQUENCY
RNSS	REGIONAL NAVIGATION SATELLITE SYSTEM
RTK	REAL TIME KINEMATIC
SBAS	SATELLITE BASED AUGMENTATION SYSTEM
SDR	SOFTWARE DESIGNED RADIO
SDX	SOFTWARE DESIGNED ANYTHING
SERC	SPACE ENVIRONMENT RESEARCH CENTER
SIBA	SPATIAL INDUSTRIES BUSINESS ASSOCIATION
SKI	SPATIAL KNOWLEDGE INFRASTRUCTURE
SNI	SYSTEMS OF NATIONAL INTEREST
SSA	SPACE SITUATIONAL AWARENESS
SSN	SPACE SURVEILLANCE NETWORK
TTFF	TIME TO FIRST FIX
UN	UNITED NATIONS
UNCOPUOS	UNITED NATIONS COMMITTEE ON THE PEACEFUL USE OF OUTER SPACE
UNECA	UNITED NATIONS ECONOMIC COMMISSION FOR AFRICA
VA	VIRTUAL ASSISTANT
VR	VIRTUAL REALITY
VRML	VIRTUAL REALITY MODELING LANGUAGE
WEF	WORLD ECCONOMIC FORUM
WIPO	WORLD INTELLECTUAL PROPERTY ORGANISATION

PURPOSE OF THIS PAPER

This paper presents a summary for 2018 of the global trends in the spatial industry in the the context of global technology and economic drivers.

KEY POINTS

This report summarises trends affecting the global Spatial Industry. It examines market size for many of the components parts of the spatial industry and its technologies. It also includes a review of those allied technologies that will be influenced by, or will influence, the use of spatial technologies. The report draws primarily on published material in the public domain.

Summary of just some of the key findings:

- There is a widely held view that the global economy as a whole is facing massive disruption from digital technologies across the board. For example, Deloitte's reports that one-third of the Australian economy faces "imminent and substantial disruption by digital technologies and business models— … 'short fuse, big bang' opportunities, for both business and government".
- PWC notes that the fourth wave of the industrial revolution, cyber-physical systems, comprises many digital technologies; mobile devices, cloud computing, augmented reality and wearable technologies, multilevel customer interaction and profiling, big data analytics and advanced algorithms, smart sensors, 3D printing, authentication and fraud detection, advanced human-machine interfaces, Internet of Things platforms, block chains, drones, robots, and location-detection technologies.
- We can also add Artificial Intelligence, autonomous vehicles, cyber threats, advanced sensor technologies, space and satellite developments including micro, nano and cube sats, and satellite constellations of dozens or hundreds of satellites functioning together in pre-designed synchronisation. Spatial technologies will operate in tandem with most of these technologies to offer substantial value adding and new applications, many of which are not yet realised.
- Geospatial Media report that the geospatial market (comprising Global Navigation Satellite Systems, GIS, Earth Observation, and 3D Scanning) is growing steadily with the 2018 market worth USD $339 billion and forecast to grow to USD $439.2 billion by 2020.
- Geospatial Media also estimate the 2017 geospatial value to the economy by market sector (in billion USD $); transport (USD $623.2), utilities (USD $603.9), construction (USD $244.9), mining (USD $222.7), agriculture (USD $111.7), banking, finance and insurance (USD $95.8), Government services (USD $90.7), manufacturing (USD $80.8), forestry (USD $32.9), and fisheries (USD $9.8).
- Australia has identified its most promising growth sectors for the spatial industry as: transport, agriculture, health, defence and security, energy, mining, and the built environment, with the environment also requiring special consideration (2026 Spatial Agenda).

- Looking at space specifically, the global industry is worth USD $344.5 billion (Bryce)
- The total number of functional satellites in all classes is around 1738 of which 803 are from the US, 204 are Chinese, and 142 are Russian (as reported August 2017 by UCS).
- The Australian Government has announced that it intends to establish a Space Agency in 2018.
- When all classes of satellites (communications, positioning, earth observations etc.) are taken into account, it has been estimated that there will be up to 6200 smallsat's launched up to 2026 worth over USD $30 billion (Euroconsult).
- There are around 597 earth observation satellites in orbit (as reported August 2017) (UCS). This number is set to nearly double by 2026 to 1100 with four companies (Planet, Digital Globe, Spire and Blacksky) planning to launch 970 (Euroconsult).
- The global market size for Global Navigation Satellite Systems is currently worth USD $201.5 billion and is expected to grow to USD $260.8 billion by 2020 (Geospatial Media).
- There are currently 5.8 million devices with Global Navigation Satellite Systems receivers, and this number is expected to grow to 8 billion by 2020 (European GNSS Agency).
- The indoor Location Based Services market is estimated to grow over 43% between 2016 and 2020, reaching Euro 7.7 billion by 2020 with global sensor deployment in 2017 made up of beacons (65%), Wi-Fi-points (20%), and Near Field Communications (15%) (European GNSS Agency).
- The average global internet connection speed (IPv4) is 7.2 Mbps. South Korea ranks first with 28.6 Mbps, and Australia ranks 50th with an average connection speed of 11.1 Mbps (Akamai).
- Virtual Reality head-mounted displays are estimated to have a compound annual growth rate of 99% between 2015- 2020 (Business Insider Intelligence).
- 3D scanning technology captures 3D representation of physical objects. It is used in digital mapping, architecture, construction, engineering, precise manufacturing, and autonomous systems. It is growing with CAGR 18% from 2017- 2020 and expected to then reach a global market size of USD $14.2 billion (Geospatial Media).
- Mobile mapping systems are driven by the need for bulk data generation derived from 3D modelling and LIDAR technology. They provide accurate and time-saving data capture for assets and inventory management. Their market is expected to grow from USD $10.28 billion in 2015 to $39.8 billion in 2022 (a compound annual growth rate of 21.3%) (ReportsWeb).
- The Geospatial Analytics market in 2017 was valued at USD $37 billion and is expected to grow at an annual compound interest rate of 17 % between 2018 and 2024 to be worth USD $112.06 billion (Inkwood Research).
- In 2017, the Artificial Intelligence (AI) market was thought to be worth USD $16.06 billion, with a compound annual growth rate of 36% from 2018 to 2025 (MarketsandMarkets).

These are just some of the many observations contained in this report, the third in a series that includes prior published reports in 2014 and 2016.

1. SETTING THE SCENE

This report builds on the previous Global Outlook reports published in 2014 and 2016 for the Spatial Information Industry and aims to give an update on the development in various fields that are relevant for spatial technologies. To avoid repetition, some topics are omitted in the 2018 report, and the reader is encouraged to refer to the previous reports [1], [2].

FIGURE 1: OVERVIEW OF TOPICS IN THIS REPORT

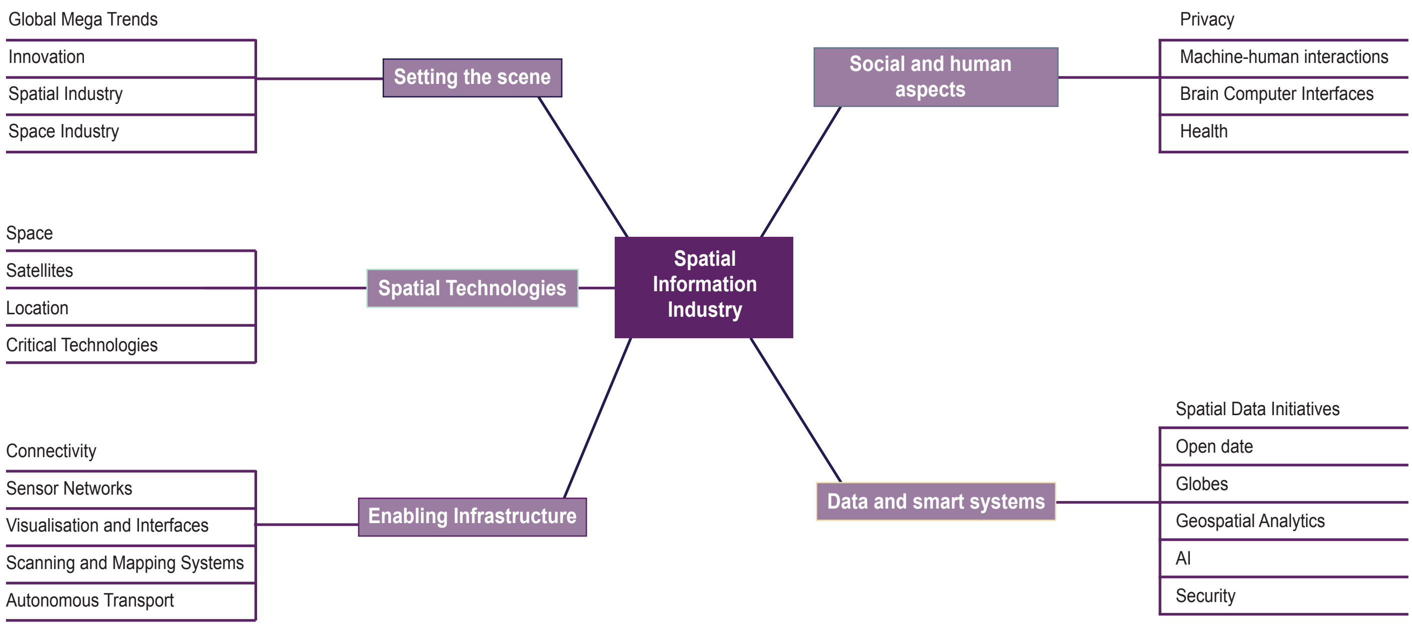


Figure 1: Overview topics discussed in this paper

1.1. GLOBAL MEGA TRENDS

Global trends and key implications through 2035, as reported by the Office of the Director of National Security (USA) include [3]:

- The life expectancy of the rich is increasing, whilst for the poor, it is not
- The global economy is shifting to lower growth in most countries
- Technology is accelerating progress but causing increasing disruptions and uncertainty
- Ideas and Identities are driving a wave of exclusion (tensions through global connectivity, weak growth, and populist influences)
- Governing is getting harder
- The nature of conflict is changing -from Nation to Nation direct engagement to terror and cyber threats from afar
- Climate change, environment, and health issues will demand more and more attention

The report remarks that ‘a lack of overall shared strategic understanding continues, however, which has resulted in a prevailing mode of international cooperation that is problem-centered, ad hoc, and issue-specific rather than anticipatory, cross-disciplinary, or universal in scope. States, corporations, and activists line up behind their specific causes, and this ad hoc approach in the long term can potentially cause a loss of coherence and direction among international bodies—the UN and others—that make up the international system. The advantage, however, is that voluntary, informal approaches can help create trust, common language, and shared goals—benefits that can eventually lead to support for, or a rebalance, in agreement at an international level. Whether the current institutions can be effective in the future, or whether new institutions or parallel mechanisms are formed, will depend largely on how governments interact with a variety of actors and whether current institutions and major powers can help states negotiate mature bargains on core national interests that recognize the interests of others’ [3].

Recent landmark agreements by some of the world's most influential governing bodies will lend momentum to necessary global changes when implemented effectively [3]:

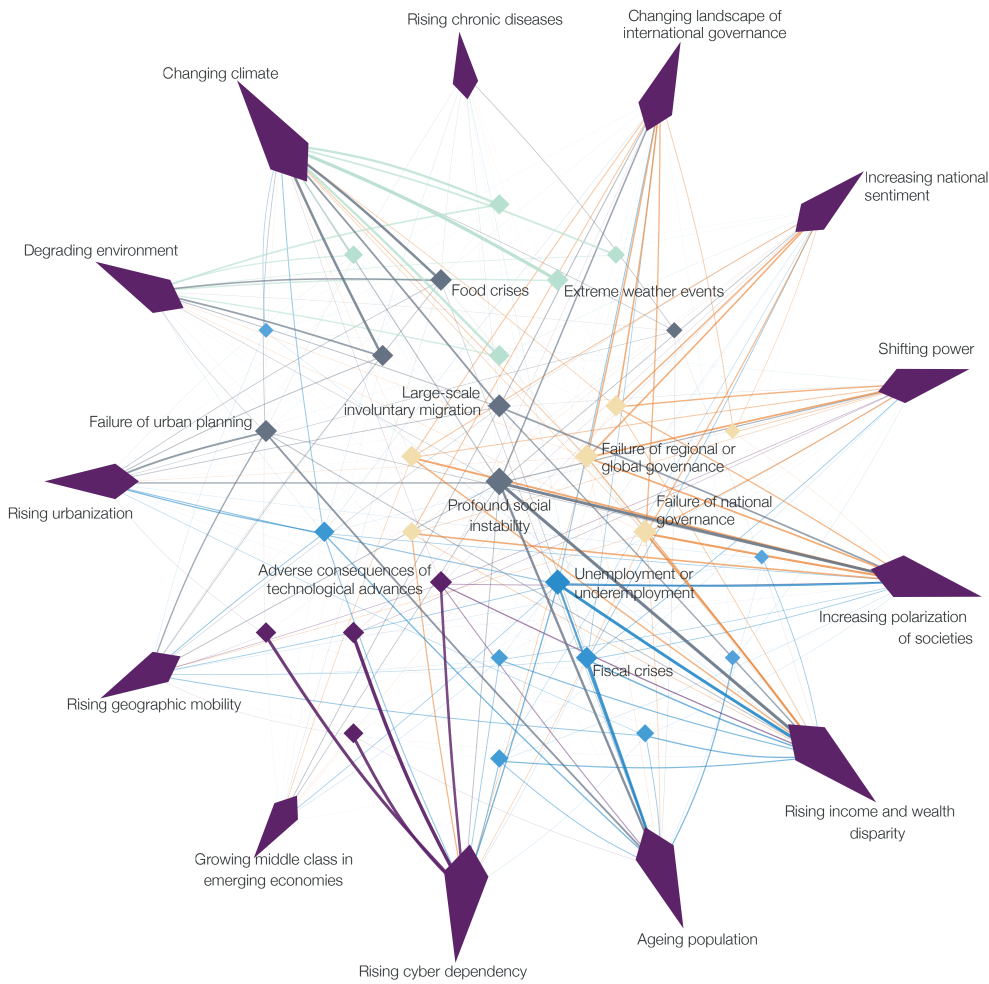
- In June 2015, the General Assembly endorsed the Sendai Framework for Disaster Risk Reduction.
- In July 2015, UN member states adopted the Addis Ababa Action Agenda on financing for development.
- In September 2015, the UN General Assembly adopted the 2030 Agenda for Sustainable Development.
- In December 2015, the Twenty-First Conference of the Parties to the UN Framework Convention on Climate Change concluded with an agreement by 195 countries to strive to keep the global temperature rise below two degrees Celsius.
- And in 2016, the International Organization for Migration joined the UN.

To harness data for sustainable development, the UN World data forum had its inaugural meeting in January 2017 attended by over 1500 data experts from more than 100 countries. Accurate, timely data, supported by sound collaboration and resources are needed in order to mobilise the world for the 2030 Agenda for sustainable development. Mr Wu Hongbo, UN Under-Secretary-General for Economic and Social Affairs expects the data forum “to offer a space where new partnerships can be forged, commitments announced, and support boosted for the Global Action Plan” [4].

1.1.1 GLOBAL RISKS

The World Economic Forum (WEF) draws on the perspectives of experts and global decision makers and analyses global risks (Figure 2) and how identified global trends relate to the global risk landscape [5]. Spatial technologies can be used to assess, measure and manage many of the risks.

FIGURE 2: THE RISKS-TRENDS INTERCONNECTIONS MAP 2018



Source: WEF [6]

1.1.2 DISRUPTION ON THE HORIZON

Deloitte reported in 'Digital Disruption: Short fuse, big bang?' [7] "one-third of the Australian economy faces imminent and substantial disruption by digital technologies and business models—what we call a 'short fuse, big bang' opportunities, for both business and government." One-third is a large part of the Australian economy, and a disruption of this magnitude will affect all of the country's citizens. McKinsey estimates that technical automation (if companies choose to do so) would globally affect $15.8 trillion of wages, and labour of 1.1 billion full-time equivalents (FTEs) [8].

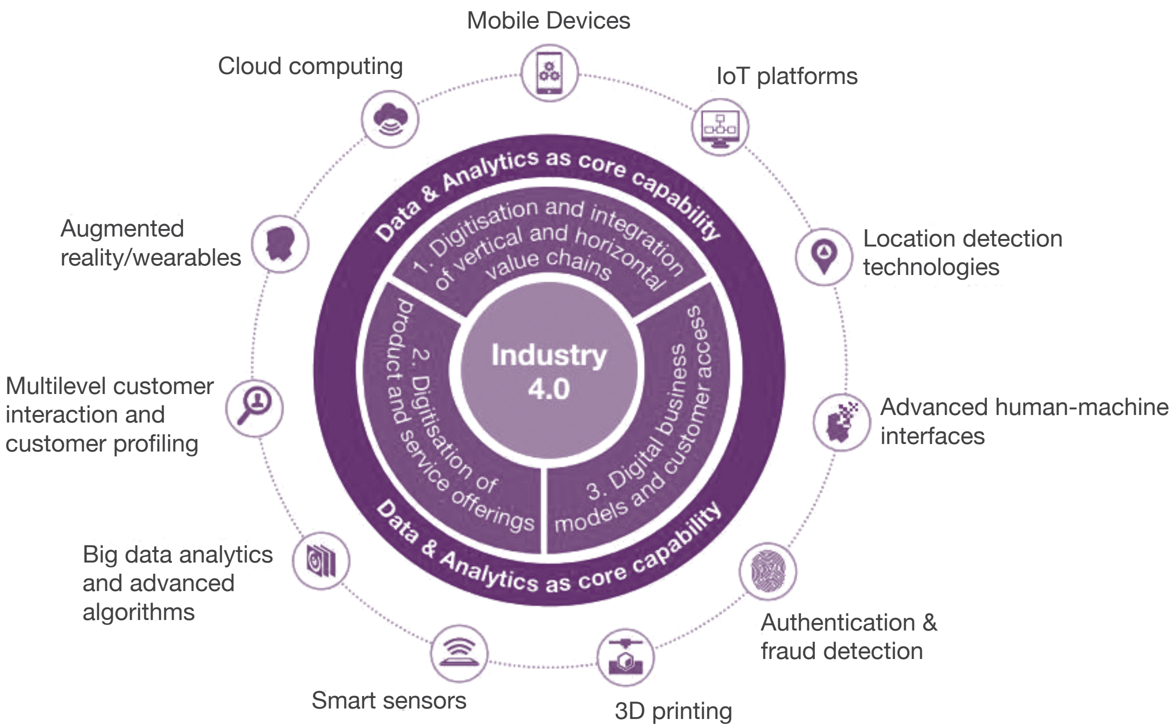
The World Economic Forum notes: 'We are in a highly disruptive phase of technological development, at a time of rising challenges to social cohesion and policy-makers' legitimacy. Given the power of the 4IR[1] to create and exacerbate global risks, the associated governance challenges are both huge and pressing... It is critical that policy-makers and other stakeholders – across government, civil society, academia, and the media – collaborate to create more agile and adaptive forms of local, national and global governance and risk management' [5].

[1] Fourth Industrial Revolution

1.1.3 BREAKTHROUGH TECHNOLOGIES

PWC assessed upcoming digital technologies for an Industry 4.0 framework (Figure 3); the framework builds on prior cycles of the industrial revolution: the first cycle comprising mechanisation, water power, steam power; the second mass production, assembly lines, electricity; the third computers and automation; and the fourth cyber-physical systems, Internet of Things (IoT). Figure 3 shows digital technologies related to the Industry 4.0 framework.

FIGURE 3: INDUSTRY 4.0 FRAMEWORK



Source: PWC [9]

The Internet of Things, augmented reality, virtual reality, blockchain, 3D printing, drones, and robots are identified by PWC as disruptive technologies that enable mega-trends. In PWC's annual Global CEO survey, 61% said they were concerned about the speed of technological change in their industries. "Most struggle to find the time and energy necessary to keep up with the technologies driving transformation across every industry and in every part of the world" [10].

Forbes' outlook on top trends shaping business notes that the landscape has changed greatly in just one year. While previously the focus was on consumer control via AI and the potential of virtual reality applications, it is now shifting to a greater focus on both local and global identity, with the reality of compromise by cyber threats including spying. Furthermore, Forbes notes other disparate but interesting trends including the shift to on-demand work, the growing economic disparity, the rise of celebrities in entrepreneurship (i.e. Elon Musk), and dark data analysis [11].

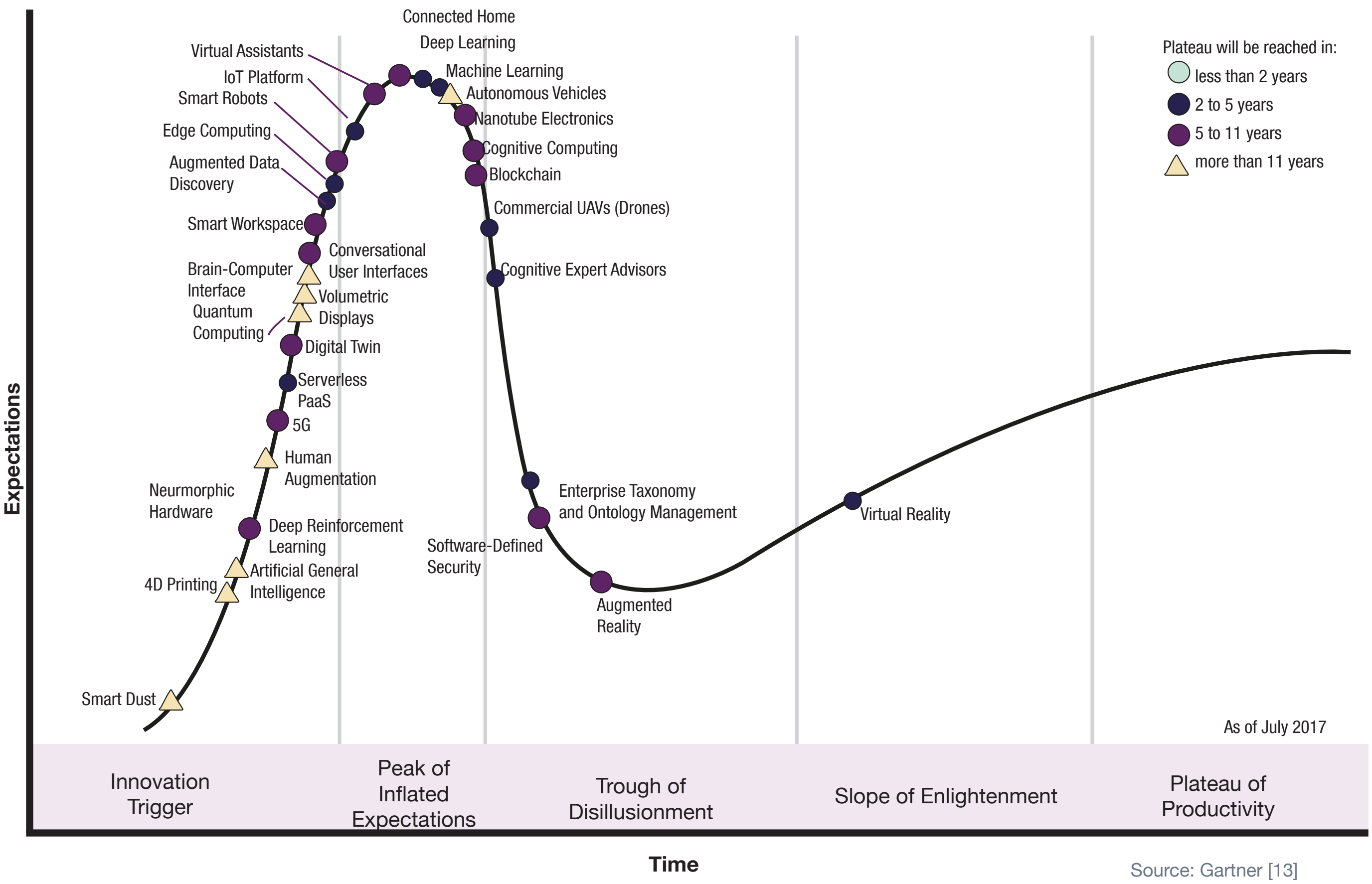
2016 Gartner hype cycle for emerging technologies observes three distinctive trends [12].

(1) Transparently Immersive Experiences- this includes Human augmentation, connected home, 4D printing, nanotube electronics, brain-computer interface, augmented reality, virtual reality, volumetric displays, gesture control devices, affective computing.

(2) Perceptual smart machine age - smart dust, commercial drones, machine learning, autonomous vehicles, virtual personal assistants, natural language Q&A, cognitive expert advisors, personal analytics, smart data discovery, enterprise taxonomy and ontology management, smart workspace, data broker PaaS (dbrPaas), conversational user interfaces, context brokering, smart robots.

(3) Platform revolution - comprising neuromorphic hardware, IoT Platform, Quantum computing, software-defined security, blockchain, software-defined anything (SDx).

FIGURE 4: GARTNER HYPE CYCLE OF EMERGING TECHNOLOGY



Source: Gartner [13]

Figure 4 shows the 2017 Gartner Hype cycle of Emerging technologies; machine learning, blockchain, commercial drones, software-designed security and brain-computer interfaces have significantly progressed on the Hype Cycle since 2016 [13]. Technologies such as 5G, artificial general intelligence, deep learning, edge computing, serverless PaaS were added and virtual personal assistants, personal analytics, data broker PaaS (dbrPaaS) are no longer included.

1.2 INNOVATION

1.2.1 STATUS OF INNOVATION IN AUSTRALIA

In December 2015 the Australian Government launched the National Innovation and Science Agenda (NISA). The initiative runs over 4 years and comprises 24 initiatives. It has AUD $1.1 billion directly allocated to it and will influence approximately AUD $10 billion per annum in government-related expenditure on innovation.

The NISA's 'idea boom' will focus on four key pillars [14] :

- Culture and capital
- Collaboration
- Talent and skills
- Government as an exemplar.

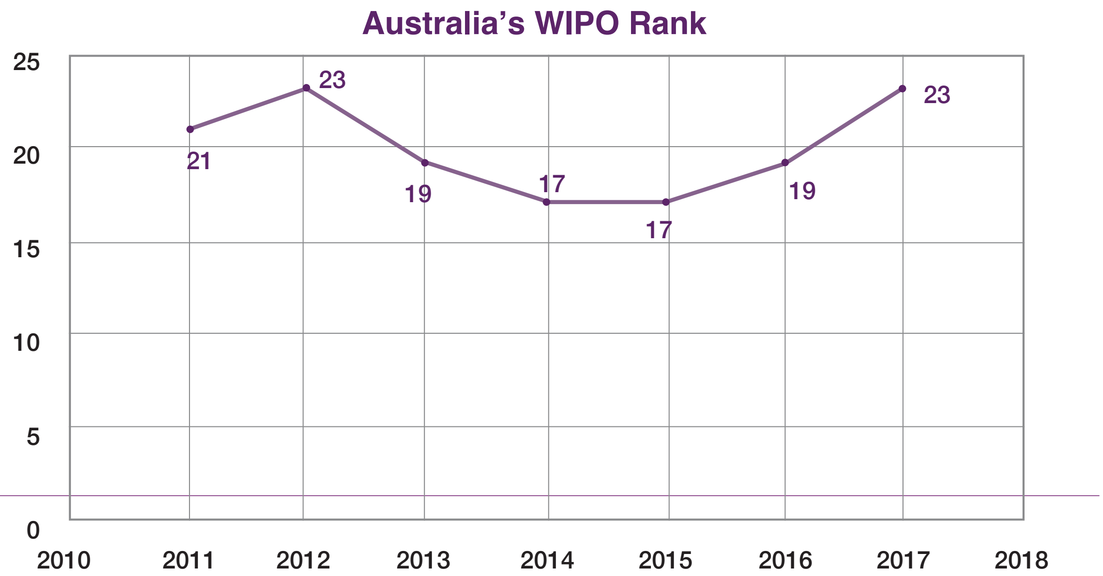
Innovation and Science Australia (ISA) has a scorecard that summarizes key criteria, benchmarking Australia's performance in innovation and industry competitiveness globally [15].

The scorecard highlights Australia's relative success in knowledge creation. It also shows there is room for improvement in applying this knowledge.

The Global Innovation Index (GII) is an annual measure of a country's capacity and success in innovation. Data are derived from several sources, including ITU, WEF and the World Bank.

Figure 5 shows Australia's WIPO rank since 2011 [16], [17].

FIGURE 5: AUSTRALIA'S WIPO INDEX RANKING 2011- 2017



Source: WIPO [16]

FIGURE 6: PERFORMANCE SCORECARD FOR AUSTRALIA

	Latest score & trend	Average for the top 5 performers	Australia's ranking
Knowledge creation			
Gross expenditure on research and development (GERD), % of GDP	2.12 ▲	3.66	15 of 37
Higher education expenditure on research and development (HERD), % of GDP	0.63 ▲	0.84	10 of 37
Government expenditure on research and development (GOVERD), % of GDP	0.24 ▼	0.40	15 of 37
Academic Ranking of World Universities top 200 universities, per million population	0.33 ▲	0.54	9 of 31
Highly cited publications (top 1% in the world, all disciplines) per million population	48.7 ▲	86.0	8 of 36
Government and higher education researchers (full time equivalent) per thousand total employment	6.48 ▲	6.27	3 of 36
Population aged 25–64 with a doctorate per thousand population	8.21 ▲	16.8	11 of 34
Knowledge transfer			
Population aged 25–64 with tertiary education, %	42.9 ▲	48.7	7 of 36
Universitas 21 national higher education systems ranking	10th ▼	n/a	10 of 34
Percentage of HERD financed by industry, %	4.73 ▼	16.8	18 of 37
Proportion of publications with industry affiliated co-authors, %	1.22 ▼	4.99	27 of 38
Proportion of Patent Cooperation Treaty (PCT) patents with foreign co-inventors, %	16.2 ▲	43.8	27 of 37
Knowledge application			
Total early-stage entrepreneurship activity, %	12.8 ▲	18.7	8 of 38
Venture capital investment, % of GDP	0.02 ▲	0.19	18 of 30
Number of international patent applications filed by residents at the PCT per billion GDP (PPP)	1.5 ▼	8.3	22 of 37
Business researchers, per thousand employed in industry	4.68 ▲	14.7	21 of 36
Business expenditure on research and development (BERD), % of GDP	1.19 ▲	2.78	16 of 37
Outputs			
Percentage of firms that introduced new-to-market product innovation, %	9.23 ▼	21.3	23 of 31
Outcomes			
Multifactor productivity change, five year compound annual growth rate, %	0.40 ▼	1.29	12 of 20
High-growth enterprise rate, measured by employment growth, industry, %	0.80 ▼	13.5	27 of 27

1. Australia's score is the latest available data point for the given metric.
2. Australia's trend in each metric is shown by the upwards and downwards arrows.
3. International comparisons are made between Australia and other OECD+ countries. OECD+ countries include all countries in the OECD, as well as China, Taiwan and Singapore (where data is available). If country data from the given reference period is unavailable, the nearest available data has been included in the analysis.
4. The average for the top five OECD+ countries represents the simple average of the scores for the top five OECD+ countries in the given metric.

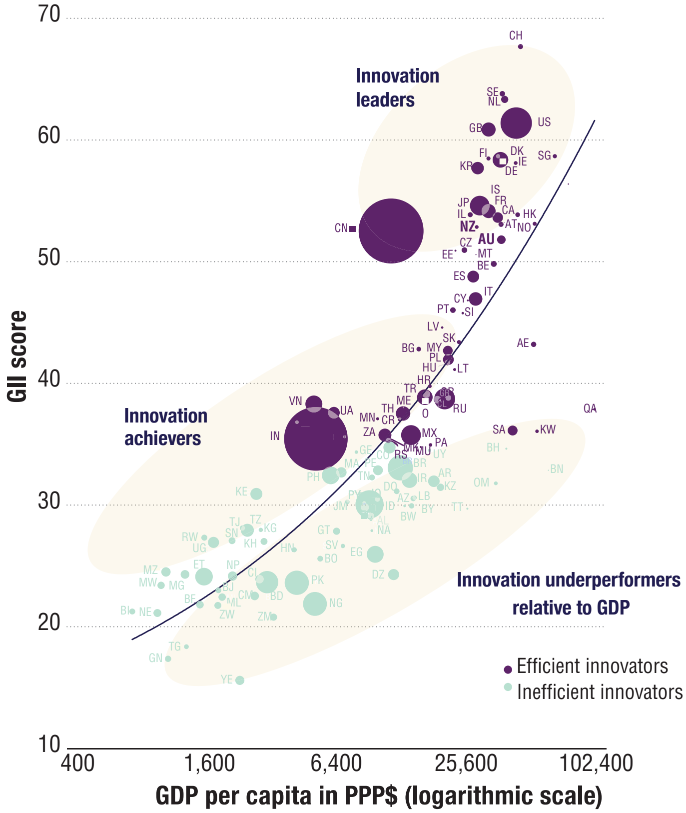
First quartile
Second quartile
Third or fourth quartile

Source: ISA [15]

When compared in an international setting (GII & GDP), Australia recently has moved from inefficient innovator [16] to efficient innovator [17] but is still not in the innovation leaders group (New Zealand is, see Figure 7).

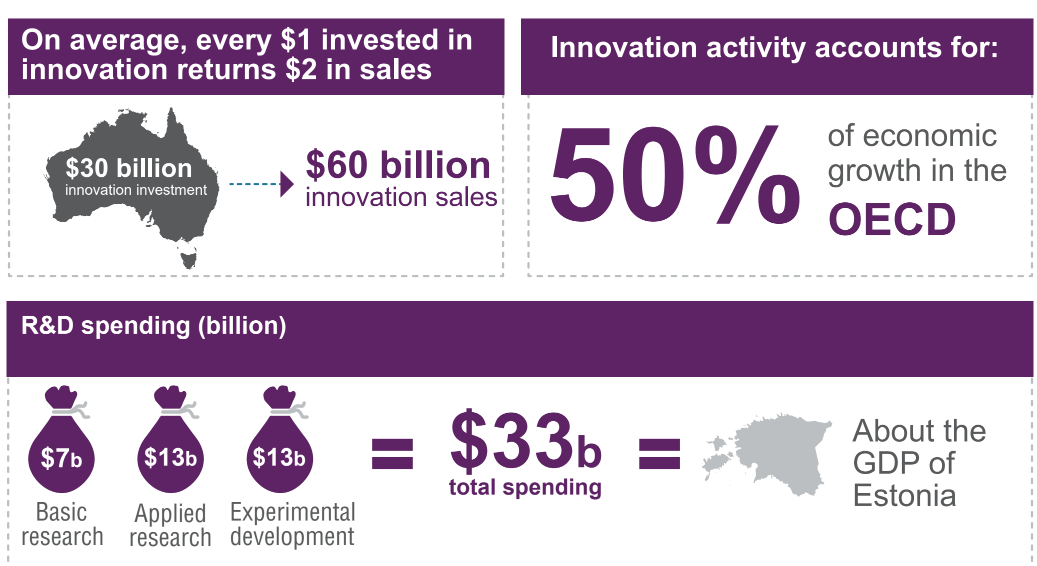
The Innovation System Report [18] highlights innovation benefits (Figure 8) and notes: ‘Just as innovation can be a source of competitive advantage for business, a high-performing innovation system can underpin the overall competitiveness of an economy’ [18].

FIGURE 7: WIPO INNOVATION MATRIX



Source: WIPO [17]

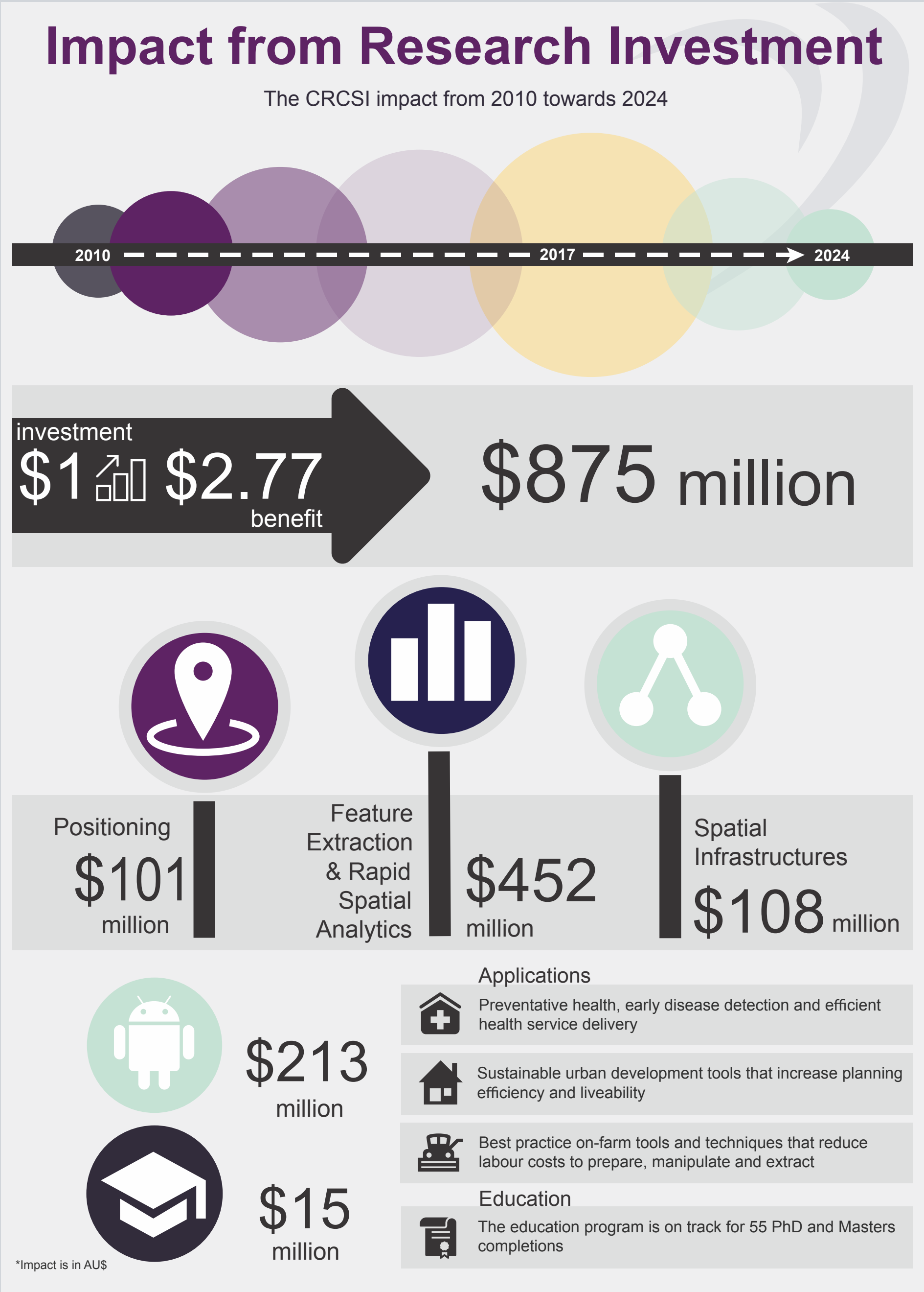
FIGURE 8: AUSTRALIAN INNOVATION SYSTEM



Source: Australian Government [18]

The Australian Innovation System Report 2017 gives a detailed update on Australia's innovation activities [19].
The figures of innovation success are echoed by results of research investments from the Australia New Zealand Cooperative Research Centre for Spatial Information (CRCSI): AUD $1 investment was turned into AUD $2.77 benefits.

FIGURE 9: FORECAST CRCSI RESEARCH IMPACT



Source: CRCSI [20]

1.2.2 AUSTRALIA'S 2026 SPATIAL INDUSTRY TRANSFORMATION AND GROWTH AGENDA (2026AGENDA)

In the spirit of the 'ideas boom,' a path for future research, development, and innovation has been developed for Australia's spatial industry. The development of the 2026Agenda has been led by the Australia New Zealand Cooperative Research Centre for Spatial Information (CRCSI), the Spatial Industries Business Association-Geospatial Industry Technology Association (SIBA-GITA), ANZLIC (Australia and New Zealand's peak government Council for spatial matters), the Australian Earth Observation Community Coordination Group, Data61 (CSIRO), Landgate, Geoscience Australia, Department of Natural Resources and Mines (Queensland Government), and the Department of Prime Minister and Cabinet.

The vision for 2026 is for Australia to be:

A global leader in integrating location intelligence within the digital economy,

A place where location-related technologies, services, and skills underpin all sectors and disciplines and

A nation where location technologies and services drive economic growth through a culture of innovation and collaboration and the development of domestic and overseas markets [21].

The nation has agreed that the 2026Agenda should reflect the following values; collaborative, innovative, user-focused, adaptive and rigorous [21].

2026Agenda vision: Australia will excel in the development of location-related technologies, services, and skills that deliver value to businesses and communities [21].

The Hon. Angus Taylor MP, Assistant Minister for Cities and Digital Transformation remarks: 'The National Innovation and Science Agenda (NISA) sets the scene for Australia to become a leading digital nation fostering innovation and entrepreneurship through collaboration. The 2026 Spatial Industry Transformation and Growth Agenda (2026Agenda) provides the vision and direction to enable the spatial industry to deliver national and global services that will support the NISA. The 2026Agenda sets out a coordinated suite of initiatives for the next decade that will foster a new era of cooperation between industry, government, and academia. It aims to expand the spatial sector's impact right across the economy and to equip all Australians with future-ready skills' [22].

Figure 10 shows numbers related to the community input and consultation for the 2026Agenda.

FIGURE 10: 2026 AGENDA

Source: 2026Agenda [21]

Three reports were delivered: An Action plan [22] (including discussions thereof [21]), the 2026 Insights report (including discussion on impediments to growth) [23], and the Ideas Paper [24]. Appendix A shows more details for the six pillars of action in the 2026 Agenda.

FIGURE 11: OVERVIEW- 2026AGENDA KEY PILLARS

A Public infrastructure and Analytics

Accelerate provision of coordinated, open access, nation-wide, public spatial information and analytic tools that are easy-to-use, and facilitate data mining and interpretation for the benefit of all users.

B Innovation and Entrepreneurship

Foster spatial innovation and entrepreneurial skills, capitalising on technological advances, developing creative business models to open up new markets and opportunities

C Outreach

Raise the prole of the spatial sector, cleary communicating the value and contribution that location intelligence brings to the economy and society

D Research and Development

Create a nation-wide, coordinated, collaborative and focused spatial R&D agenda that meets changing national needs and continues to grow linkages between research, innovation and commercialisation

E Education, Training and Capacity Building

Introduce location-related training at all education levels, nation-wide, including regional communities, to develop a well-prepared and diverse workforce that benefits from fundamental spatial skills.

F Representation

Unify and consolidate representative spatial bodies to speak with one voice, and provide effective leadership and advocacy for spatial

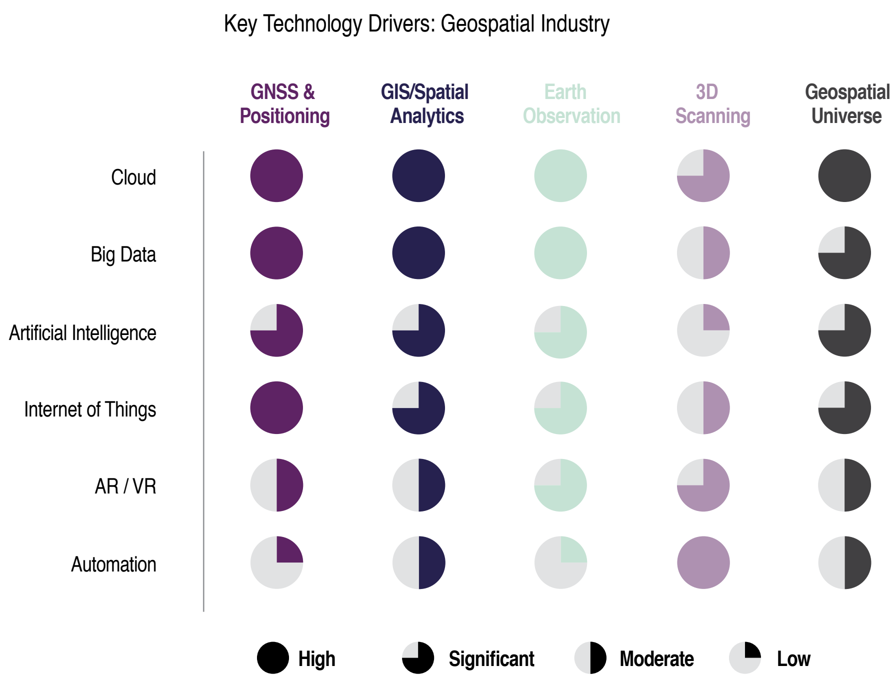
Source: 2026Agenda [22]

1.3 SPATIAL INDUSTRY

1.3.1 GEOSPATIAL DRIVERS

Technology drivers that advance Geospatial Technologies were identified in the Global Geospatial Outlook and Readiness Index Report as cloud, big data, artificial intelligence technologies, Internet of Things, augmented and virtual reality, and automation [25]. Figure 12 shows how relevant the listed technologies are for Positioning, Spatial Analytics, Earth Observations, 3D Scanning and the Geospatial Universe.

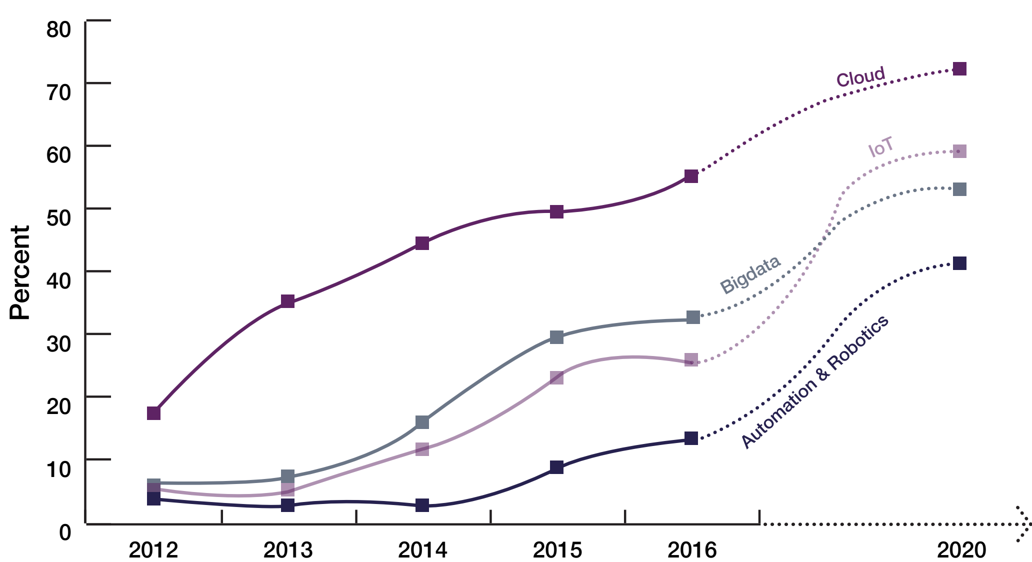
FIGURE 12: KEY TECHNOLOGY DRIVERS



Source: Geospatial Media Analysis [25]

The Global Geospatial Industry Outlook report 2017 [26] sets out the expected trends until 2020 (Figure 13):

FIGURE 13: TECHNOLOGY TRENDS INFLUENCING THE GEOSPATIAL INDUSTRY



Source: Geospatial Media and Communications [26]

The report [26] notes upcoming technologies furthermore as context-rich systems; holograms/ virtual reality; gamification; digital mesh; nano-technology/ microsatellites; surface computing; enterprise mobility; 3D printing; wearable; and self-driving cars; and lists the following geospatial areas that will be influenced [26]:

- Nano and small satellites (EOS)
- High-definition maps, imaging, and videography (EOS)
- High resolution (EOS)
- Increased modularity (EOS)
- Developments in mobile power technology (EOS)
- Increased accuracy (Positioning)
- Compactness & light-weight (Positioning)
- Multi-sensor systems (Positioning)
- Robotic total station (Positioning)
- Total Station with integrated video technology (Positioning)
- From Cloud to mobile (GIS/ Spatial Analytics)
- Reality modelling- better and quicker (GIS/ Spatial Analytics)
- Comprehensive delivery platforms (GIS/ Spatial Analytics)
- Software integrated with hardware (GIS/ Spatial Analytics)
- Integrated SDK and developers platform (GIS/ Spatial Analytics)
- Portability (Scanning)
- Increase effectiveness of documentation process (Scanning)
- Multi-sensor vehicle-borne laser mapping system (Scanning)

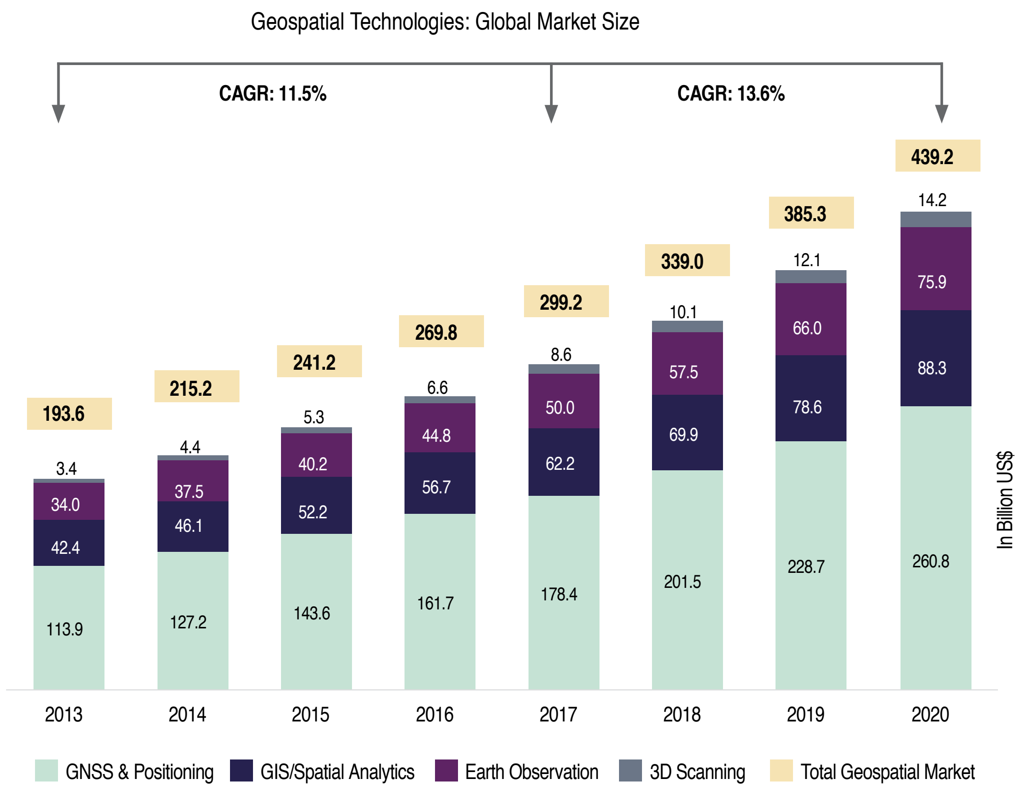
1.3.2 GEOSPATIAL MARKET SIZE

The Global Geospatial Industry Outlook Report groups Geospatial Technologies as follows:

- GIS/ Spatial Analytics (desktop; web/cloud; mobile):
- GNSS & Positioning (navigation; indoor positioning; surveying):
- Earth Observation (satellite remote sensing; aerial mapping; drones):
- Scanning (LiDAR; laser scanning; radar):

The Geospatial market is growing steadily. Figure 14 shows the market size and contributions from GNSS, GIS, Earth Observation, 3D Scanning; in 2018 the market is worth USD $339 billion and is forecast to grow to USD $439.2 billion by 2020.

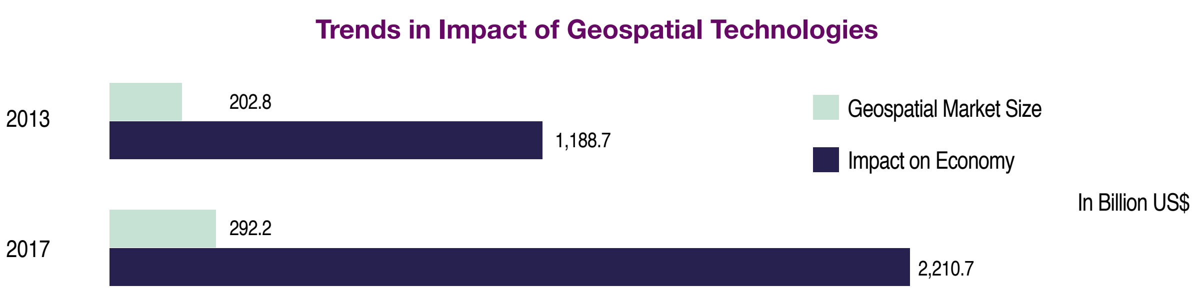
FIGURE 14: GLOBAL MARKET SIZE- GEOSPATIAL TECHNOLOGIES



Source: Geospatial Media and Communications [25]

Figure 15 shows the benefit to GDP from geospatial technologies, with respect to the size of the geospatial market.

FIGURE 15: GEOSPATIAL TECHNOLOGY BENEFITS



Adapted from Indecon International Economic Consultants, ACIL Tasman, BCG, AlphaBeta, Oxera, Natural Resources Canada and Geospatial Media Analysis

Source: Geospatial Media and Communications [25]

Geospatial Services bring significant benefit to the economy and society (see Figure 16), not only in cost savings, but also in time and fuel savings, and have an impact with respect to emergency response and education [26], [27].

FIGURE 16: IMPACT OF GEOSPATIAL SERVICES DURING 2016

GLOBAL ECONOMIC IMPACT OF GEOSPATIAL SERVICES DURING 2016:

CONSUMER BENEFITS

Consumers value digital maps at up to
US$105 PER USER
resulting in total benefits of
US$347 BILLION PER YEAR.

Digital maps reduce travel time by
12% ON AVERAGE.
The value of time saved is
US$264 BILLION
based on local wage rates.

Consumers save more than
21 BILLION HOURS
per year from more efficient purchasing descisions.
The value of time saved is
US$283 BILLION.

BUSINESS BENEFITS

Geospatial services industry generated revenue of approximately
US$400 BILLION IN 2016.

Geospatial services could have a significant productivity impact in sectors representing approximately
75% OF GLOBAL GDP.

Digital maps have supported over
US$1 TRILLION
of yearly sales for businesses.

SOCIETAL BENEFITS

CO^2 emissions from vehicles could be reduced by
1,686 MILLION MT
from more efficient trips and reduced congestions.

Potential employment directly linked to digital maps of over
4 MILLION JOBS GLOBALLY.

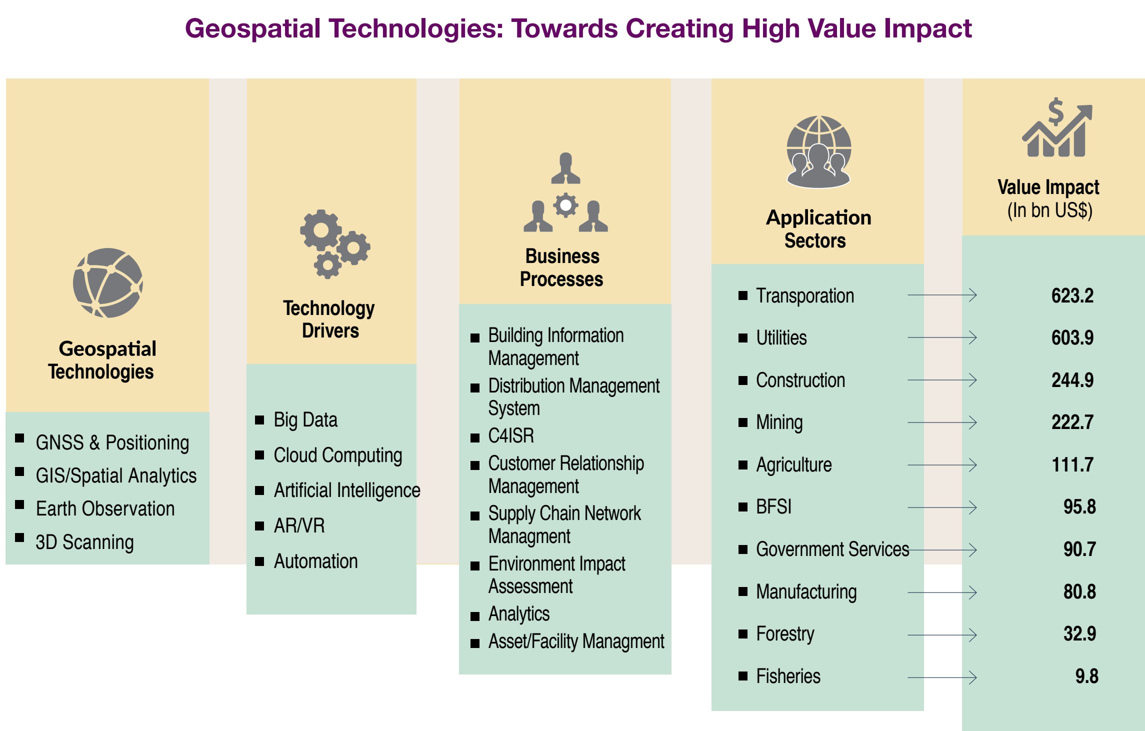
Emergency response times
DECREASED BY 20%
resulting in more lives saved.
Geo-services also help prepare for a natural disaster (e.g., highlighting flood risk).

Data in exhibit is estimated by AlphaBeta using a rangge of original and third party sources.

Source: AlphaBeta [27]

The value to the economy has been segmented to various application sectors in Figure 17.

FIGURE 17: VALUE IMPACT CREATED BY GEOSPATIAL TECHNOLOGIES



Geospatial Media and Communications [25]

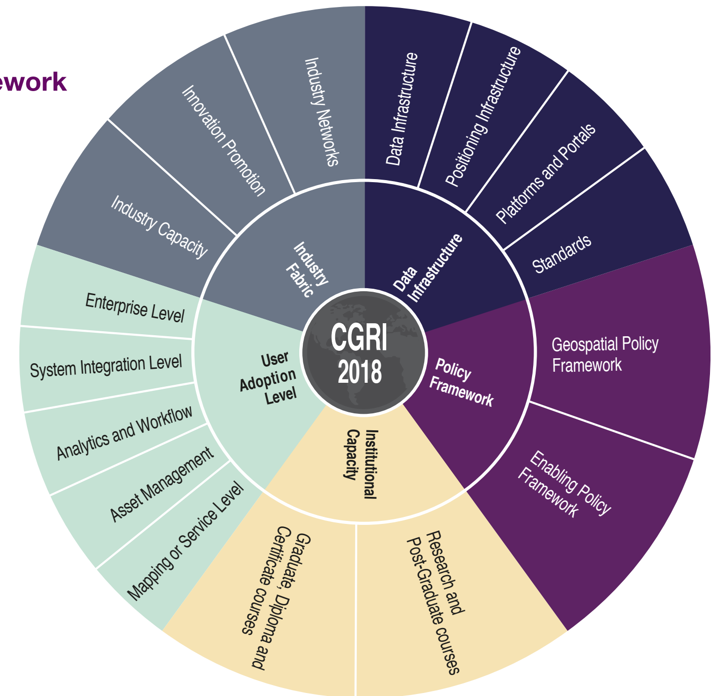
1.3.3 GEOSPATIAL READINESS INDEX

Conducting research across the geospatial industry, the report rates the 'Geospatial Readiness' of approximately 50 nations, assessing factors shown in Figure 18 [25]. The colours relate to 'pillar' topics, used for the assessment.

FIGURE 18: GEOSPATIAL READINESS INDEX ASSESSMENT FACTORS

CGRI 2018

Assessment Framework



Source: Geospatial Media and Communications [25]

In 2018, the USA scored the highest, followed by the UK and Germany.

Australia was placed overall at 14th place (28.804), with specific scores for the pillars [25] as:

- Pillar 1: Geospatial Data Infrastructure Index: #16 (85.12)
- Pillar 2: Geospatial Policy Framework Index: # 18 (25.18)
- Pillar 3: Geospatial Institutional Capacity Index: # 5 (6.339)
- Pillar 4: Geospatial User Adoption Index: # 14 (22.691)
- Pillar 5: Geospatial Industrial Fabric Index: # 9 (11.52)

New Zealand ranked overall at number 25 (20.695) [25]:

- Pillar 1: Geospatial Data Infrastructure Index: #26 (62.46)
- Pillar 2: Geospatial Policy Framework Index: # 35 (12.65)
- Pillar 3: Geospatial Institutional Capacity Index: # 11 (3.697)
- Pillar 4: Geospatial User Adoption Index: # 22 (19.746)
- Pillar 5: Geospatial Industrial Fabric Index: # 24 (7.50)

Figure 19 shows the countries ranking in the first 25 positions of the Global Readiness Index.

FIGURE 19: GLOBAL READINESS INDEX CGRI 2018 RANKING

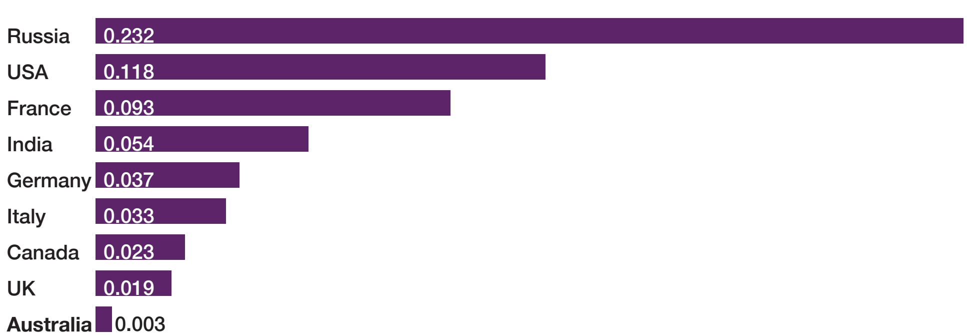
Rank 2018	Country Name	Total Score	Data Infrastructure	Policy Framework	Institutional Capacity	User Adoption	Industry Fabric
	Maximum Score	100	20	10	20	20	30
1	USA	67.77	27.94	3.23	13.51	6.62	16.46
2	UK	40.63	21.23	3.54	3.41	6.41	6.03
3	Germany	37.54	17.35	2.81	1.23	5.62	10.51
4	Singapore	34.97	22.47	2.68	1.41	6.05	2.33
5	The Netherlands	33.35	20.54	2.64	0.98	5.81	3.36
6	China	32.17	20.92	1.76	0.85	4.59	4.03
7	Canada	31.96	16.64	2.60	2.24	5.73	4.73
8	Denmark	31.37	21.08	2.69	0.36	4.33	2.88
9	Switzerland	30.67	18.71	2.61	0.75	4.92	3.67
10	France	30.62	17.83	2.62	0.31	5.77	4.07
11	Belgium	29.97	19.26	2.66	0.51	4.495	3.03
12	Spain	29.72	17.75	2.56	0.90	4.89	3.60
13	Austria	28.88	17.79	2.73	0.50	5.12	2.72
14	Australia	28.80	17.02	2.51	1.26	4.53	3.45
15	South Korea	28.12	18.62	2.39	0.36	3.98	2.75
16	Japan	27.00	16.11	2.59	0.61	4.54	3.13
17	Russia	26.96	17.14	2.78	0.22	4.56	2.25
18	Italy	26.35	15.87	2.77	0.27	4.10	3.33
19	Poland	26.31	17.75	2.99	0.21	3.2	2.15
20	Sweden	26.18	15.15	2.97	0.6	4.23	3.22
21	Portugal	23.58	14.71	1.92	0.39	3.48	3.06
22	Finland	23.18	13.10	2.36	0.47	4.32	2.91
23	UAE	22.95	16.20	1.68	0.11	3.61	1.32
24	Norway	22.73	13.37	2.43	0.35	4.36	2.20
25	New Zealand	20.69	12.49	1.26	0.73	3.94	2.2

Geospatial Media and Communications [25]

1.4 SPACE INDUSTRY

Most OECD Nations are active in Space. Compared with other nations, Australia in the recent past has invested relatively small proportions of GDP into space (see Figure 20).

FIGURE 20: SPACE EXPENDITURE (% OF GDP)



Data for Australia refer to 2013. Other data refer to 2014. China not present as no official data could be provided. Source: G.Lania (2016)

Source: Phinn; Lania [28] [29]

1.4.1 AUSTRALIAN SPACE INDUSTRY

Australia does not have a Space Agency, being one of only two OECD Nations (Iceland being the other) without a national Space Agency. Nor does Australia own any substantial resources in space. New Zealand established its own agency in 2016. Australia has focused its efforts on advances in data enhancements and in developing uses for earth observation data. The Australian Government announced in 2017 that it intends to develop its own Space Agency in 2018.

Australia already has significant involvement in national and international space activities [30]; with estimates putting the number of employees in the space sector at between 9,500 and 11,500 people and around USD $4 billion of activity (0.8% share of global space economy) Figure 21 and Figure 22 are summary tables from the South Australian Space Capability Report, 2017 [31];

FIGURE 21: OVERVIEW SA SPACE CAPABILITIES

	Space Systems							Launch Activities				Ground Systems						Space Enabled Services							Support Services				R&D	Other
	Prime/System Integration	Space Subsystem Supply	Component and Material Supply	Space Qualified Testing and Facilities	System Engineering and Technical Support	Satellite Owner/Operator	Specialisation on nano and micro satellites (<50kg)	Launch services	Launch Vehicle Manufacturing and Assembly	Component and Subsystem Manufacturing	Launch Support Services	Ground Segment Prime/System Integration	Ground Segment Subsystem & Equipment Supplier	Antenna/Ground Station Component or Material Supplier	System Engineering and Technical Support Services	Ground Station/Teleport Owner/Operator	Tracking, Telemetry & Command Operations	Satellite Broadcast Service Providers	Satellite Communications Service Providers	User Equipment Manufacturer	User Equipment Suppliers	Earth Observation Services & Applications	Satellite Navigation Service & Applications	Technical Support Services	Legal Services	Financial Services	Insurance Services	Consultancy Services		
Industrial Associations																														
American Institute of Aeronautics and Astronautics (AIAA)) - Adelaide Section																														Industry advocacy
Defence Teaming Centre																														Industry advocacy
Space Industry Association of Australia																														Industry advocacy
Private Consultancies																														
ACIL Allen Consulting																														
Coutts Communications																														
Frazer-Nash Consultancy					X										X									X				X	X	
KasComm																												X		
Minter Ellison																									X					
Education & Research Organisations																														
Airborne Research Australia				X	X																							X		
Flinders University			X	X											X							X		X				X	X	Space archaeology
Hamilton Secondary College																														STEM pathway
Mullard Space Science Laboratory		X	X	X	X		X						X		X	X	X												X	
Southern Hemisphere Space Studies Program																													X	Space education Prof. qualification
TAFE SA																														Training Services
University of Adelaide							X				X		X	X	X		X								X			X	X	
University of South Australia							X									X	X					X		X				X	X	
Government Departments																														
Bureau of Meteorology																	X					X						X		
Department of Defence	X	X			X	X						X	X	X	X	X	X					X	X	X	X	X		X		X
Department of Education and Child Development																														STEM education
Department of Environment, Water and Natural Resources																						X								
Investment Attraction South Australia																														Investment support
Space Industry and R&D Collaborations																														Stakeholder engagement Industry advocacy

Source: Defence SA [31]

FIGURE 22: SA SPACE CAPABILITY (CONT.)

	Space Systems							Launch Activities				Ground Systems						Space Enabled Services							Support Services				R&D	Other
Private Companies	Prime/System Integration	Space Subsystem Supply	Component and Material Supply	Space Qualified Testing and Facilities	System Engineering and Technical Support	Satellite Owner/Operator	Specialisation on nano and micro satellites (<50kg)	Launch services	Launch Vehicle Manufacturing and Assembly	Component and Subsystem Manufacturing	Launch Support Services	Ground Segment Prime/System Integration	Ground Segment Subsystem & Equipment Supplier	Antenna/Ground Station Component or Material Supplier	System Engineering and Technical Support Services	Ground Station/Teleport Owner/Operator	Tracking, Telemetry & Command Operations	Satellite Broadcast Service Providers	Satellite Communications Service Providers	User Equipment Manufacturer	User Equipment Suppliers	Earth Observation Services & Applications	Satellite Navigation Service & Applications	Technical Support Services	Legal Services	Financial Services	Insurance Services	Consultancy Services		
Aerometrex																						X								X
Airbus Defence & Space	X	X	X	X	X	X		X	X	X	X					X	X		X			X							X	X
Auspace													X							X	X			X						
Axiom Precision Manufacturing	X		X							X	X			X						X								X		
BAE Systems Australia	X	X	X	X	X		X	X	X	X	X	X	X	X	X		X			X	X	X		X						X
Boeing	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X		X					X	X	X		X	X	
Cobham Aviation Services												X				X			X			X		X						
Elementrex																						X						X		X
Fleet Space Technologies						X	X												X		X									
Fullarton Space Biotech Pty Ltd																													X	
Geoplex					X		X								X		X					X	X	X				X		
Greenhouse Gas Monitor Australia		X																				X						X		
Inovor Technologies	X	X			X	X	X								X		X					X	X	X				X	X	
Irriscan Australia																						X								
Launchbox Australia						X	X												X		X									X
Lockheed Martin	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					X		X					X	
Myriota																			X	X										
Neumann Space Pty Ltd		X																											X	X
NodeSat							X				X								X					X				X	X	
Northrop Grumman Australia	X	X	X	X	X										X	X				X			X	X						
Norseld Pty Ltd			X																	X									X	
Nova Systems											X	X			X		X													
Shoal Engineering					X						X				X													X	X	
Small World Communications			X										X																	
SpeedCast					X	X						X	X	X	X	X	X	X	X		X		X	X						
Toolcraft Precision Engineering	X							X						X																

Source: Defence SA [31]

In Figure 23 the capabilities of various Australian space segments are assessed. Strengths can be found in ground systems, space enabled services and applications, and research.

FIGURE 23: SPACE COMPETENCIES IN AUSTRALIA

Segment	Category of Capability	Intensity of Capability Amongst Companies Interviewed
Space Systems	Space systems prime / Systems integration	Low
	Space subsystems supply	Low
	Space component and material supply	Low
	Space qualified testing and facilities	Low
	System engineering and technical support services	High
	Satellite owner / operator	Medium
	Other	Low
Launch and support Services	Launch services	None
	Launch vehicle manufacturing and assembly	Low
	Launch vehicle component and subsystem manufacturing	Low
	Launch support services	Low
	Other	Low
Ground Systems	Ground Segment Prime / System Integration	High
	Ground Segment Subsystem & Equipment Supplier	High
	Antenna / Ground Station Component or Material Supplier	Medium
	System Engineering and Technical Support Services	High
	Ground Station / Teleport Owner / Operator	High
	Tracking Telemetry & Command Operations	High
	GNSS Reference Stations & Fixed GNSS Receivers	High
	Other	Low
Space Enabled Services and Applications	Satellite Broadcast Service Providers	Medium
	Satellite Communications Service Providers	High
	User Equipment manufacturer	Low
	User Equipment supplier	Medium
	Earth Observation Services & Applications	High
	Satellite Navigation Services & Applications	High
	Technical Support Services	High
Space Support Services	Legal Services	None
	Financial Services	Low
	Insurance Services	None
	Consultancy Services	High
Research & Development	Space Science	Medium
	Space Engineering	High
	Development of Applications for Space Derived Data	High
	Research Using Space Derived Data	Medium
	Space Related Socio/Economic Legal Research	Low
Space Education & Training	University Course Provision	Low
	Vocational or Technical College Course Provision	Low
	Professional Development Courses	High
	Commercial Training Courses	High
	Professional Training Organisation	Low
	Other	Low

Key:
- High level of Australian capability (more than 7 companies out of 46 interviewed)
- Medium level of Australian capability (3 to 6 companies out of 46 interviewed)
- Low level of Australian capability (1 or 2 companies out of 46 interviewed)

Source: APAC [32]

Asia Pacific Aerospace Consultants (APAC) undertook in-depth interviews with Australian space sector companies to provide an evidence-base of current Australian industry capability in civil space. The findings were summarized in the report ‘A selective review of Australian space capabilities: growth opportunities in global supply chains and space-enabled services’ [32]. To quote from this report:

“Australian companies have the relevant capabilities and world-class skills to participate in the rapidly growing global space economy.

A number of Australian firms are already actively involved in international markets

Globally, commercial space activities are continuing to outpace government activities, growing by 9.7% in 2014 and now representing 76% of the global space economy.

The use of space systems, space-derived data and space-enabled services to generate 70% of space economic activities worldwide.

The commercialisation of space activities is being driven by an emerging consumer market in areas such as satellite broadband, and navigation/positioning technologies, such as GPS-enabled applications.

Australian firms have greatest capabilities in ground systems and related space-enabled services and applications, driven by the extensive use of satellite communications and navigation in Australia.

Space-related products and services are used in every sector of the Australian economy.

Annual revenue from the Australian space industry sector is estimated at $3 to $4 billion - 92% domestic and 8% export activity."

Some space-related skilled staff is ‘sourced' overseas (see Figure 24).

FIGURE 24: COUNTRIES SUPPLYING SPACE SKILLED WORKERS TO AUSTRALIA

Skill Shortages	Country Supplying Skilled Staff
Adaptive Optics & Optomechanical	France, Germany, Canada, Belarus
Geospatial & Google Fusion skillsets	USA, Ireland, South Africa, Israel
RF & networking skills	South Africa
Satellite communications & software engineers	China but recruited in Australia after they migrated independently
GIS skills & EO imagery	Columbia
Specialist spatial processing skills	SouthEast Asia, South Africa, India, NZ
Photolithography skills	Singapore
Combined Satcom & IT skills	Europe
Software developers with modelling skills	UK
Spacecraft Manufacturing & Design skills	Expat Australians in US & UK

Source: APAC [32]

In October 2017, ACIL Allen submitted a report to the Department of Industry, Innovation, and Science, assessing the Australian Space Capabilities [33]. An extract of the report summarizing particular strengths in the Space Applications sector is included in Figure 25.

FIGURE 25: REVIEW OF AUSTRALIAN SPACE APPLICATIONS

SPACE APPLICATIONS

Capability	Level of maturity	Relevant infrastructure	International competitiveness
Communications	Mature capability Emerging optical communications capability	Optus satellites, NBN satellites, ground stations Laser ranging telescopes	Internationally competitive Potentially competitive if successful
Earth Observation and meteorology - data storage, management, and archiving	Mature capability	Australian Geoscience Digital Earth Australia, NCI, BoM supercomputer	Data storage moving to cloud based solutions to support commercial applications
Earth Observation and meteorology - data processing and technical support	Mature capability	Australian Geoscience Digital Earth Australia, NCI, BoM supercomputer, cloud storage	Competitive in Australian context and potentially competitive internationally
Positioning	Mature government and commercial services exist	Reference stations and beacons Internet for some services	Competitive in Australia
Third generation SBAS Augmentation service	Emerging - Test bed research underway	Reference stations and space based communications	Potentially leading edge if successful
Technical support for integration of position data into GIS, on line mapping, monitoring and control systems	Mature in parts. Emerging in other areas such as autonomous vehicles.		Emerging competitiveness
Integrated applications	Mature and strong capabilities in agriculture, weather and ocean modelling, vegetation mapping and emergency services. Emerging applications in finance, insurance and agricultural trade.	Intergovernmental relationships and agreements for data access Australian Geoscience Digital Earth Australia BoM supercomputer, NCI and cloud storage	Leading edge competiveness
Virtual reality for space	Start-up stage		Potential opportunity for Australian Start up in partnership with NASA.

Source: Acil Allen [33]

Bryce Space and Technology [34] identifies Australian space opportunities with respect to mature and emerging markets. Opportunities in the mature market include satellite radio, satellite broadband, fixed satellite service (FSS) managed services, GNSS devices, chipset and applications and network ground equipment.

Figure 26 gives an overview of emerging market developments and identifies EO driven data analytics, commercial space situational awareness (SSA) and smallsat manufacturing as prime opportunities for Australia in the global space industry. A similar table can be found in the report [34] for the mature market.

FIGURE 26: EMERGING SPACE MARKETS

Markets	Examples	Growth Trend	Required Per Venture Investment	Barrier to Entry	Significant Current Activity in Australia?	Prime Australia Growth Opportunity?
Satellite Servicing	MDA/SSL, Orbital ATK	+	~$500M+	High	N	
Suborbital Human Spaceflihght	Virgin Galactic, Blue Origin	+	~$1B+	High	N	
EO Smallsat Constellations	Planet, Spire Global	++	~$100M+	Low	N	
EO-Driven Data Analytics	Orbital Insights, HexiGeo, GeoImage	++	~$10M+	Low	Y	✓
Ubiquitous Global Broadband	OneWeb, SpaceX,	++	~$3B+	High	N	
Commercial SSA	AGI, Schafer, EOS, US military infrastructure in Australia	+	~$10M+	Medium	Y	✓
Dedicated Smallsat Launch	Vector, Virgin Orbit, Rocket Lab	+	~$100M+	Medium	N	
Smallsat Manufacturing	Clyde, Pumpkin, Spaceflight Services	+	~$1M+	Low	N	✓

Source: Bryce [34]

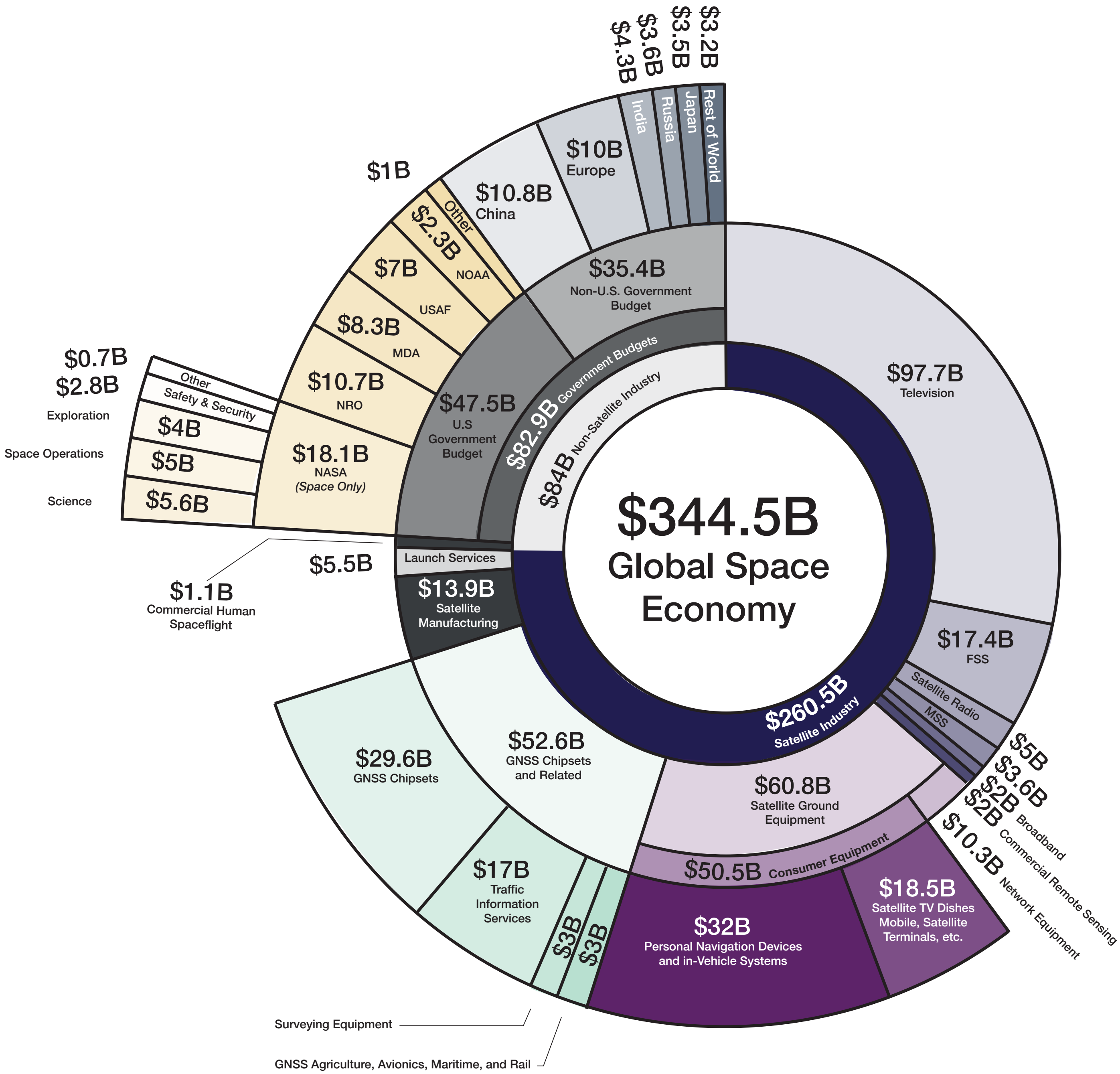
In a report to the Australian Government, Bryce Space and Technology [34] identify for Australia global opportunities:

- Consumer broadband
- Managed services
- Earth observation-driven data analytics
- Satellite radio
- Navigation devices and applications
- Commercial space situational awareness
- Smallsat manufacturing
- Possible Benefit from launch facilities
- Space mining

1.4.2 GLOBAL SPACE INDUSTRY

Figure 27 elaborates on the various aspects and size of the global Space economy.

FIGURE 27: THE GLOBAL SPACE ECONOMY AT A GLANCE



Source: Bryce [34]

Looking at the global startup scene in space, the following companies were noted by Euroconsult [35]. Figure 28 also details quantity of funding that was raised for these companies.

FIGURE 28: NEW SPACE STARTUPS TO WATCH

Key to funding:

- Raised > $100M
- Raised $50-100 M
- Raised <$50 M

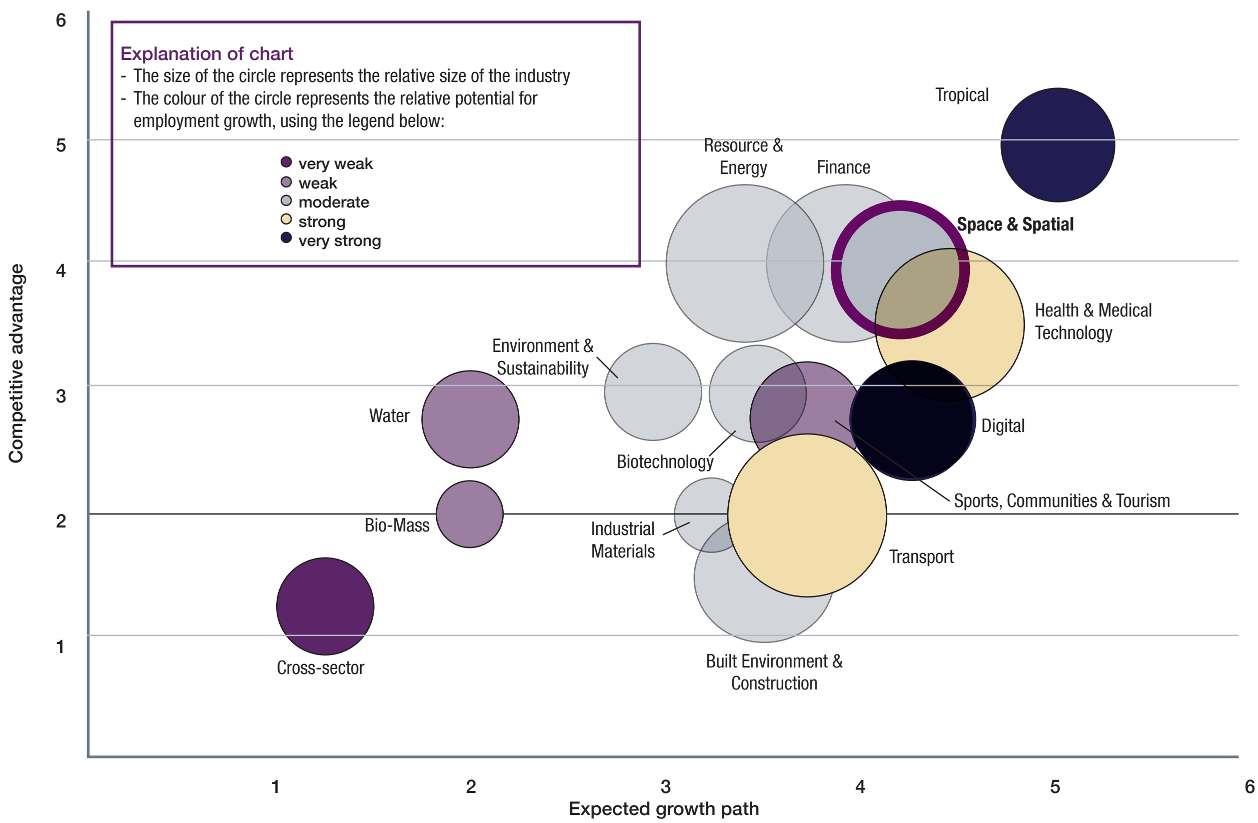
		HIGHLIGHTS	TARGET MARKETS	
SATCOM CONSTELLATIONS	**BridgeSat**	Rapid downlink of large datasets efficiently	Earth observation and UAV data	Raised <$50 M
SATCOM CONSTELLATIONS	**Cloud Constellation**	In-orbit data processing, storage, and downlink	Large enterprise, storage providers	Raised <$50 M
SATCOM CONSTELLATIONS	**LeoSat**	High speed, secure, enterprise grade data transmission	Top enterprise users, e.g., banks	Raised <$50 M
SATCOM CONSTELLATIONS	**OneWeb**	Affordable, low latency, ubiquitous connectivity	Underserved areas, mobility markets	Raised > $100M
SATCOM CONSTELLATIONS	**Outernet**	Datacast of curated content to underserved markets	Remote locations, first responders	Raised <$50 M
SPACE EXPLORATION AND SERVICES	**Deep Space Industries (DSI)**	Water-based thrusters, optical navigation, asteroid mining	Space exploration missions	Raised <$50 M
SPACE EXPLORATION AND SERVICES	**Firefly**	Light vehicles to provide dedicated multi-satellite launch	Smallsat/cubesat launchers	Raised <$50 M
SPACE EXPLORATION AND SERVICES	**Nanoracks**	Facilitate ISS-based commercial scientific experiments	Commercial community	Raised <$50 M
SPACE EXPLORATION AND SERVICES	**Planetary Resources**	Earth observation data while gearing up for asteroid mining	Earth observation, and space explorers	Raised $50-100 M
SPACE EXPLORATION AND SERVICES	**Spaceflight**	Launch brokerage and hosting service	Smallsats, cubesats, nanosats	Raised $50-100 M
EARTH OBSERVATION	**BlackskyGlobal**	High temporal coverage, high revisit rate images	LBS (Location-based services), defense	Raised $50-100 M
EARTH OBSERVATION	**Hera Systems**	High frequency change detection at high resolution	Defense, finance / business intel	Raised <$50 M
EARTH OBSERVATION	**OmniEarth**	Change-detection products and analytics at low resolution	Natural resources, energy	Raised <$50 M
EARTH OBSERVATION	**Planet**	Low-cost, moderate resolution daily imaging of entire earth	Natural resources, LBS, infrastructure	Raised > $100M
EARTH OBSERVATION	**Satellogic**	“Platform as a service” high res images and video	Natural resources, oil & gas	Raised <$50 M
EARTH OBSERVATION	**Spire**	Commercial weather data; 100K daily GPS RO readings	Government, enterprise, maritime	Raised $50-100 M
EARTH OBSERVATION	**Tempus Global**	Severe weather data based on readings from six sensors	Government, commercial	Raised <$50 M
EARTH OBSERVATION	**UrtheCast**	SAR and optical multispectral imaging	Maritime, defense, infrastructure	Raised $50-100 M
EQUIPMENT	**Accion Systems**	Electronic propulsion systems targeted toward smallsats	Smallsat operators (gvmt and private)	Raised <$50 M
EQUIPMENT	**Kymeta**	Flat-panel, electronically steered antennas	Mobility (aero, maritime, auto)	Raised > $100M

Source: Euroconsult [35]

2. SPACE AND SPATIAL TECHNOLOGIES

PWC groups the Australian industry sectors ‘Space and Spatial’ together as an emerging medium-sized industry sector with a strong growth path, strong competitive advantage and moderate potential for employment growth [36] (see Figure 29).

FIGURE 29: EXPECTED GROWTH AND COMPETITIVENESS BY AUSTRALIAN INDUSTRY SECTOR



Source: PWC [36]

2.1 SPACE

2.1.1 UN SPACE RESOLUTIONS

A recent initiative is seeking to establish the 'Space Kingdom of Asgardia'. The aim is to become a recognized 'Space Nation'. Asgardia has a constitution, several hundreds of thousands of members are voting a 150-person parliament (March'18) [37], and has not yet reached its aim for recognition as a nation state, including representation at the UN. In late 2017 the community launched a satellite 'Asgardia-1' (NORAD 43049) which is basically an 'orbiting hard disk' with data containing member contributions [38]. Scholars doubt Asgardia will be recognized (territory being one of the conditions to qualify as a Nation State). The initiative raises interesting discussions around citizenships for humans living not on Planet Earth, a relevant consideration in the light of preparations for proposed Mars missions that may come as soon as the next decade.

Commercial Space launches bring challenges to nation states that have signed certain UN resolutions. Australia is a signatory to the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (referred to as the "Outer Space Treaty" or OST). The treaty, drafted by the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS), came into force on October 10, 1967.

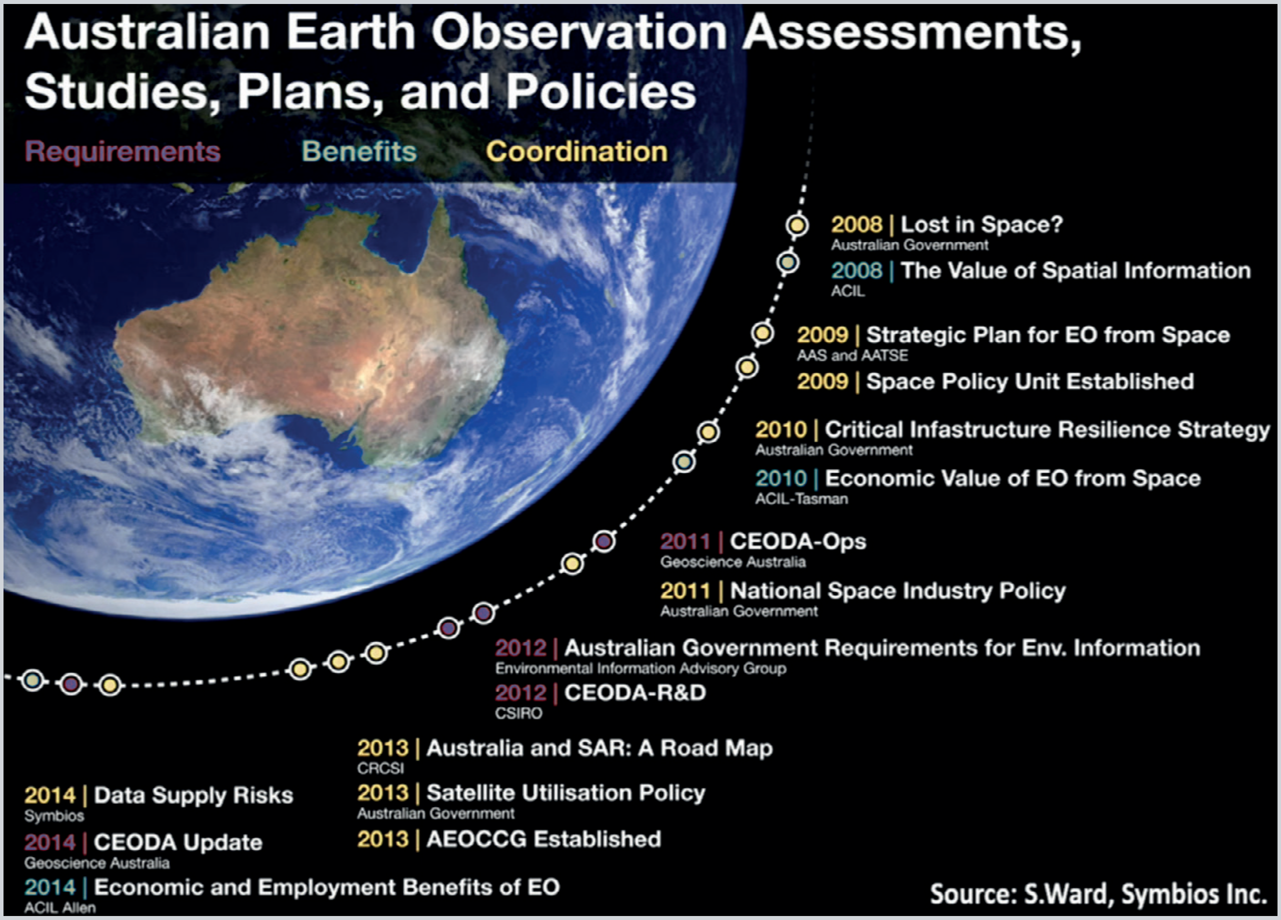
The OST principles include: [39]

- The exploration and use of outer space shall be carried out for the benefit and in the interests of all countries and shall be the province of all mankind;
- Outer space shall be free for exploration and use by all states;
- Outer space is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means;
- States shall not place nuclear weapons or other weapons of mass destruction in orbit or on celestial bodies or station them in outer space in any other manner;
- The moon and other celestial bodies shall be used exclusively for peaceful purposes;
- Astronauts shall be regarded as the envoys of mankind;
- States shall be responsible for national space activities whether carried out by governmental or non-governmental entities;
- States shall be liable for damage caused by their space objects; and
- States shall avoid harmful contamination of space and celestial bodies.

Australia has had a space program since 1947, but the 2013 Satellite Utilisation Policy [40] states that it "does not commit Australia to human spaceflight, domestic launch capabilities or to the exploration of other planets".

An overview of recent Australian EO studies, plans and policies are summarized in Figure 30. This overview gives background on previous activities that are relevant for the discussions of the Space Policy review that is underway.

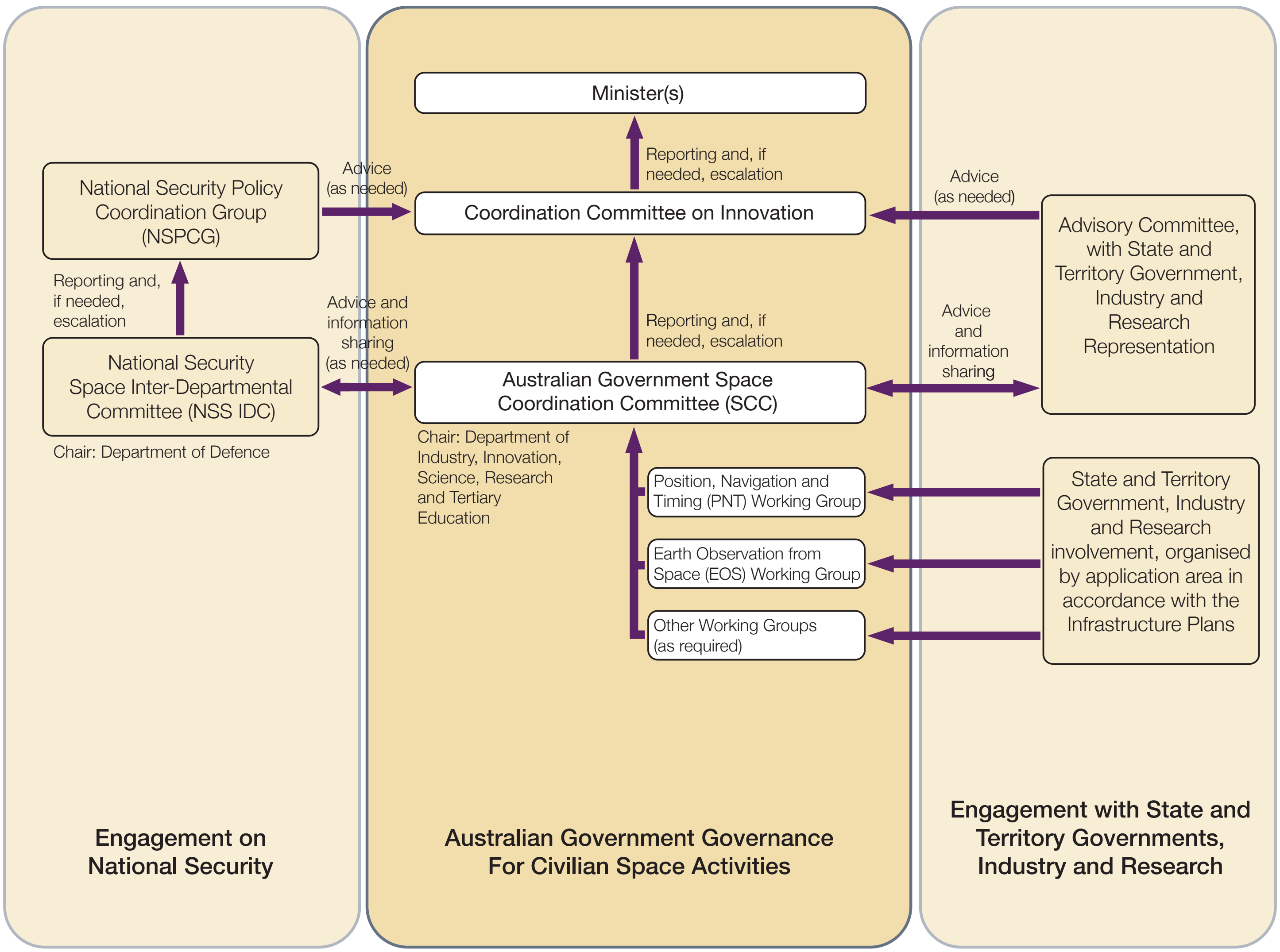
FIGURE 30: AN OVERVIEW OF THE AUSTRALIAN RECENT TIMELINE WITH RESPECT TO EO STUDIES, PLANS, AND POLICIES IN AUSTRALIA



Source: Symbios as quote in [41]

In October 2015 the then Minister for Industry, Innovation and Science the Honorable Christopher Pyne MP called for a review of legislation governing civil space activities in Australia to "ensure it appropriately balances Australia's international obligations with encouraging industry innovation and entrepreneurship". The review is being led by an Expert Reference Group (ERG), chaired by Dr Megan Clark AC. The formal review was concluded in September 2017, and a final strategy will be given to Government around April 2018 [42]. Figure 31 shows the framework for civilian space activities in Australia.

FIGURE 31: FRAMEWORK FOR CIVILIAN SPACE ACTIVITIES



Source: Australian Government [40]

2.1.2 SPACE LAUNCH TRENDS

When assessing space launches, a clear trend can be observed in the last few years away from nation states to commercial endeavours. Venture capital firms have been active in recent years in financing space startups [43] (see Figure 32).

FIGURE 32: CAPITAL FOR SPACE STARTUPS

Most active VC in Space

Investor	Investments
Lux Capital	Kymeta Orbital Insight Planet Labs
RRE Ventures	Accion Systems Spaceflight Industries Spire Global
Bessemer Venture Partners	Rocket Lab Skybox Imag ing Spire Global
Khosla Ventures	Rocket Lab Skybox Imaging The Climate Corporation
Promus Ventures	Mapbox Spire
Founders Fund	Accion Systems Moon Express Planet Labs SpaceX The Climate Corporation
Draper Fisher Jurvertson	ALOHA Networks HuaXun Microelectronics Mapbox Planet Labs SpaceX
First Round Capital	Planet Labs Swift Navigation The Climate Corporation

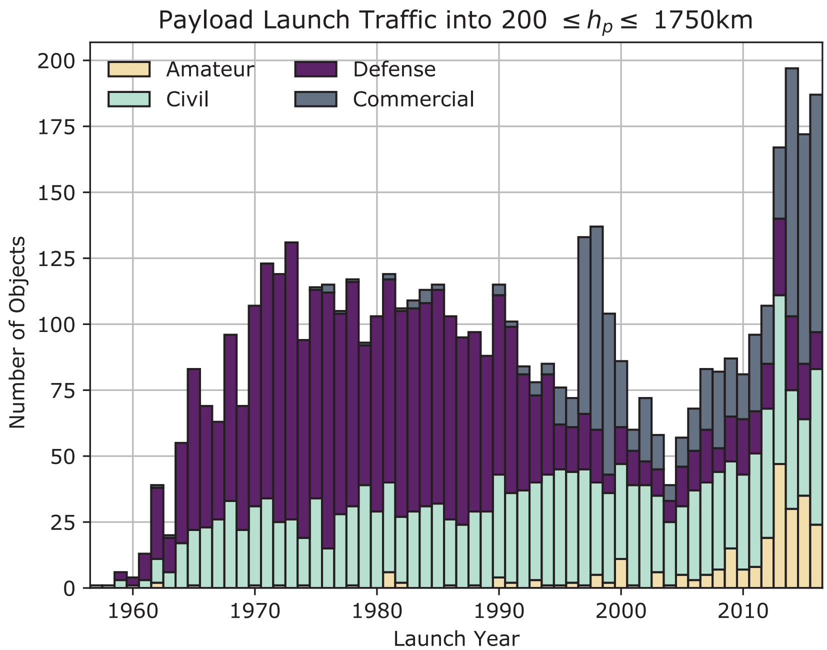
Best funded Space Start-up until Q2 2016

Rank	Company	Equity financing raised (US$M)
1	SpaceX	$1,185
2	OneWeb	$519
3	Blue Origin	$500
4	Planet Labs	$171
5	Kymeta	$144
6	Spire	$67
7	MapBox	$61
8	Spaceflight Industries	$45
9	Astroscale	$43
10	Collecte Localisation Satelllites	$41

Source: Spinelli [43

It is anticipated that over 6200 smallsats (not including other satellite classes) will be launched in the next 10 years (estimated to be worth over USD $30 billion) [44]. Details about the recent Space launches are summarized in ESA's Annual Space Environment Reports [45].

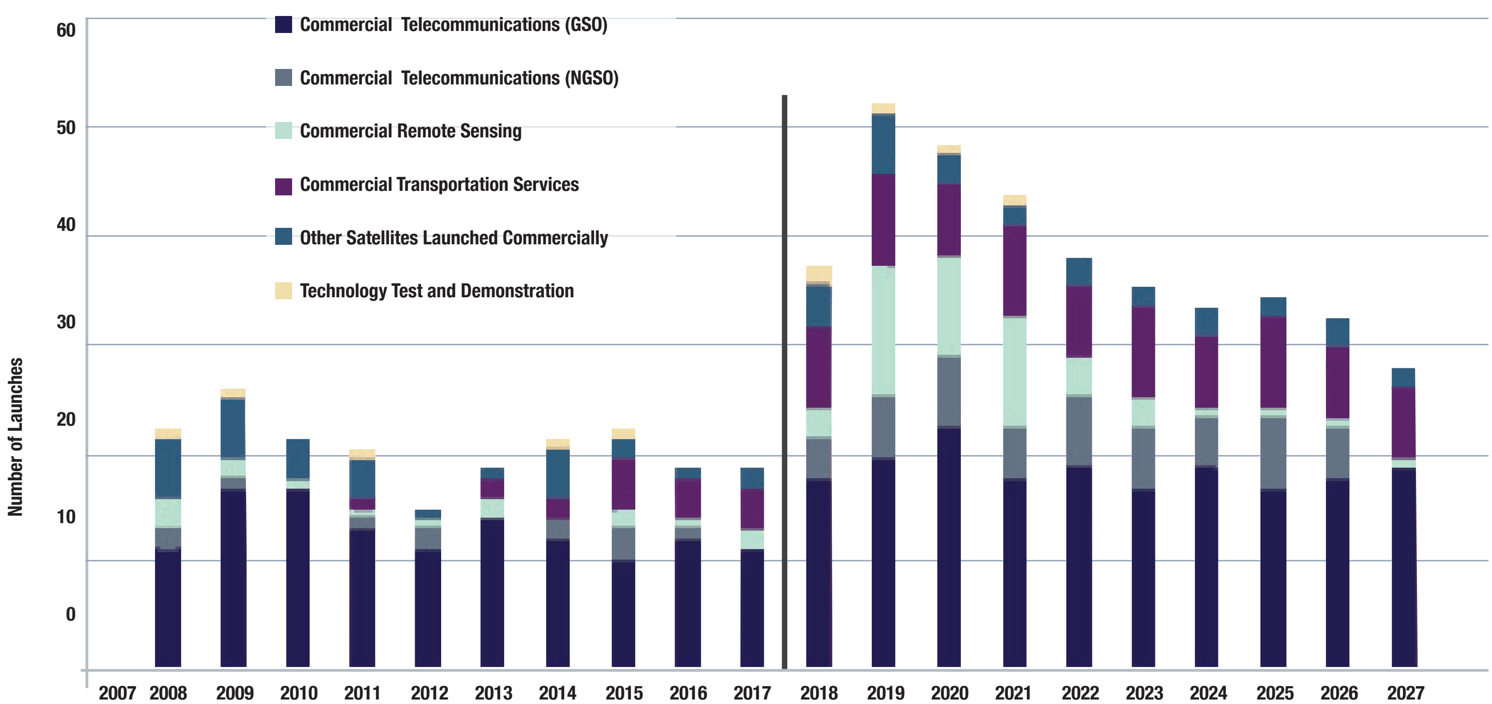
FIGURE 33: SPACE LAUNCHES



Source: ESA [45]

Figure 34 shows commercial historical and projected orbital launches by use sector. For the interested reader, the report also details launch events, launch vehicles, launch sites and launch projections [46] [47].

FIGURE 34: COMMERCIAL ORBITAL LAUNCHES BY INDUSTRY SECTOR



Source: FAA [46]

Demand for space launches is rising significantly and companies such as SpaceX, Rocket Lab (with New Zealand launch sites), Virgin Galactic and Vector Space are offering launch services. There has been a proposal from the company Equatorial Launch Australia (ELA) to establish launch sites in Arnhem Land in the Northern Territories of Australia, located about 30km south of Nhulunbuy. The proximity to the equator (12 degrees South) lowers launch costs significantly and NASA visited the site in 2017.

2.2 SATELLITES

Key findings of the 'Profiles of Government Space Programs: Benchmarks, Profiles & Forecasts to 2026' report include: [48]

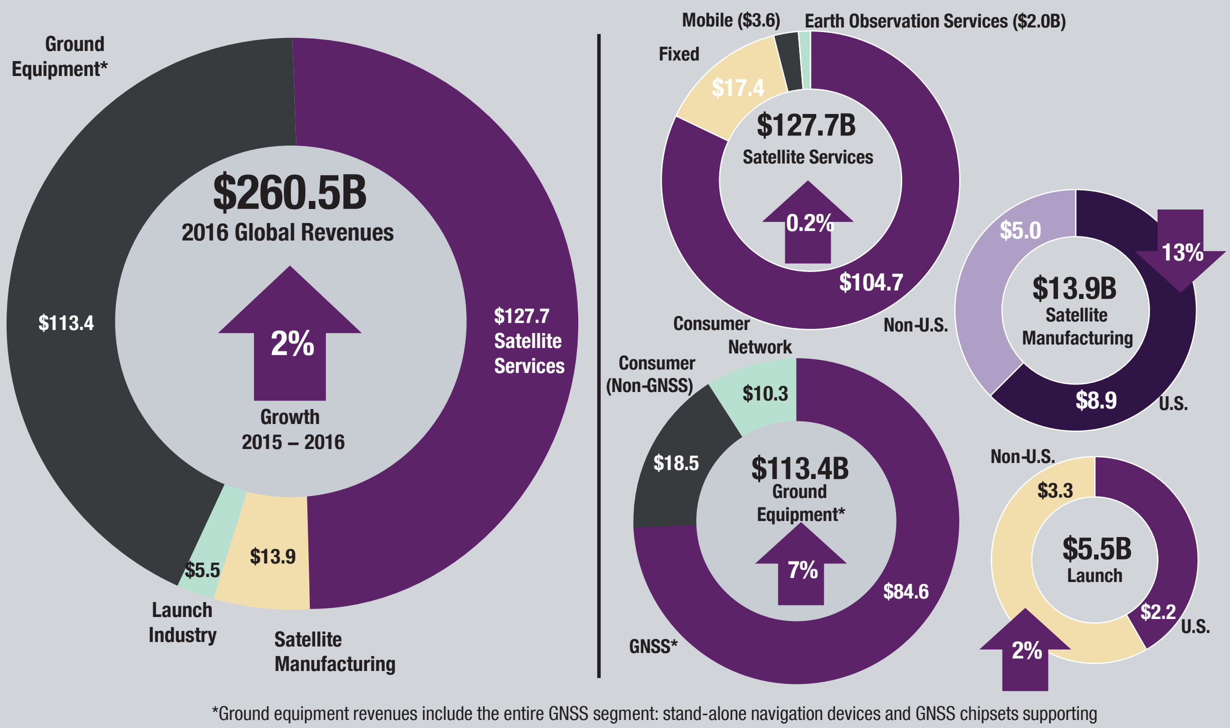
- Civil programs account for a growing proportion of global expenditures (65%). Defense and civil expenditures were almost on par at the end of the last decade
- The US, by far the world's largest space spender with $35.9 billion estimated in 2016, has started to reverse the budget slide initiated in 2010 from which it lost 25% of its investment
- China overtook Russia in 2016 as the second largest space program at an estimated RMB 32.6 billion ($4.9 billion), growing at 11% CAGR in local currency
- After 15 years of continuous and strong growth, Russian investment in space dropped sharply in 2016, due to budget cuts, down by 20% in local currency (₽213 billion, $3.2 billion)
- Another four countries plus the EU invest over $1 billion in their space programs: Japan, France, Germany and India
- Manned spaceflight is the largest expenditure with $11.4 billion invested. The development of next-generation orbital infrastructures and future space exploration missions will support growing investment in the domain. Earth observation, at $10.9 billion, is the second-highest spending area with 58 countries investing, the highest of any application. Launchers come third at $6 billion as Asia posts strong growth, with China equalling US orbital launches in 2016

2.2.1 SATELLITE MARKET TRENDS

Euroconsult gives an overview of the satellite value chain [47].

- About 30 companies manufacture satellites, worth USD $4.9 billion; 5Y CAGR: 8.6%.
- About 10 companies launch satellites, worth USD $2.5 billion; 5Y CAGR: 10.4%
- About 50 companies operate satellites, worth USD $14 billion; 5Y CAGR: 0.7%
- About 5000 companies offer services, worth: USD $228 billion; 5Y CAGR: 7.0%.

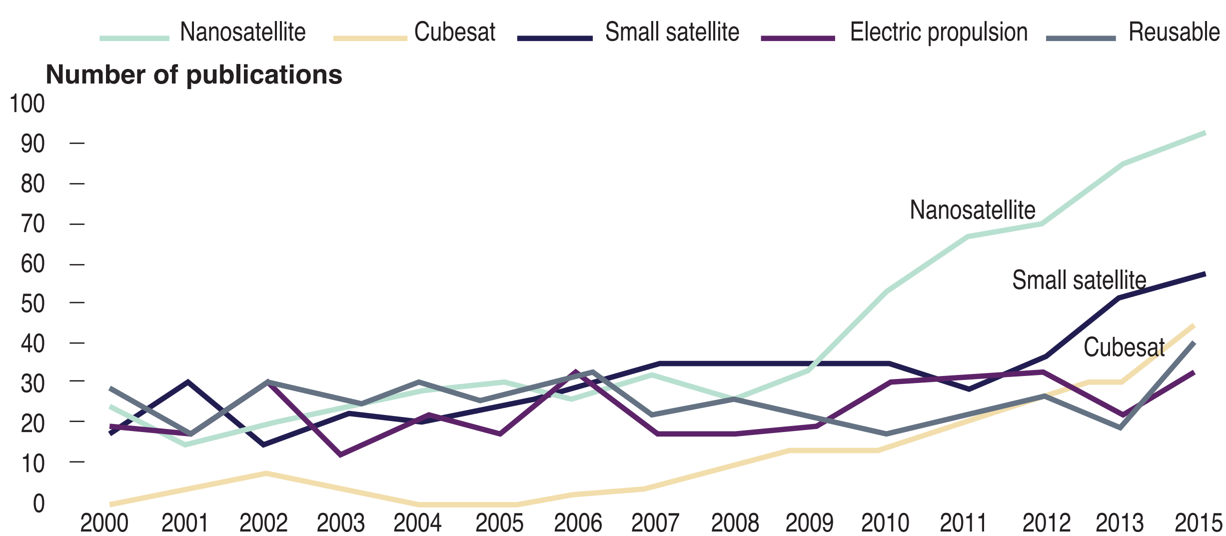
FIGURE 35: OVERVIEW OF SATELLITE INDUSTRY INDICATORS



Source: Bryce [47]

Looking at trending topics in the space literature it can be seen that miniaturisation of satellites and deployment of small satellites, nano satellites, and cube satellites is most relevant in recent years.

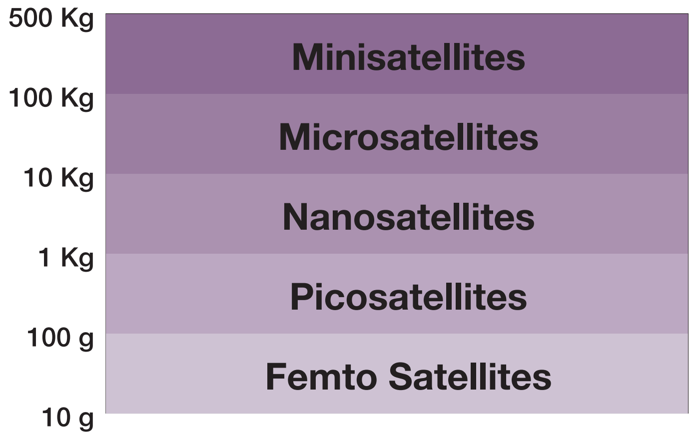
FIGURE 36: SELECTED HOT TOPICS IN SPACE LITERATURE



Source: OEDC [49]

Smallsats/ Cubesats are some of the fastest growing sectors in the space industry. With the availability of commercial off-the-shelf (COTS) components, costs to build such satellites have come down significantly, bringing it within the reach of even smaller companies to have their own asset in the sky. Analysts predict between 1,400 to up to 2,500 small satellites to be built and launched between 2016- 2020 [32].

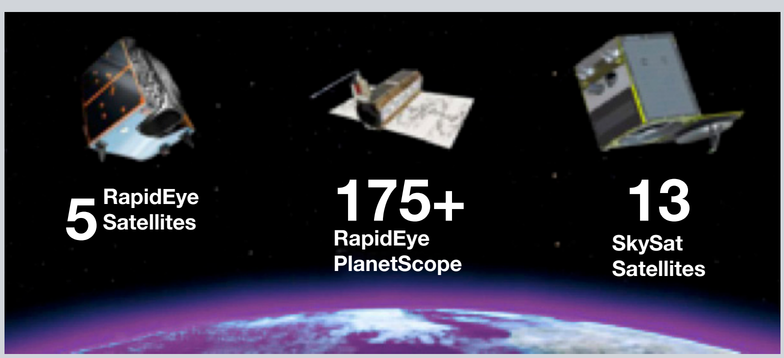
FIGURE 37: DIFFERENT CLASSES OF SMALL SATELLITES



Source: ISU [50]

The number of upcoming satellite launches is very substantial. The world is heading towards a time where EOS imagery will be abundant. Planet is powering ahead launching 88, comprising 48 satellites in 2017 alone. After acquiring Blackbridge (with its RapidEye constellation) in 2015, in 2017 Planet also took over Terra Bella and it’s SkySat constellation in a deal with Google.

FIGURE 38: PLANET CONSTELLATION



Aleph plans a constellation of up to 300 satellites. The company already has the hyperspectral capability, and offers scientists free data; this is of particular interest since NASA recently decommissioned Hyperion [52].

WorldView Legion is the next generation satellite constellation (to be completed by 2021) of Digital Globe, that announced a merger with MDA in February 2017. The combined companies are estimated to control 54% of the market [53]. Further summarized details on various satellite companies are detailed in [46].

Figure 39: Small Satellite Market; Source: Euroconsult [44] shows some selected EOS constellations that are/ will be available.

FIGURE 39: SMALL SATELLITE MARKET

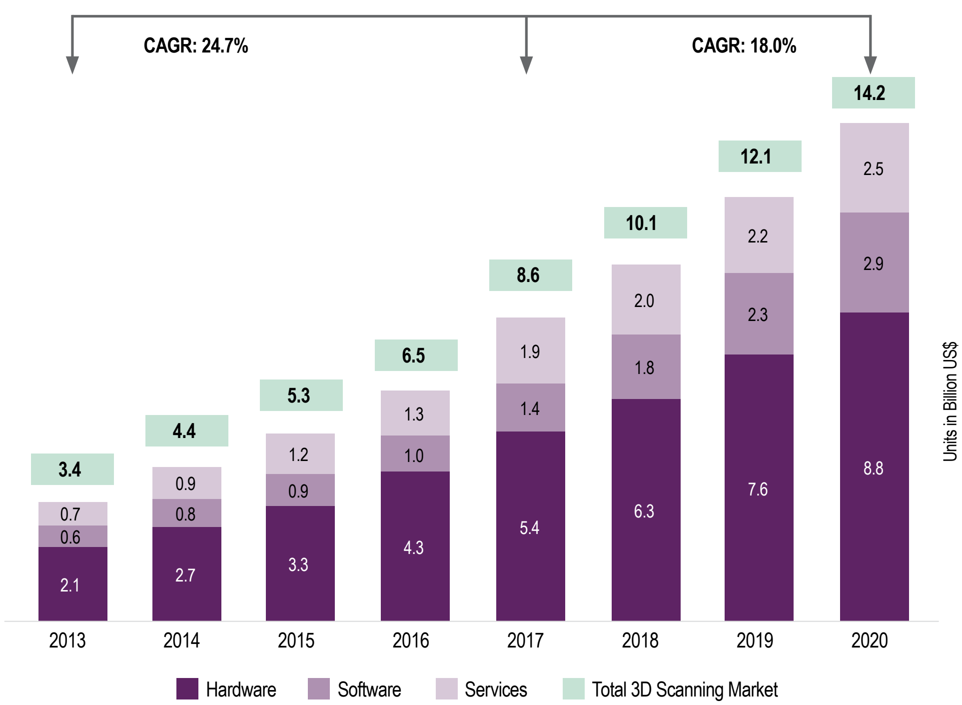
CONSTELLATION (Ownership)	LAUNCHES PRE-2017	LAUNCHES 2017-2026	UNIT MASS (kg)	EST. UNIT COST (million)	CONST. SIZE (Max. units in-orbit	ESTIMATED CONST. COST (million)	PRIME	LAUNCH PROVIDER
Terra Bella (Planet)	7	14	120	$15	21	$450	SSL / Skybox	Arianespace, Orbital, ISRO, TsSKB, Kosmotras
Planet	178	586	5	$0.4	150+	$500	Planet	ULA, Orbital,TsSKB, Kosmotras, SpaceX, MHI, Rocket Lab
Aleph (Satellogic)	2	24	37	$2	Up to 300	$150	Satellogic	CGWIC
BlackSky	1	120	50	$5	60	$750	Spaceflight Industries	ISRO, SpaceX
UrtheDaily	-	8	340	$27.5	8	$220	SSTL	SpaceX
Worldview Legion	-	60	100 (est.)	$13	60	$780	MDA / SSL	-
Landmapper	2	30	10/20	$2/$3.5	30	$90	Astro Digital	TsSKB
Iceye	-	21	50 (est.)	$7	20	$145	Iceye / York SS	Vector
Cicero (GeoOptics)	-	13	10	$1.1	23	$15	Tyvak	TsSKB, ISRO
PlanetIQ	-	12	20	$4	12	$50	Blue Canyon Tech	ISRO
Zhuhai-1	2	17	<55	$2/$3/$4	19	$50	CAST	CGWIC
AxelGlobe	-	13	80	$8.5	60	$110	Axelspace	-
HyperCube	-	12	5	$0.6	12	$7	Harris	-

*Spire's prime application is AIS services, with GPS-RO as a secondary function. We therefore consider it as an Information constellation, rather than an Earth observation constellation

Source: Euroconsult [44]

There is a multitude of EO satellites being launched, as satellites are smaller and cheaper to produce with commercial off-the-shelf- components (COTS). Satellites are also easier to transport into space as most weigh less than a decade ago. Figure 40 shows details of the global Earth Observation market size.

FIGURE 40: EARTH OBSERVATION GLOBAL MARKET SIZE



Source: Geospatial Media and Communications [25]

2.2.2 AUSTRALIAN SATELLITES

After many years, Australia is back in Space, with several payload/ satellite launches. Wresat was launched from Woomera 1967. Its purpose was to collect data on the upper atmosphere and to improve Australia's knowledge about how to launch and operate satellites. It weighed only 45 kg. It made Australia just the fourth country in the world to launch its own satellite from its own territory after the then USSR, the US, and France. Fedsat, a research satellite, was launched in 2002. It had six payloads including communications, a GPS receiver and a magnetometer.

In 2016, Science and Industry Minister Christopher Pyne signed the "Overseas Launch Certificate" to allow Australian Startup Cuberider to launch a payload, built by High school students, bound for the International Space Station (ISS). The Cuberider mission launched on 9 December 2016 on board of a Japanese H-IIB rocket and then deployed from the International Space Station (ISS) via the Nanoracks CubeSat Deployer [54].

In May 2017 several Australian CubeSats launched, three as part of the QB50 project [55]. QB50 is a network of 50 cube satellites which will focus on the lower thermosphere and ionosphere. Initially there were issues with the satellites, but Inspire-2 [56] and UNSW-EC0 [55] could be recovered in a well-reported rescue, involving HAM radio enthusiasts in the Netherlands with access to the Dwingeloo radio telescope (a restored 25-metre dish from the 1950s), and resolving that EC0 had been mislabelled by NORAD [57]. SuSAT failed to become functional [58].

Biarri Point is a four-nation defence related satellite (Australia, USA, UK, Canada) that was also deployed from the International Space Station (ISS) in May 2017 [59], on the Biarri SHARC (satellite for high accuracy radar calibration). Following, Biarri Squad (a further three satellites) are scheduled to be launched together in 2018 and perform formation-flying experiments [60]. The Buccaneer Mission of UNSW/ DSTO plans to launch a CubeSat to calibrate the Jindalee Over-the-Horizon Radar Network (JORN) [61]. In June 2017 the Australian Federal Government announced the allocation of AUD $500 million towards improving Australia's space-based intelligence, surveillance and reconnaissance capabilities for Defence and Commerce [62].

Sky and Space Global is a company listed on the Australian Stock Exchange (ASX: SAS, working with the UK and Israeli aerospace centers) aiming to build an equatorial (+/-15degree) communication network with over 200 nanosatellites (“Perls”) by 2020. In June 2017 three demonstrators (“blue, red and green diamond”) satellites were launched and successfully tested [63] [64].

NovaSAR is a new sophisticated high-performance satellite that has been developed by UK based companies SSTL/Airbus UK, and expected to launch in 2018. CSIRO has secured a ten percent tasking and acquisition time (worth AUD $10.45 million over seven years) of NovaSAR (S-Band SAR) for Australian scientists [65].

UCS regularly updates a database of active satellites in Space. Figure 41 summarizes an overview of current satellites in the sky. The UCS database lists 597 Earth Observation Satellites, 745 Communication Satellites, and 109 Navigation and Positioning Satellites. Furthermore 316 satellites are allocated to other classes. Several satellites are counted in multiple categories.[2]

[2] i.e. the Korean COMS-1 /Communication, Ocean and Meteorological Satellite; Cheollian; NORAD 36744 is listed (and counted) under ‘Communication’ and ‘Earth Observations’

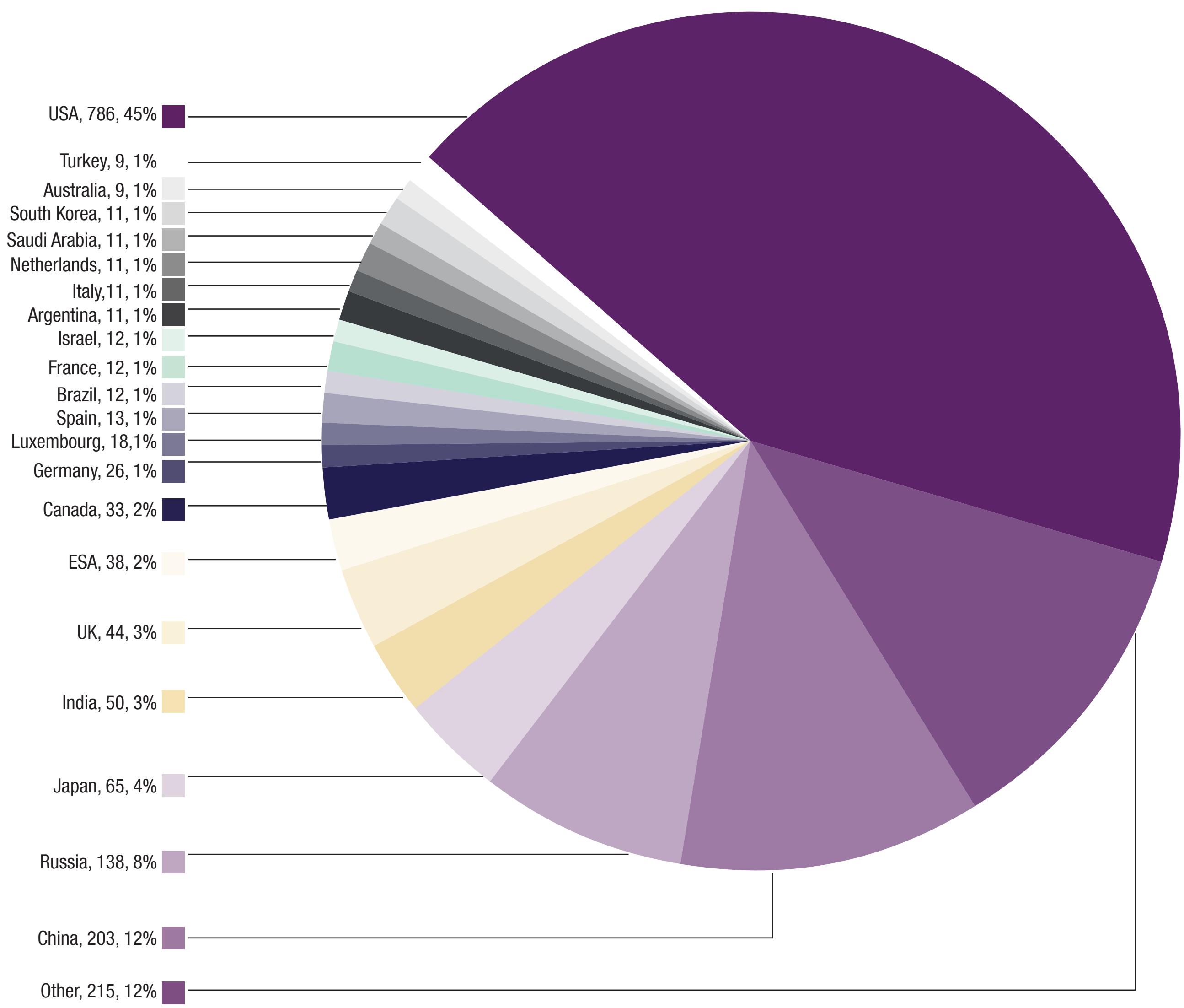
FIGURE 41: SATELLITE QUICK FACTS

Satellite Quick Facts (includes launches through 8/31/17)

Total number of operating satellites: **1,738**			
United States: **803**	Russia: **142**	China: **204**	Other: **589**
LEO: **1,071**	MEO: **97**	Elliptical: **39**	GEO: **531**
Total number of US satellites: **803**			
Civil: **18**	Commercial: **476**	Government: **150**	Military: **159**

Source: UCS [66]

FIGURE 42: OVERVIEW ALL SATELLITES BY COUNTRY



Source: UCS [66]

Details on future satellite are described in Euroconsult's 2017 report: Satellites to be build and launched by 2026 [67].

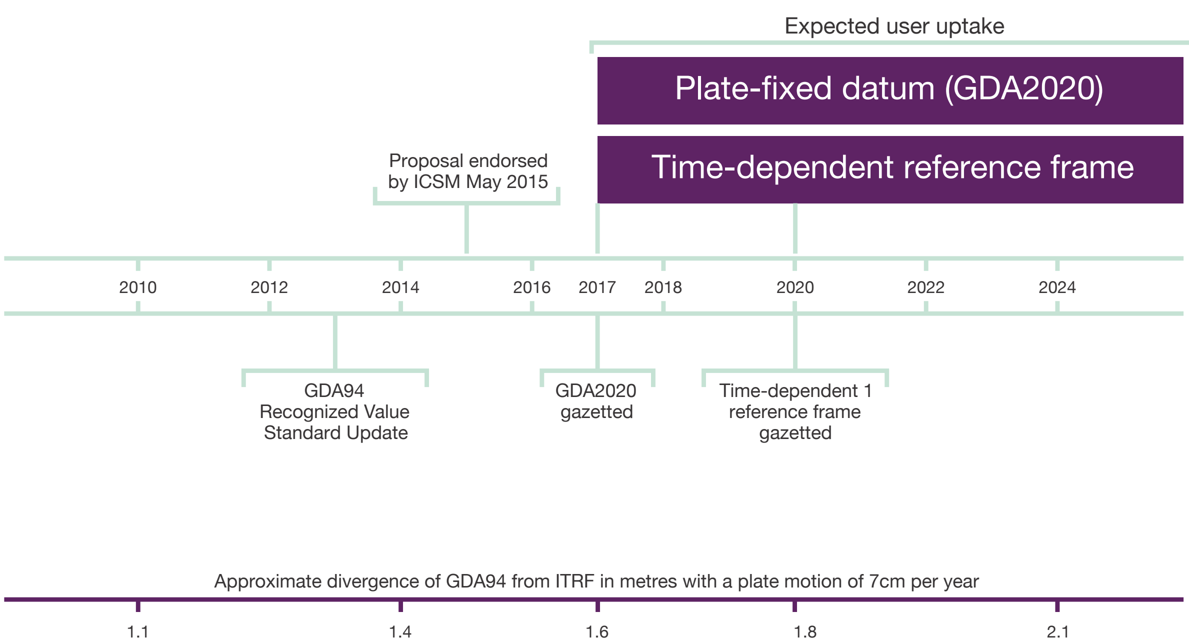
A comprehensive list of imaging satellites (EOS, sourced from UCS) is given in Appendix B.

2.3 LOCATION

2.3.1 DATUM GDA2020/ ITRF

Precise Positioning will contribute 2.1% of Australia's GDP by 2030. Therefore, having a datum that underpins exact location is essential. The continent drifts about 7cm per annum to the north-east. The Australian datum has progressed, from Clarke 1858/ANG, AGD66/AMG66, AGD84/AMG84, GDA94, MGA94 to GDA2020. The next step is a shift from a plate-fixed datum to a (dynamic) time-dependent reference frame [68]. ICSM launched the GDA2020 datum in early 2017 for user testing. Details can be found in [69].

FIGURE 43: TIMELINE FOR DATUM MODERNISATION



Source: CRCSI [70]

2.3.2 AUSTRALIAN NATIONAL POSITIONING INFRASTRUCTURE (NPI)

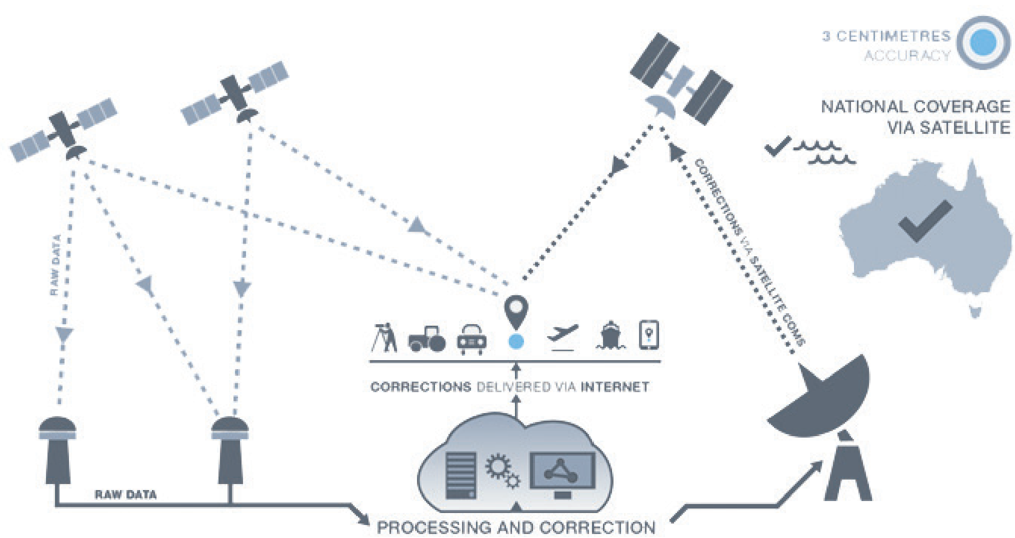
Australia has been an early adopter of GNSS technology, despite not owning navigation satellites. Stand-alone GNSS satellites are not suitable for high accuracy, high-reliability positioning, hence investments have been made over the last few decades into ground infrastructure and positioning services. This has benefited the precision agriculture, mining and surveying industry, and created opportunities for new industries such as location-based services (LBS) and intelligent transport systems (ITS) [41].

To optimise investments in location-based assets, a coordinated approach across government and industry has been taken, led by Geoscience Australia under the umbrella of the National

Positioning Infrastructure (NPI) strategy for positioning, navigation and timing (PNT). The NPI is covering; data and service standards, spectrum management, GNSS capability development, multilateral cooperation and legal traceability of position. [71]:

The NPI's vision is "instantaneous, reliable and fit-for-purpose access to position and timing information anytime and anywhere across the Australian landscape and its maritime jurisdictions" (Geoscience Australia 2016). The NPI is seeking to achieve accuracies of the order of a couple of cm's, x and y, with no latency for most locations outdoors. In time the NPI is also seeking to marry up the precision outdoor positioning with indoor positioning and location systems to create a seamless positioning and navigation capability for the nation. To achieve its vision, the NPI has been developing a solution to the signal processing and economic impediments to the creation of a sparse, continental-scale, precise positioning multi-GNSS network. This has involved complex and extensive collaboration between universities, private industry, and government agencies for the past decade (Geoscience Australia 2016) [41].

FIGURE 44: NATIONAL POSITIONING INFRASTRUCTURE



Accurate positioning information via satellite, anytime, anywhere in Australia

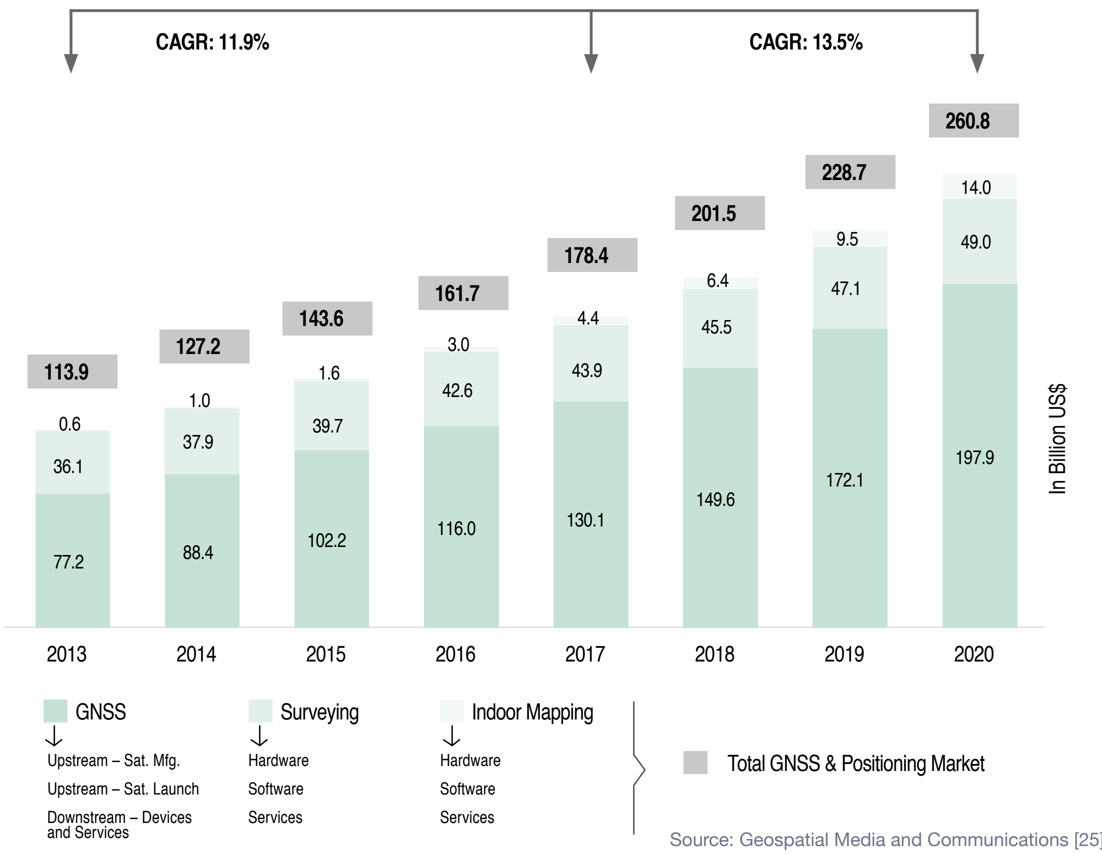
Source: Geoscience Australia [71]

An overview of Australia's positioning infrastructure (CORS, PPP-RTK, Multi GNSS and others) and future developments is available in reference [41].

2.3.3 GNSS

The Global Geospatial Industry Outlook & Readiness Index Report details the global market size for GNSS and Positioning. The market is expected to grow to from around USD $201.5 billion to USD $260.8 billion in 2020.

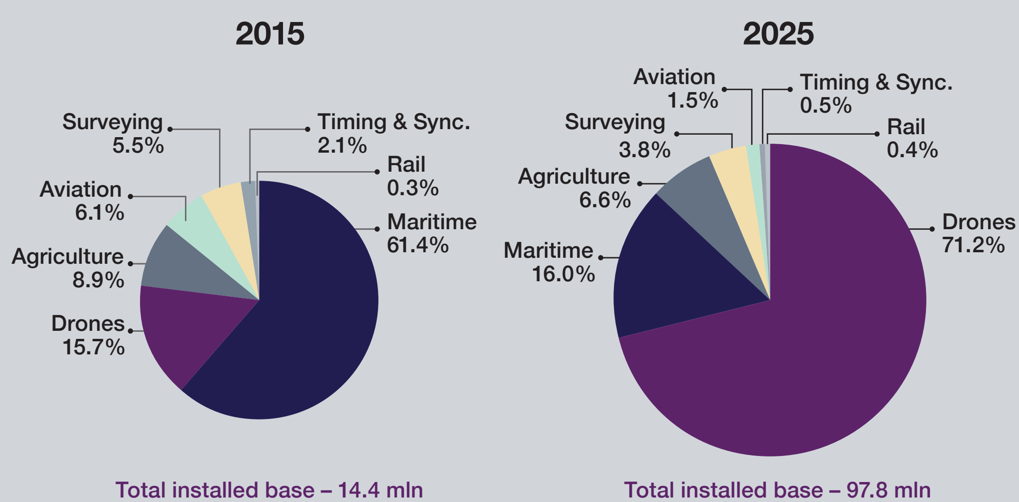
FIGURE 45: GNSS GLOBAL MARKET SIZE & POSITIONING



Source: Geospatial Media and Communications [25]

GNSS receivers are widely used, with 5.8 billion devices operational in 2017. It is estimated that by 2020 eight billion receivers will be in use [72]. Almost 80% of GNSS receivers are found in smartphones. Figure 46 shows categories of the installed base of professional GNSS segments for 2015 and a decade later. It is projected that by 2025 drones will dominate with over two-thirds of the total use cases.

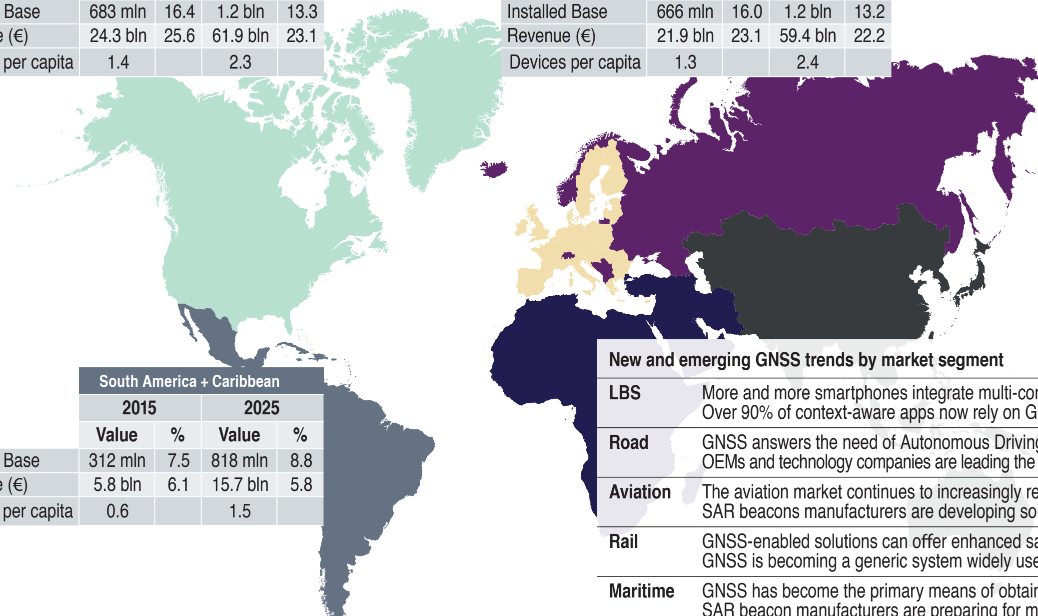
FIGURE 46: INSTALLED BASE OF 'PROFESSIONAL' SEGMENTS



Source: GSA [72]

Figure 47 shows new and emerging GNSS trends by market segments, and regional user numbers for 2015 and 2025 respectively. It is note-worthy that Asia-Pacific will consolidate its position as the largest regional GNSS market.

FIGURE 47: GLOBAL OVERVIEW GNSS



North America	2015		2025	
	Value	%	Value	%
Installed Base	683 mln	16.4	1.2 bln	13.3
Revenue (€)	24.3 bln	25.6	61.9 bln	23.1
Devices per capita	1.4		2.3	

European Union (EU28)	2015		2025	
	Value	%	Value	%
Installed Base	666 mln	16.0	1.2 bln	13.2
Revenue (€)	21.9 bln	23.1	59.4 bln	22.2
Devices per capita	1.3		2.4	

Russia and Non-EU 28 (Non-EU28 Europe)	2015		2025	
	Value	%	Value	%
Installed Base	264 mln	6.3	570 bln	6.2
Revenue (€)	6.3 bln	6.7	15.8 bln	5.9
Devices per capita	1.1		2.4	

Asia-Pacific	2015		2025	
	Value	%	Value	%
Installed Base	1.9 bln	46.1	4.3 bln	46.8
Revenue (€)	32.7 bln	34.5	96.8 bln	36.1
Devices per capita	0.5		1.0	

South America + Caribbean	2015		2025	
	Value	%	Value	%
Installed Base	312 mln	7.5	818 mln	8.8
Revenue (€)	5.8 bln	6.1	15.7 bln	5.8
Devices per capita	0.6		1.5	

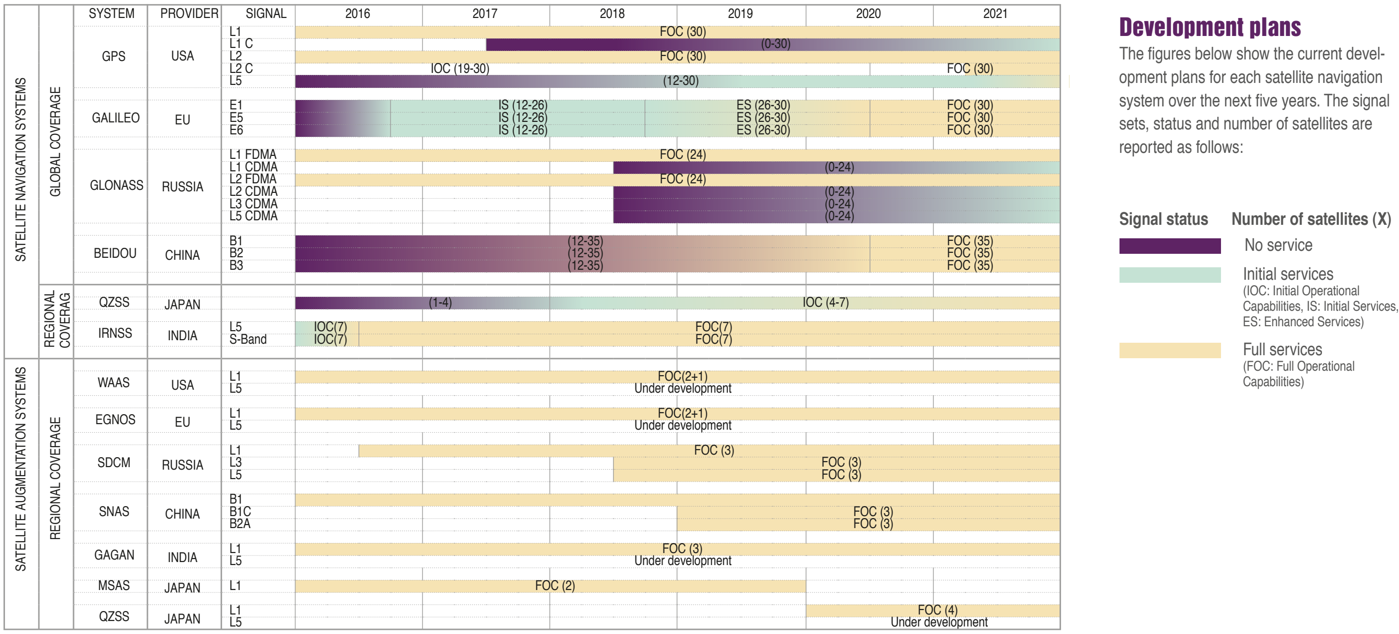
Middle East + Africa	2015		2025	
	Value	%	Value	%
Installed Base	322 mln	7.7	1.1 bln	11.7
Revenue (€)	3.8 bln	4.0	18.5 bln	6.9
Devices per capita	0.2		0.6	

New and emerging GNSS trends by market segment	
LBS	More and more smartphones integrate multi-constellation GNSS, boosting GNSS performance. Over 90% of context-aware apps now rely on GNSS.
Road	GNSS answers the need of Autonomous Driving (AD) for reliable and accurate positioning. OEMs and technology companies are leading the development of Autonomous Vehicle encouraged by governments.
Aviation	The aviation market continues to increasingly rely on GNSS, including rotocraft and unmanned vehicles. SAR beacons manufacturers are developing solutions for Aircraft Distress Tracking leveraging GNSS.
Rail	GNSS-enabled solutions can offer enhanced safety for lower cost, e.g. in railway signalling. GNSS is becoming a generic system widely used in non-safety relevant applications.
Maritime	GNSS has become the primary means of obtaining PNT information at sea. SAR beacon manufacturers are preparing for multi-constellation GNSS.
Agriculture	GNSS applications represent a key enabler for the integrated farm management concept. Drone uptake in agriculture is increasing, accounting for over half of the commercial market.
Surveying	Falling device prices drive the democratisation of mapping. GNSS remains the backbone technology in increasingly sophisticated applications.
Timing & Sync	GNSS timing is at the core of many critical infrastructures, including telecoms, energy, finance. Evolution of telecom networks makes GNSS increasingly essential, driving future shipments.

Source: GSA [72]

An overview of the various Global Navigation Satellite Systems (GNSS) and Regional Navigation Satellite Systems (RNSS) is given in Figure 48. The graph outlines respective development plans over the next few years.

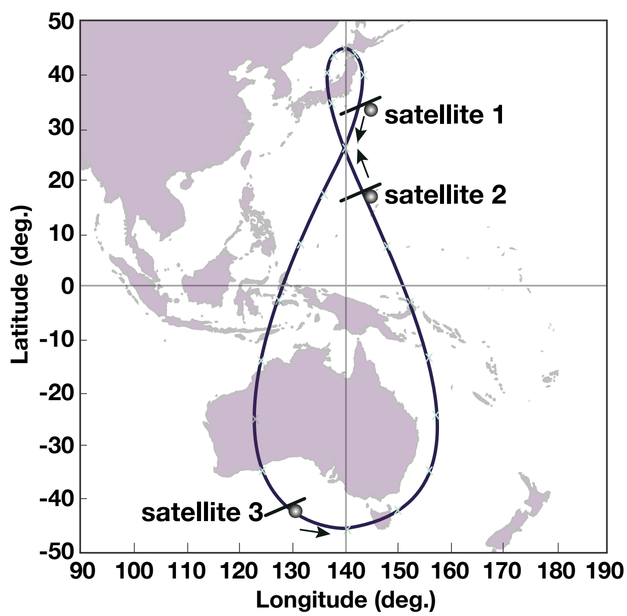
FIGURE 48: DEVELOPMENT PLANS FOR VARIOUS GNSS/RNSS SYSTEMS



Source: GSA [73]

In 2017, the second and third QZSS satellite were successfully launched by Japan; 'Michibiki 2' and 'Michibiki 3' follow a quasi-zenith orbit (see Figure 49) as the 2010 launched Michibiki-1. Due to the satellite orbit, the constellation is particularly useful for applications in Australia.

FIGURE 49: QZSS ORBITS



Source: Yoshida [74]

A detailed table of operational GNSS and RNSS satellites is included in Appendix C.

Australia is in a fortunate geographic location to be able to receive and utilize signals from all available satellite systems. Figure 50 shows a map with the densities of coverage of these satellites.

FIGURE 50: VISIBLE GNSS SATELLITES IN 2018

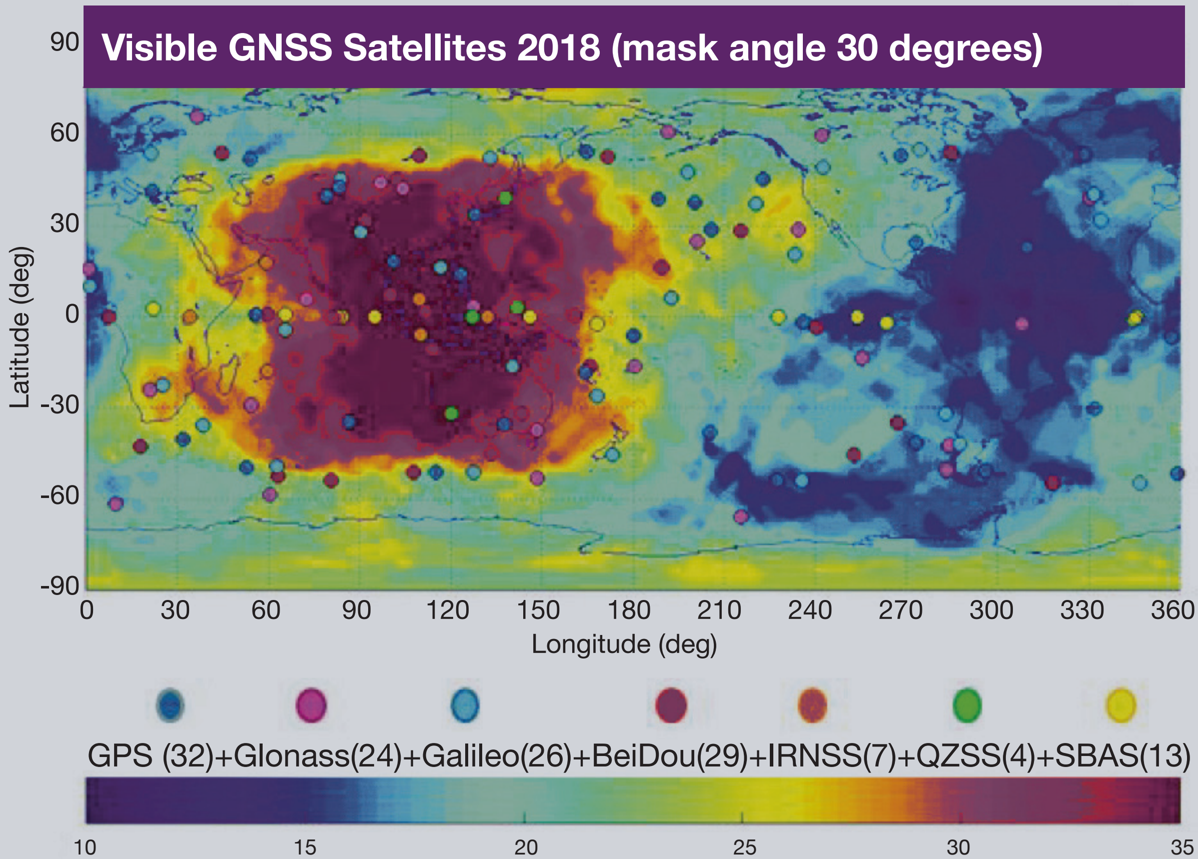


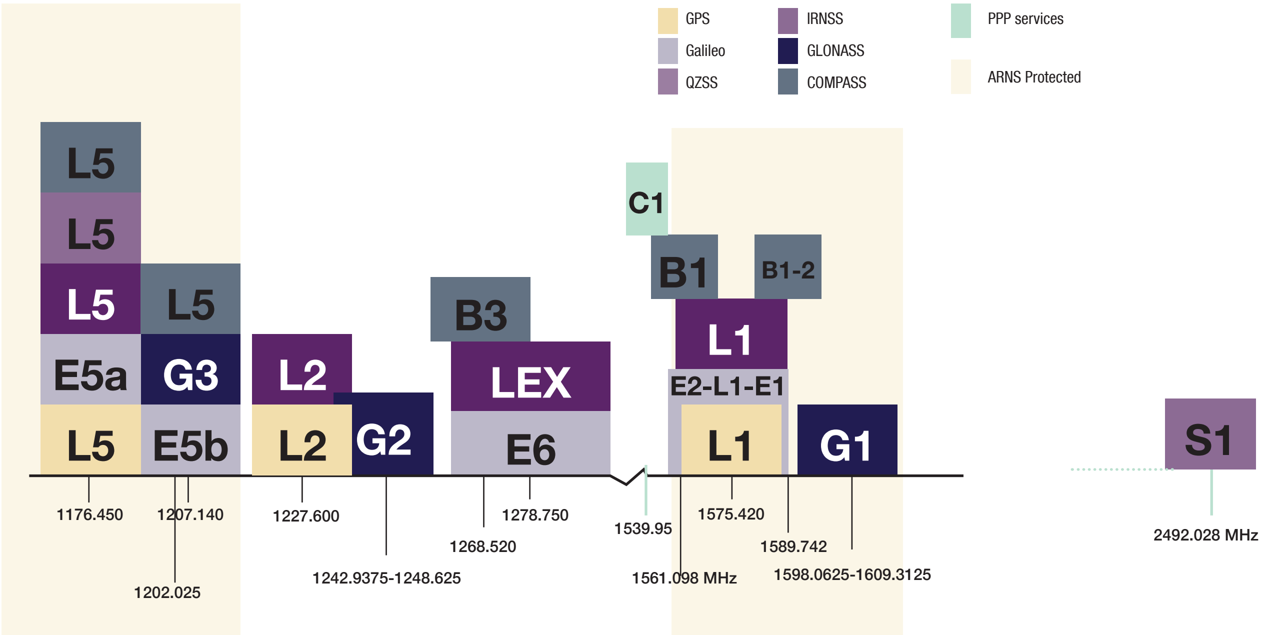
Image courtesy of Professor Chris Rizos, UNSW as published in Hausler 2015: [75]; mask angle: 30°

Source: Hausler [75]

The European Galileo system went live in December 2016 and anticipates being fully functional by 2020. It aims to be accurate to within a metre, the most accurate of the GNSS systems. Paying clients can receive centimetre accuracies. However, there have been issues with the Galileo GNSS constellation; early in 2017, the ESA Director told journalists that nine clocks (out of 72 launched at the time) on board the satellites have been failing. Each Galileo satellite has two rubidium and two hydrogen maser ultra-accurate atomic clocks. Three rubidium and six hydrogen maser clocks had become defunct. Each satellite only needs one clock to work, the rest of the clocks are contingencies. The failure of the rubidium clocks was found to be due to a faulty component that can cause a short circuit. [76]

Figure 51 shows the frequency of bands from various GNSS and RNSS systems. Having various systems share similar frequencies, allows multi-GNSS receivers to choose the best available signals from various constellations. The Australian Communications and Media Authority (ACMA) created a new class licence in 2015 to better facilitate the use of GNSS frequencies in Australia. Authorized frequencies include 1164 to 1215 MHz, 1215 to 1240MHz, 1240 to 1300MHz, and 1559 to 1610MHz.

FIGURE 51: GNSS/ RNSS FREQUENCIES (CURRENT AND PROPOSED)



Notes: Representation of the signals of the radio navigation-satellite service (L-band) seen in Australia- Modified from ACMA 2015; L Band (1176-1609 MHz except IRNSS SI (Wi-Fi band); CDMA transmission except GLONASS (currently FDMA, but moving to CDMA)

Source: MacLeod [77]

2.3.4 SBAS

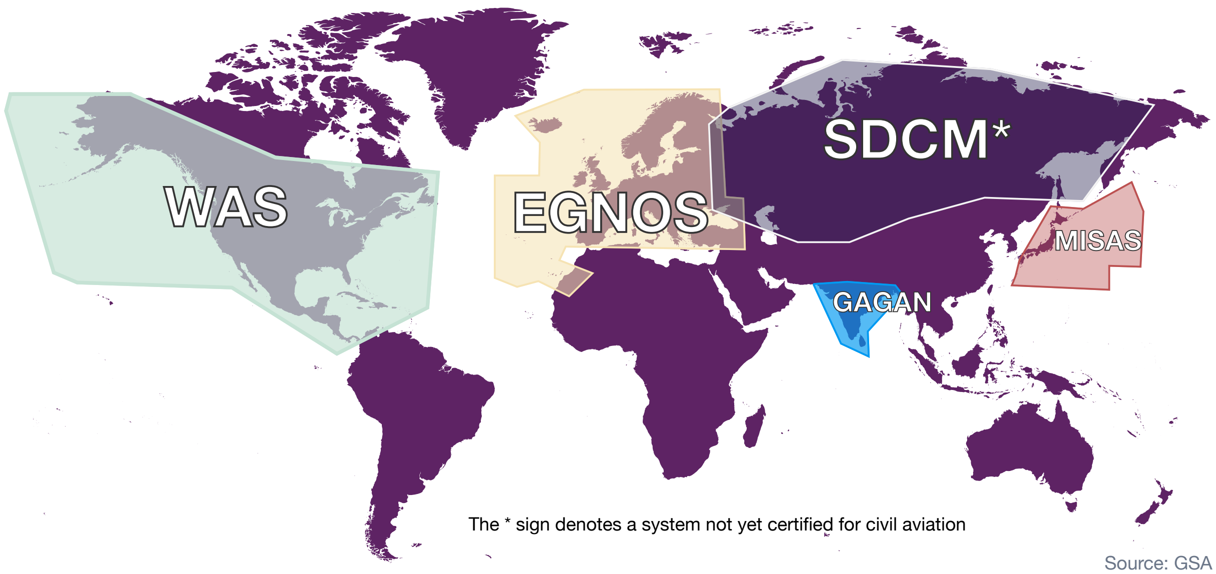
In January 2017 the Australian Government announced an investment of AUD $12 million into a Satellite-Based Augmentation System (SBAS) testbed trial, which is also supported by the New Zealand Government with a further AUD $2 million. The program will test the potential of SBAS in the four transport sectors of aviation, maritime, rail and road as well as in the agriculture, consumer, construction, resources, spatial and utility sectors in Australia and New Zealand. Space-based and ground-based infrastructure is used to improve and augment the accuracy, integrity, and availability of basic GNSS signals. With SBAS technology it is anticipated to derive location accuracy better than 5cm. The test is facilitated by Geoscience Australia, together with the Australia and New Zealand Cooperative Research Centre for Spatial Information [78]. A widespread adoption of improved positioning technology has the potential to be worth AUD $73 billion to Australia by 2030 [79].

The SBAS testbed will provide access to the following signals [80]:

- SBAS L1 Legacy Service – GPS single frequency SBAS augmentation signal transmitted on the L1 frequency. Achievable accuracy of sub-metre.
- SBAS L1/L5 DFMC Service – GPS + Galileo dual frequency SBAS augmentation signal transmitted on the L5 frequency.
- PPP service – GPS + Galileo precise orbits and clocks broadcast through the SBAS L1 and SBAS L5 signals. Expected accuracy of 5-10cm.

The test-bed is an initial step to join other nations with SBAS capabilities (see Figure 48, Figure 52), and part of the Australian National Positioning Infrastructure initiative (see Figure 44). The adoption of SBAS will bring Australia and New Zealand up to the level of the USA, Europe, China, India, Russia, and Japan.

FIGURE 52: GLOBAL SBAS CAPABILITIES



Source: GSA [73]

Figure 53 gives more details on the various available and planned SBAS systems.

FIGURE 53: SUMMARY OF CURRENT AND PLANNED SBAS SYSTEMS

SBAS Name	Space Segment	Operations supported	Operational since	Evolutions planned
EGNOS (Europe)	3 Geostationary satellites: • Inmarsat AOR-E (15.5° W) • SES-5 (5° E) • ASTRA 5B (31.5° E)	Open service (OS) ~1m accuracy	2009	Guaranteed operation until 2030 in compliance with ICAO SBAS SARPS. 2021 and beyond: EGNOS 'V3', including SBAS L1 and L5 (dual frequency), Galileo support and extended coverage
		Safety of Life (SoL) LPV-200	2011	
		Data Access (EDAS) ~1m accuracy	2015	
WAAS (USA)	3 Geostationary satellites: • Inmarsat AMR (98° W) • Galaxy 15 (133° W) • Anik F1R (107° W)	LPV-200	2012	Support for L1 legacy until 2028 Transition to L1/L5 to provide a dual frequency service
MSAS (Japan)	2 Geosynchronous satellites: • Himawari-8 (140.7° E) • Himawari-9 (140.7° E) launch in 2016	NPA	2003	Incorporation of L5 signal
GAGAN (India)	3 Geostationary satellites • GSAT-8 (55° E) • GSAT-10 (83° E) • GSAT-15 (93.5° E) launched Nov 2015	APV-1	2007	
SDCM (Russia)	3 Geosynchronous satellites: • Luch-51 (167° E) • Luch-5B (16°° • Luch-5C (95° E)	APV-2	2013	Aiming for certification for APV-2 over Russian territory
KASS (Korea)	In development	Aviation	2016	L1/L5 and L1/L3 (GLONASS) by 2018
SNAS (China)	In development	<1m accuracy	2022	Collaboration with GAGAN
SACCSA (South America)	Feasibility study	APV-1	2020	Multi-constellation and dual frequency support intended

Source: GSA [73]

2.3.5 OTHER LOCATION SYSTEMS

When GNSS signals are augmented with systems and services, performance in accuracy and integrity can be greatly improved; This includes mentioned SBAS, DGPS (Differential GPS), A-GNSS/ TTFF, and PPP and RTK.

Figure 54 gives an overview of globally available systems. For a detailed explanation of technology and systems, see reference [73].

FIGURE 54: MAIN WORLD-WIDE COMMERCIAL AUGMENTATION SERVICES

Name	Service	Stated performance	Supported Constellations	Method	Owned by
OmniStar	VBS	<1m	GPS	DGNSS	Trimble
	HP	10cm	GPS	LR-RTK	
	XP	15cm	GPS	PPP	
	G2	<10cm	GPS + GLONASS	PPP	
RTX	ViewPoint	<1m	GPS + GLONASS + BDS	PPP	Trimble
	RangePoint	<50cm	GPS + GLONASS + BDS	PPP	
	FieldPoint	<20cm	GPS + GLONASS + BDS	PPP	
	CenterPoint	<4cm	GPS + GLONASS + BDS	PPP	
StarFix	HP	10cm	GPS	Phase DGNSS	Fugro
	G2	10cm	GPS + GLONASS	PPP	
	G2+	3cm	GPS + GLONASS	PPP	
	G4	5-10cm	GPS + GLONASS + BDS + Galileo	PPP	
	L1	1.5m	GPS	DGNSS	
	XP2	10cm	GPS + GLONASS	PPP	
Atlas	H100	1m	GPS + GLONASS + BDS	PPP	Hemisphere
	H30	30cm	GPS + GLONASS + BDS	PPP	
	H10	8cm	GPS + GLONASS + BDS	PPP	
StarFire	SF2	5cm	GPS + GLONASS	PPP	John Deere
C-Nav	C1	5cm	GPS	PPP	Oceaneering international
Veripos	C2	5cm	GPS + GLONASS	PPP	Hexagon AB
	Apex	10-20cm	GPS	PPP	
	Apex^2	5cm	GPS + GLONASS	PPP	
	Ultra	15cm	GPS	PPP	
	Ultra^2	8cm	GPS + GLONASS	PPP	
	Standard	1m	GPS	DGNSS	
	Standard^2	1m	GPS + GLONASS	DGNSS	
TerraStar	TerraStar D	10cm	GPS + GLONASS	PPP	Hexagon AB
	TerraStar M	1m	GPS + GLONASS	DGNSS	
	TerraStar C	2-3 cm	GPS + GLONASS	PPP	

Source: GSA [73]

An Australian company Locata uses phase measurements (without differential technique) from a synchronized transceivers network to enable centimetre-accurate single point positioning. The System is used at NASA Langley Research Center, and offered (by Hexagon Mining) in the Jigsaw Positioning System for mining [81].

2.3.6 LOCATION BASED SERVICES

The indoor LBS market is estimated to grow over 43% between 2016 and 2020 and expected to reach Euro 7.7 billion in 2020 [72]. In order to facilitate a seamless navigation experience between indoor and outdoor navigation, a hybrid positioning system is needed.

The range and accuracy of location systems vary, subject to the technology applied to derive the location information (see Figure 55).

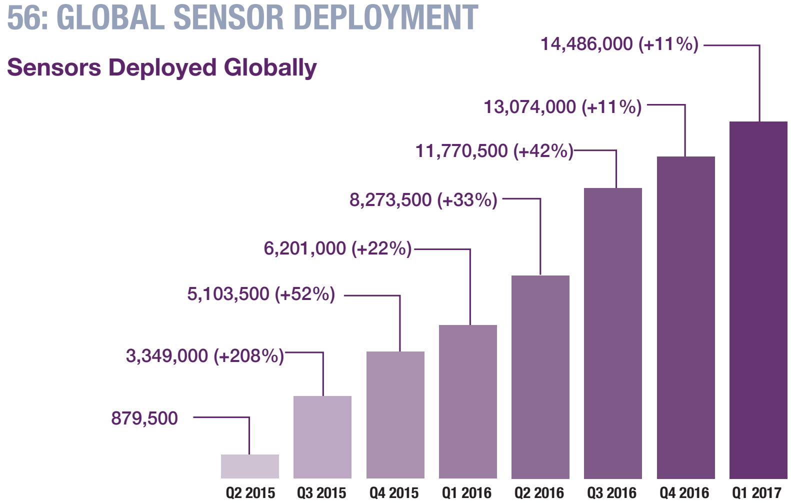
FIGURE 55: SENSORS USED IN POSITIONING SYSTEMS

Designation	Measured quantity	Measurement method	Environment	PVT strategy
Accelerometer	Body acceleration	Pendulous / Vibrating beam	All	Dead Reckoning: Inertial
Altimeter Barometric	Altitude (vertical range to MSL)		Air / Land	Position Fixing:Aiding or Map correlation (TRN)
Altimeter Radio	Altitude (vertical range to relief)	Timing	Air	Position Fixing:Aiding or Map correlation (TRN)
Balise / Eurobalise	Proximity detection	H Field	Land / Train	Position Fixing: Proximity
Camera (Incl. Stereo)	Angles	Optical	All	Position Fixing: Map (image) correlation, Aiding (Visual Odometry)
Cell phones – Cell Id	Proximity detection	E Field strength	Land	Position Fixing: Proximity
Csac Clocks				Position Fixing: Aiding
Doppler Log	Velocity	Acoustic Frequency shift	Marine	Dead Reckoning
Doppler Radar	Velocity	Radio Frequency shift	Land (rail)	Dead Reckoning
DSRC	Proximity detection Ranging		Terrestrial	Position Fixing: Proximity / Ranging
Gravimeter	Gravity field		Marine	Position Fixing: Map correlation
Gyroscope	Body angular rate	Mechanical / optical / vibratory	All	Dead Reckoning: Inertial
Laser Scanner & Lidar	Distance	Optical	Air / Land	Position Fixing: Map (image) correlation
LPWAN (LoRa, SigFox, Weightless - IoT networks)	Ranges		Land	Position Fixing: Ranging
Magnetometre	Magnetic field	H Field strength & direction	All	Position Fixing: Map correlation
Magnetic compass	Magnetic heading	H Field direction	All	Dead Reckoning
Odometer	Velocity		Land (automotive, rail)	Dead Reckoning
Pedometer (Step counter)	Distance travelled		Land (pedestrian)	Dead Reckoning
Pressure sensor	Depth		Marine underwater	Position Fixing: Map correlation (TRN)
Radar (Incl. Imaging - SAR)	Range & Azimuth Intensity		All	Position Fixing: Range + Bearing / Map (image) correlation
Radio beacons	Range (field strength) & Direction		All	Position Fixing: Range + Bearing
Radio & TV broadcast (incl. DAB, DVB-T)	Range		Land	Position Fixing: Ranging
RFID	Proximity detection		Terrestrial	Position Fixing: Proximity
Sonar (incl. Multibeam)	Distance to seafloor	Timing	Marine underwater	Position Fixing: Map correlation (TRN)
WLAN (Incl. Wi-Fi)	Signal strength	E Field strength	Land (urban / indoors)	Position Fixing: Map correlation
WPAN (ANT+, Bluetooth, ZigBee & derivatives)	Ranges (proximity detection)	E Field strength	Land (urban / indoors)	Position Fixing: Map correlation / Proximity / Ranging

Source: GSA [73]

Figure 56 shows global sensor deployment, in 2017 with 65% being beacons, 20% Wi-Fi-points, and 15% NFC [82].

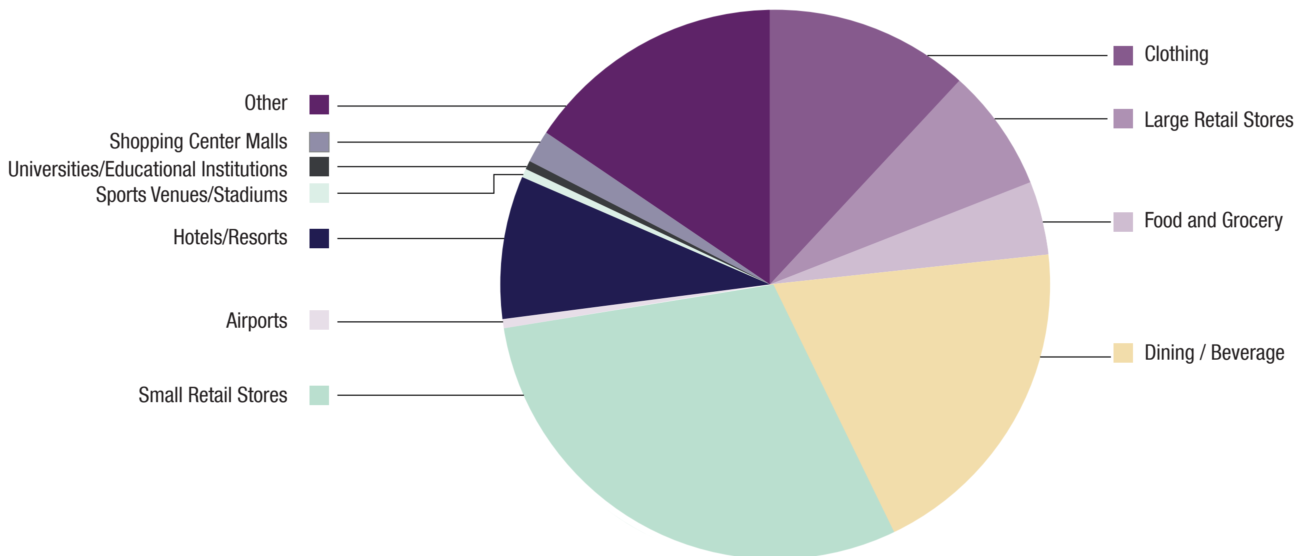
FIGURE 56: GLOBAL SENSOR DEPLOYMENT



Source: Unacast [82]

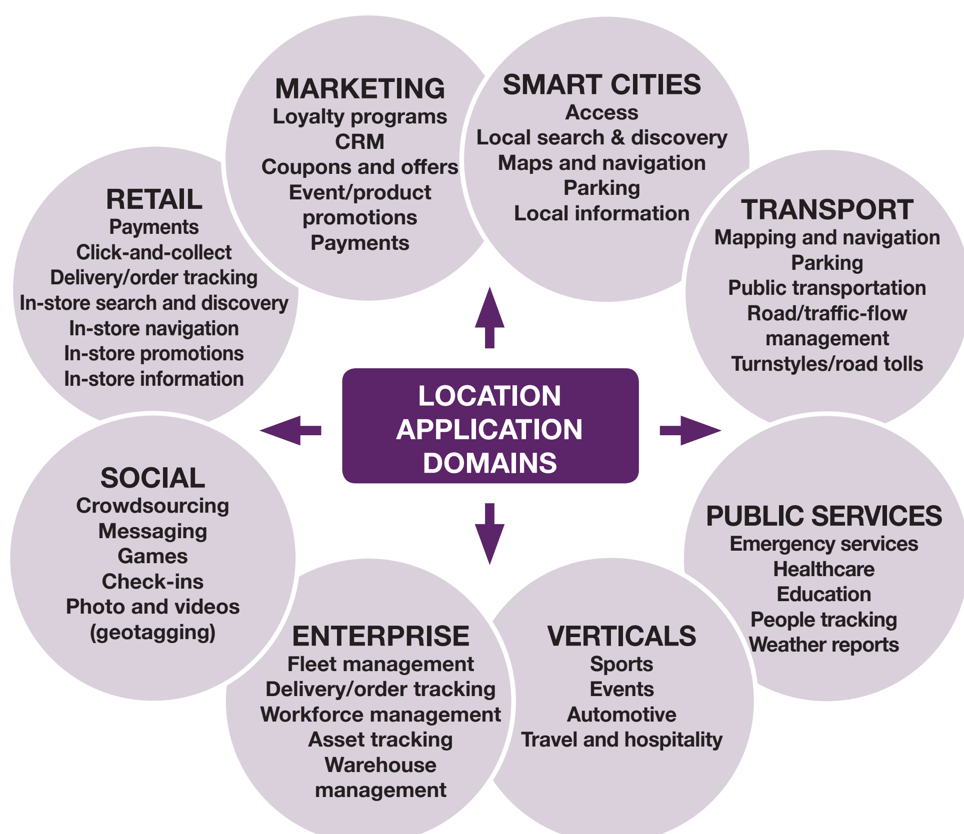
ABI Research published a graph on indoor positioning use cases (see Figure 57). Figure 58 summarizes location application domains and use cases.

FIGURE 57: INDOOR LOCATION SERVICES USE CASES



Source: ABI Research [84]

FIGURE 58: LOCATION-BASED APPLICATIONS



Source: Ovum

2.4 RELIANCE ON CRITICAL TECHNOLOGIES

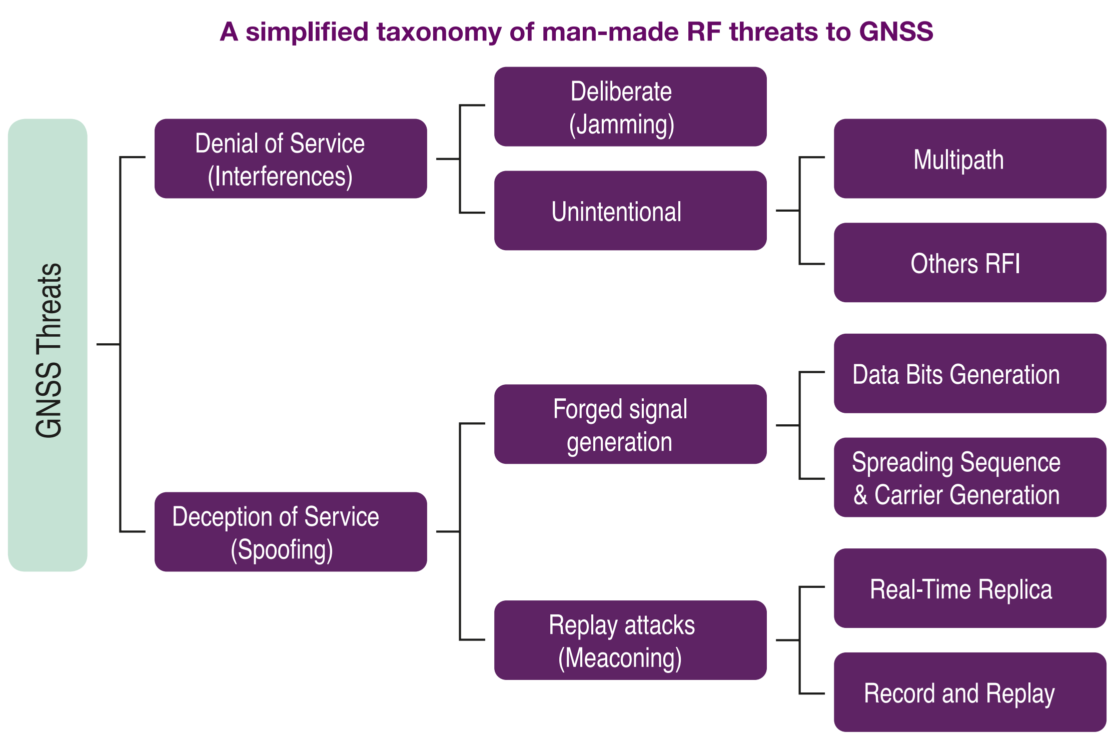
Spatial information, in particular position, navigation and timing information (PNT) have become a crucial component in many supply chains. Location information is increasingly used as a verification tool, and timing information is essential to keep critical infrastructure operational. Amongst many other applications, timing information is used to keep the electricity grid stable and telecommunication infrastructure functional. It is also used for emergency services and transportation [85] [86]. Risks to (GNSS) satellites include adverse space weather (geomagnetic storm), the collision of satellites with space debris, and issues around signal deterioration (unintended and wilful interference, jamming, and spoofing) [85].

2.4.1 SIGNAL DETERIORATION

Despite GNSS jammers being illegal to sell or use in most countries, they can be bought via the internet. Typically, such devices are used to disrupt 'asset tracking', but often such jammers work in a much larger area than advertised. Unintentional jamming can be caused by RF interference from i.e. microwave devices, airport radars, and TV transmitters.

Signal spoofing uses navigation message replica and forgery. A low-cost GNSS software defined radio (SDR) was presented at DEFCON23. It can be used by GNSS non-specialists to spoof navigation signals [72]. On 26 January 2016 a number of GPS satellites were uploaded with a minuscule offset in the timing signal, and this minute error was unnoticed for 12 hrs and affected GPS dependent timing equipment around the world. Figure 59 gives an overview of various man-made GNSS treats.

FIGURE 59: OVERVIEW GNSS MAN-MADE GNSS DISRUPTIONS



Source: GSA [73]

These sort of threats reinforce the need for improved protection of the integrity and redundancy of timing signals, to ensure authentic, robust, accurate and traceable signals.

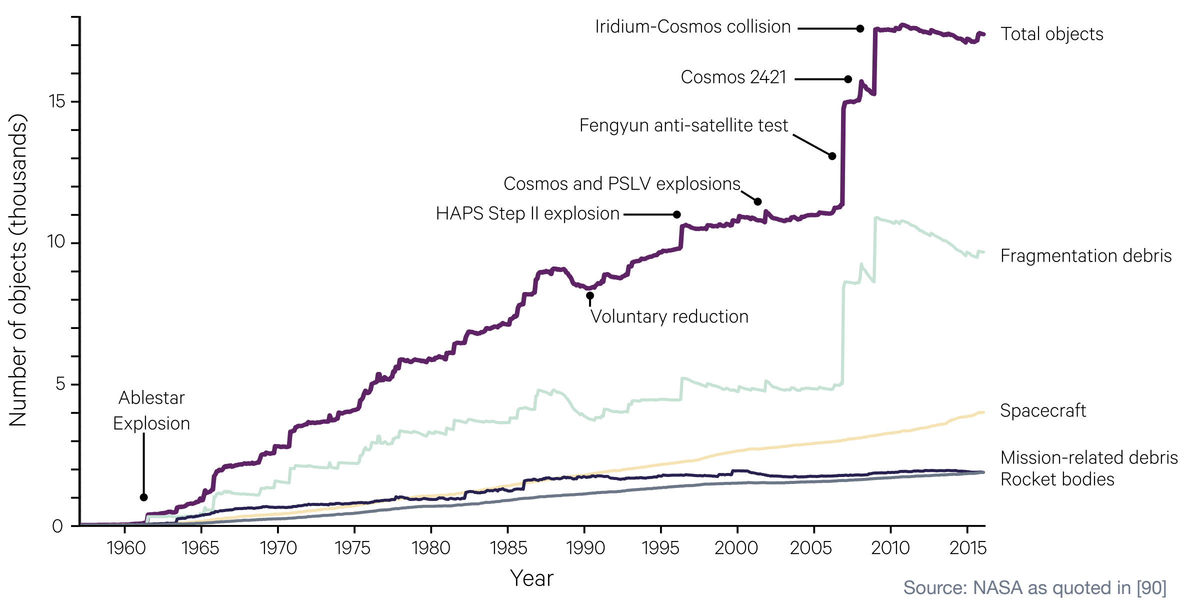
Current civil US GPS signals are not cryptographically secured. Next generation military GPS applications are secured, and user equipment (i.e. from L-3) need to be certified; the Air Force Military GPS User Equipment (MGUE) program is led by the GPS Directorate within the Space and Missile Systems Center (SMC) at Los Angeles Air Force Base [87]. The European Galileo satellite will include civil cryptographical authentication. Anti-spoofing applications control access to the signal by use of NAVSEC (encryption of the ranging codes) and COMSEC (navigational messages), this only granting access to authorized users. Further techniques for enhanced counter measures are described in [73].

GNSS signals are broadcast from about 20,000 km above the earth and as a result of the long distance are a weak signal. eLoran systems (such as from S Korea) are 1.3 million times stronger than the GPS signal [88]. The eLoran system was put in place after N Korean hackers (N Korea, however, does deny responsibility) repeatedly jammed the navigation of fishing vessels. In July 2017, the US House of Representatives passed a bill which includes provisions for the US Secretary of Transportation to also establish an eLoran system. Russia (in cooperation with the UK) has also looked at an eLoran system, called eChayka, aimed at the Arctic regions [88].

2.4.2 COLLISION WITH SPACE DEBRIS

Space debris is man-made objects, such as non-functioning satellites, rocket upper stage bodies, metallic fragmentations etc. More than 20,000 debris items are trackable from Earth, but smaller debris can't be tracked. Archives of NASA's Orbital Debris Quarterly [89] document the history of space junk:

FIGURE 60: NASA CATALOGUED SPACE DEBRIS OVER TIME



Source: NASA as quoted in [90]

The Low Earth Orbit zone (LEO—800 to 2,000 km altitude) contains the highest concentration of orbital debris. Based on NASA data it is estimated there are 10,000 objects greater than 10 cm and 100,000 objects sized between 1 and 10 cm. Once space junk exists, it presents a danger to other spacecraft and satellites in a colliding orbit. Collisions give rise to more space debris, and the worst-case scenario is a run-away chain reaction (Kessler Effect) rendering earth orbits unusable for centuries. Therefore, Space Debris is a reoccurring topic with UN's Committee on the peaceful uses of Outer Space (UNCOPUOS) and ESA initiated Inter-Agency Space Debris Coordination Committee (IADC) [91] to enhance international collaboration. ESA reports annually on the Space Environment and summarizes the 2016 findings as follows [45]:

- The number of objects, their combined mass, and their combined area has been steadily rising since the beginning of the space age, leading to the appearance of involuntary collisions between operational payloads and space debris.
- On average, 8.1 non-deliberate fragmentations occur in the space environment every year, a number which is stable however the impact of each event is variable. This number drops if the lifetime of the generated fragments is considered a factor of importance.
- The amount of mission-related objects released into the space environment is steadily declining, but still significant for Rocket Bodies.
- Launch traffic into the LEO protected regions is on the rise, fuelled by the proliferation of small payloads, i.e. below 10.0 kg in mass, during the last few years in terms of number, but not contributing significantly to the mass.
- Around 85% of small payloads, i.e. below 10.0 kg in mass, launched recently and injected into the LEO protected region do so in orbits which adhere to the space debris mitigation measures.
- Between 40 and 60% of all payload mass recently reaching end-of-life in the LEO protected region does so in orbits which adhere to the space debris mitigation measures.
- Around 60% of all rocket body mass recently reaching end-of-life in the LEO protected region does so in orbits which adhere to the space debris mitigation measures. A significant amount of this is due to controlled re-entries after launch, a practice which is increasing.
- Between 15 and 20% of payloads recently reaching end-of-life in the LEO protected region in a non-compliant orbit attempt to comply with the space debris mitigation measures. Around of 5% do so successfully.
- Between 50 and 60% of rocket bodies recently reaching end-of-life in the LEO protected region in a non-compliant orbit attempt to comply with the space debris mitigation measures. Around of 40% do so successfully.
- Around 90% of all payloads recently reaching end-of-life in the GEO protected region attempt to comply with the space debris mitigation measures. Around 70 % do so successfully.

The Defense Advanced Research Projects Agency (DARPA) facilitated several programs, aiming to improve the 29 space surveillance sensors (radar and optical) of the United States Space Surveillance Network (SSN) for debris tracking. Some program also involves the public providing low-cost and efficient solutions [92]. The DARPA study (Wade Pulliam, Catcher's Mitt Final Report, Defence Advanced Research Projects Agency, 2011) [93] found that [94]:

- The development of debris removal solutions should concentrate on pre-emptive removal of large debris in both Low Earth Orbit and Geosynchronous Orbit. It was noted that the greatest threat to operational spacecraft actually stems from medium-sized debris (defined as 5 mm–10 cm).

- No reasonable solution was found to effectively remove medium-sized debris. Therefore, proposals for active debris removal focus on large space debris objects.
- Removal of large objects generally employs advanced rendezvous and proximity operations and sophisticated grappling techniques. Various methods of capturing large objects were proposed involving a net, inflatable longeron, tethered harpoon, articulated tether/lasso, and an electrostatic/adhesive blanket. Some solutions attached or used an active thrust device, while others made use of natural forces found in the space environment to impart a force on the debris to relocate it.

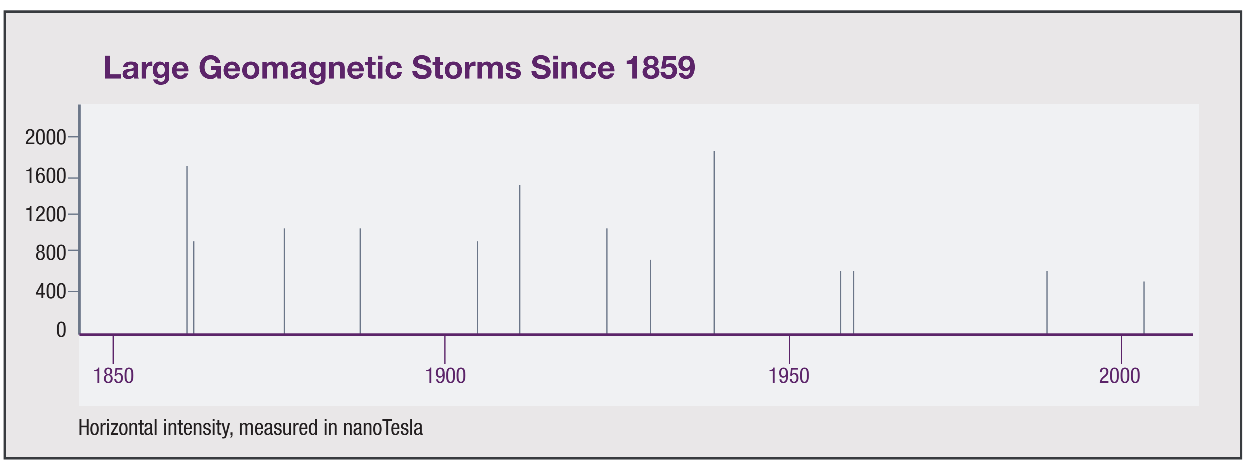
The website SatView gives details about upcoming and recent space junk atmospheric re-entries [95].

In Australia, the Cooperative Research Centre for Space Environment Management, managed by the Space Environment Research Centre (SERC) builds on Australian and international expertise in measurement, monitoring, analysis and management of space debris to develop technologies to preserve the space environment [96]. SERC aims to improve the accuracy and reliability of orbit predictions, thus avoiding potential collisions in space. SERC also designs tools and models to calculate atmospheric mass density and earth gravitational field influences. An On-orbit demonstration of debris movement with lasers aims to engage space objects from earth [96].

2.4.3 ADVERSE SPACE WEATHER

Severe space weather is a low-frequency high-consequence event (LF/HC). It is caused by solar coronal mass ejections/solar flares (CME), and the related solar wind /the interplanetary magnetic field (IMF) is carried by solar wind plasma causing auroras and geomagnetic storms on earth (not too dissimilar to effects of an EMP in the upper atmosphere). Figure 61 shows the frequency of large geomagnetic storms since 1850. Peter Riley evaluated events over the last 50 years and estimates there is 12% chance of a severe CME event to hit Earth in the next decade [97].

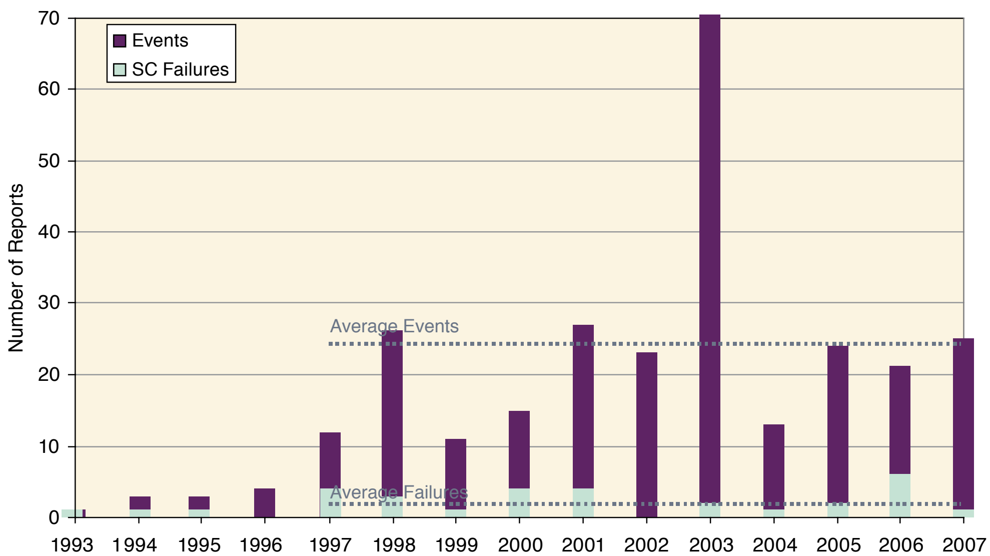
FIGURE 61: LARGE MAGNETIC STORMS 1859 TO 2003 BASED ON HORIZONTAL INTENSITY



Source: Centra/ OECD [98]

Noteworthy is the Carrington event in 1859 (estimated Dst -850 nT,-1600 nT), where induction caused by a geomagnetic storm had sparks appeared on telegraph wires, and auroras could be seen as far south as Hawaii and Central America. The Quebec storm in 1989 caused widespread power outages, melted transformers, and many satellites were ‘lost’ (see Figure 62).

FIGURE 62: SPACE WEATHER EVENTS



Average # of **events/yr** = **24.3**

Average # of **failures/yr** = **2.5**

Most events/failures are not attributed to space weather, but 46 of 70 in 2003 occurred during Halloween storms

Source[3] : National Research Council [99]

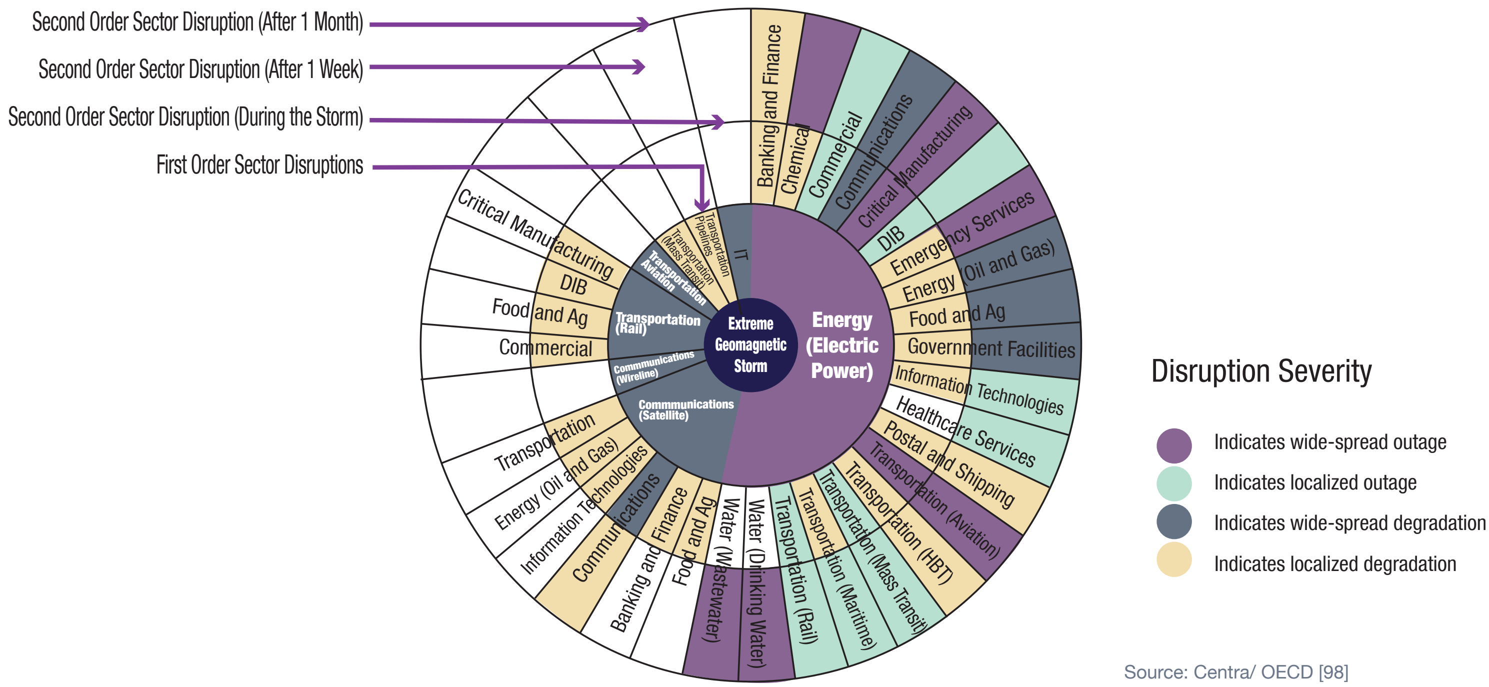
The 2003 Halloween storms had severe effects: i.e. the ADEOS satellite failure (cost USD $640 million), International Space Station astronauts were ordered to take shelter, and the Wide Area Augmentation System (WAAS) had a vertical error of 50m+ (not usable for precision approaches). A large storm in 2012 luckily missed Earth by just one week; however, insightful data could be collected by space-based sun observatory STEREO A [99] [98].

Geomagnetically induced currents (GIC) have the potential to severely affect power grid operations causing blackouts and voltage collapse, knocking out satellites, triggering the need for passenger aircrafts to be re-routed, disrupting communications and causing corrosion of pipelines (just to name a few). Some commentators have suggested that a severe geomagnetic storm could force human-kind back to the stone age [100], cost society USD $1-2 trillion in the first year, and, depending on the degree of damage, have a recovery time of four to 10 years [99]. Strategies to help manage these space weather issues are set out in [101], [102].

Figure 63 illustrates the disruption of a severe space weather event for global supply chains.

[3]Michael Bodeau, Northrop Grumman, “Impacts of Space Weather on Satellite Operators and their Customers,” Presentation to the Space Weather Workshop, May 22, 2008.

FIGURE 63: CRITICAL INFRASTRUCTURE DISRUPTION BY EXTREME GEOMAGNETIC STORMS

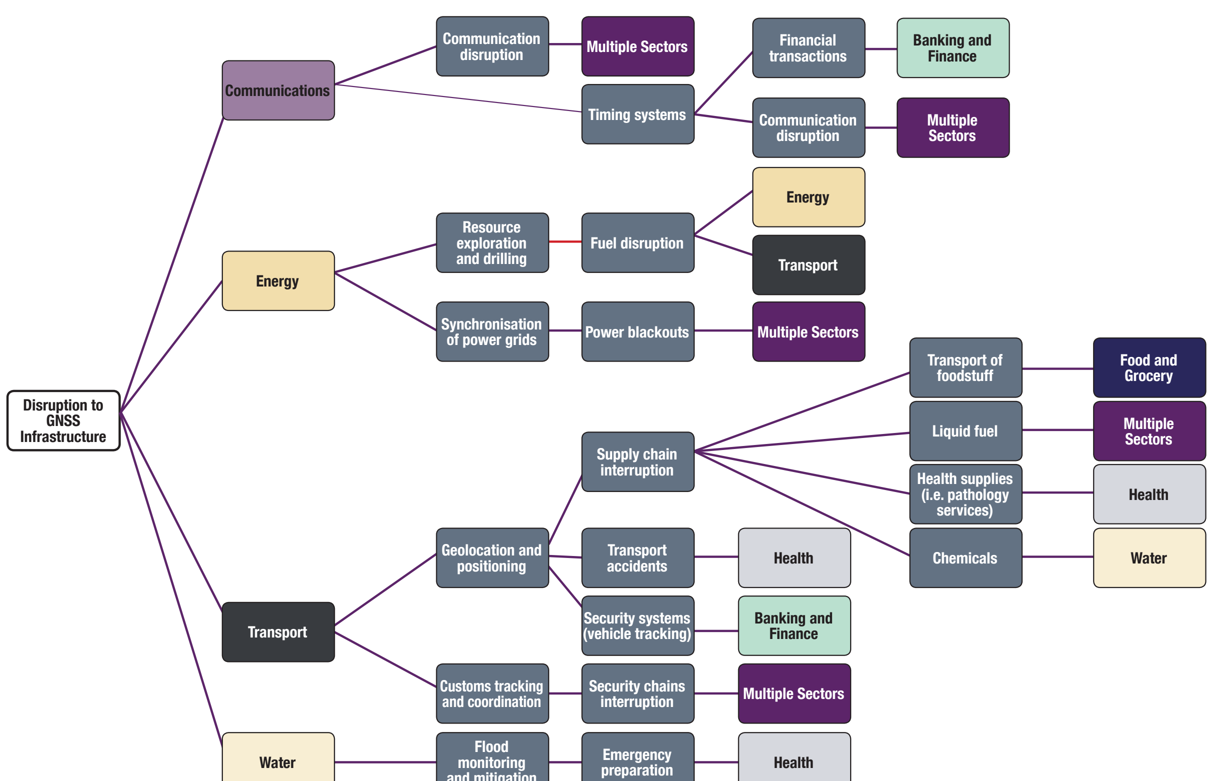


Source: Centra/ OECD [98]

2.4.4 CRITICAL INFRASTRUCTURE RESILIENCE STRATEGY

If there is a disruption to the GNSS signals due to factors discussed in the previous sections, a nations whole supply chains can be compromised [86]. Figure 64 visualizes affected infrastructure components.

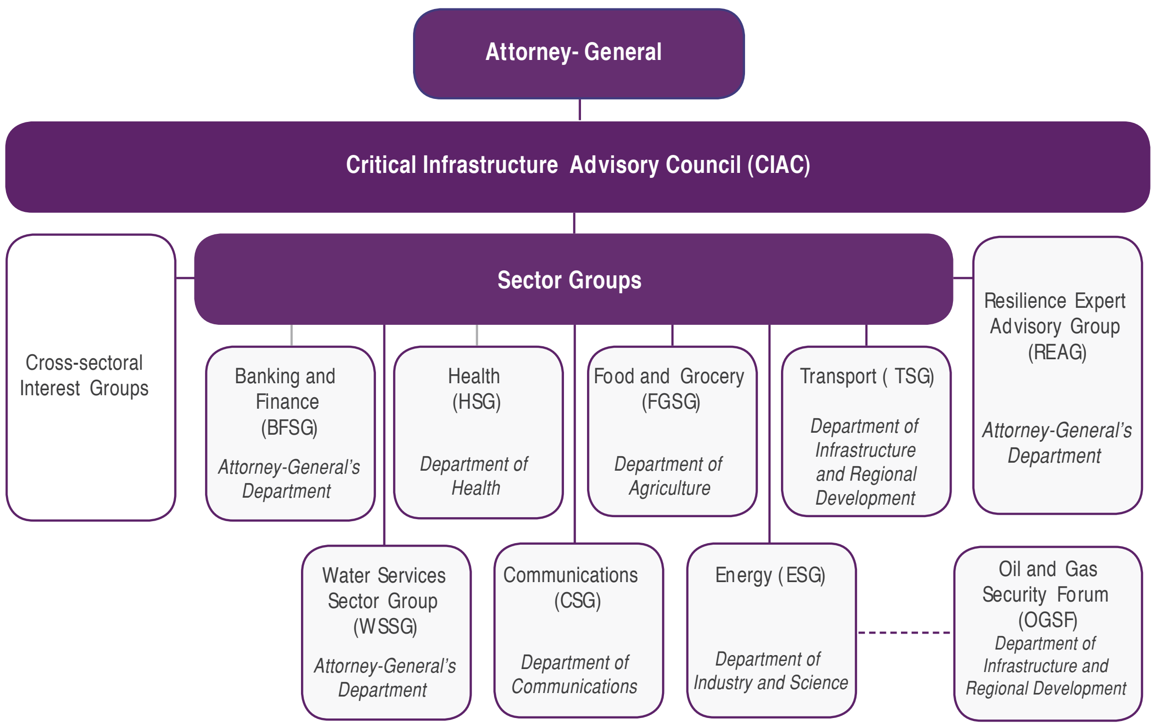
FIGURE 64: OVERVIEW OF GNSS DISRUPTION EFFECTS ON CRITICAL INFRASTRUCTURE



Source: Garred [103]

In Australia, the Critical Infrastructure Advisory Council (CIAC) (see Figure 65) [103], [104] seeks to plan risk mitigation strategies for the protection of critical infrastructure from all threats. The Space Cross-Sectoral Interest Group (Space CIG) reports to the CIAC regarding impacts on critical infrastructure from major disruption to space-based systems and technologies [105]. The Space CIG is currently reviewing the dependence of critical infrastructure on communications, earth observation and GNSS-RNSS satellites and the threats that may need to be managed in the future.

FIGURE 65: GOVERNANCE STRUCTURE FOR AUSTRALIA'S CRITICAL INFRASTRUCTURE ADVISORY COUNCIL (CIAC)



Source: Australian Government [104]

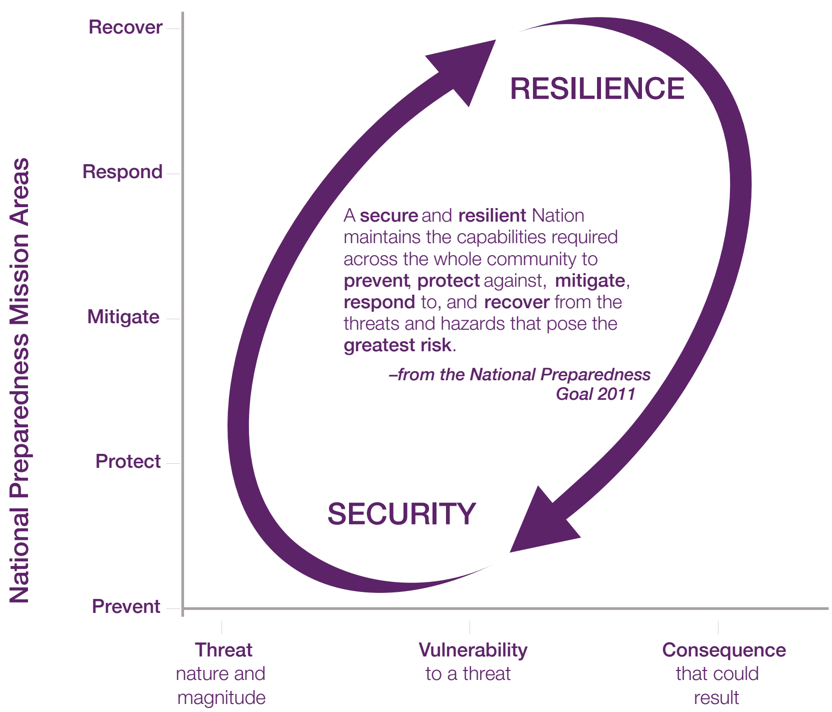
Resilience strategies are also being worked on [85] and published by the US Department for Homeland Security [106], [107], [108], [109], [110], [111], [112], [113], [114].

Disaster resilience strategies are visualized in Figure 66 and Figure 67. The focus is on building resilience to minimise recovery times.

FIGURE 66: US DISASTER RESILIENCE STRATEGIES

Source: The National Academies (US) [106]

FIGURE 67: US NATIONAL RESILIENCE CYCLE



Source: DHS [107]

Risk management goes beyond strategies to compensate for lost technology and location signals. In the past government agencies have somewhat overlooked the importance of spontaneous volunteering in emergency response and recovery. The unpredictable and uncontrolled nature of spontaneous volunteering caused volunteers to be perceived as a risk and sometimes nuisances. However, research shows that spontaneous volunteers contribute vital activities in the aftermath of a disaster, such as a search and rescue, first aid, and assessment of community needs [115]. There is scope to structure and optimise the help of volunteers- i.e. in Australia EV CREW [116] works with disaster response agencies organize their volunteer management capacity- a database compiles skills and tools of volunteers and directs them in an emergency situation to where they can work to achieve the greatest impact [117].

The Global Disaster Management Platform GDMP framework identified four components: an interactive geospatial platform; a user-based land and property disaster management tool; stakeholder networking tools; and a disaster management education portal. [118]. While there are several platforms and tools for emergency response (Ushahidi, OpenStreetMap, etc.), there is a case for a dominant global web platform that is the go-to place (front-of mind) – such as is 'Airbnb' (peer to peer for accommodation) or 'Uber' (peer- to peer for transport) for peer to peer assistance in disaster situations. Such a platform has the potential to enhance national resilience.

3 ENABLING INFRASTRUCTURE AND TECHNOLOGY

3.1 NETWORK CONNECTIVITY

A solid communication infrastructure is essential for spatial information applications to function. Hence communication infrastructure is an enabler for the spatial industry, and this section of the paper will look at the topic in a global context and for Australia.

3.1.1 MOBILE CONNECTIVITY

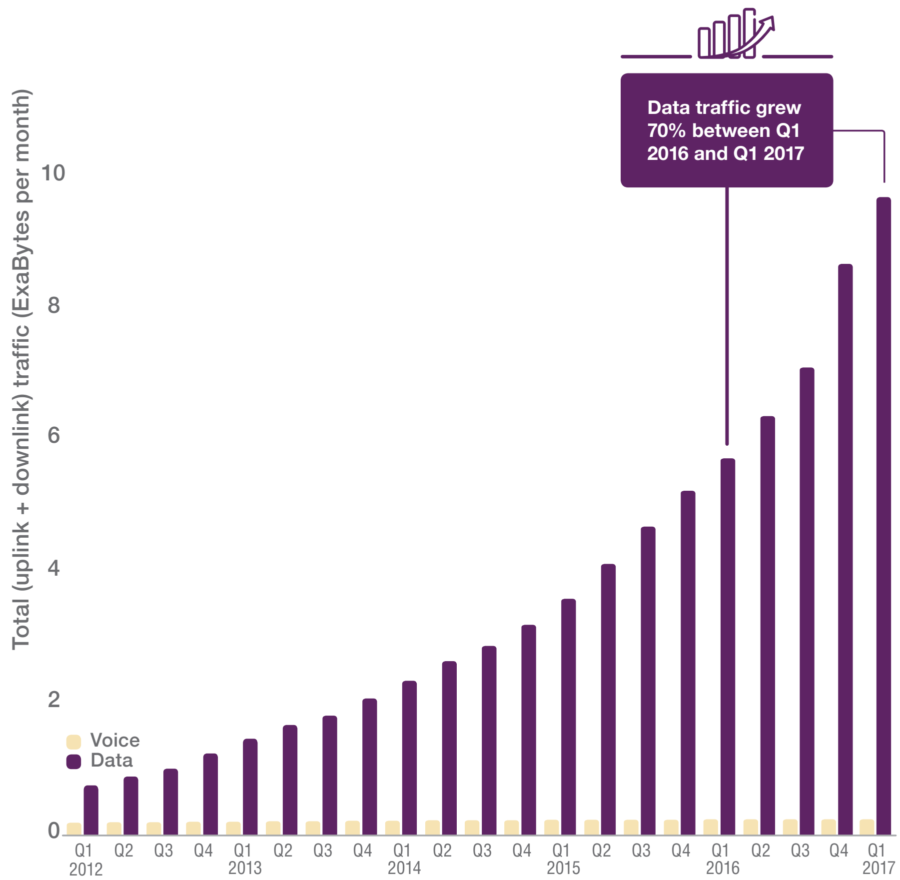
According to GSMA [119], by mid-2017 there were 5 billion mobile phone subscriptions worldwide. In Australia, there are about 26 million mobile handset subscribers (June 2017). The combined mobile data download over the prior 3 months was 175,076 Terabytes [120]. This equates to approximately 2.2 GB per month per user representing an increase of 19.9% when compared with the three months prior and most likely fuelled by mobile data plans dropping in price.

As for the dominant mobile carrier service providers (as reported by Kantar), in Australia (March 2017) Telstra had a 41.4% market share, Optus 22.8%, and Vodaphone 13.9%. The smartphone vendor market share (shipment data Q2 2017) was: Samsung (23.3%), Apple (12.0%), followed by Huawei (11.3%), OPPO (8.1%), Xiaomi (6.2%) and others (39.0%) [121] .

The Global smartphone market is dominated by the Android operating system (according to IDC 85.0% in Q1 2017, vs 14.7% for IOS, others 0.2%). In Australia, Android has 65.5% of the market (August 2017), while IOS has 33.9%) [122]. The Android APP store and the Apple APP store are the platforms the majority of mobile developers utilize. These two platforms will also have the most potential to expand their reach into Internet of Things (IoT) applications. IoT and M2M (machine to machine) applications will significantly increase mobile data traffic. Mobile data traffic grew 70%

in just one year (from Q1 2016 to Q1 2017, data from Ericsson) and contributes to the impending data deluge (see Figure 68).

FIGURE 68: MOBILE DATA TRAFFIC

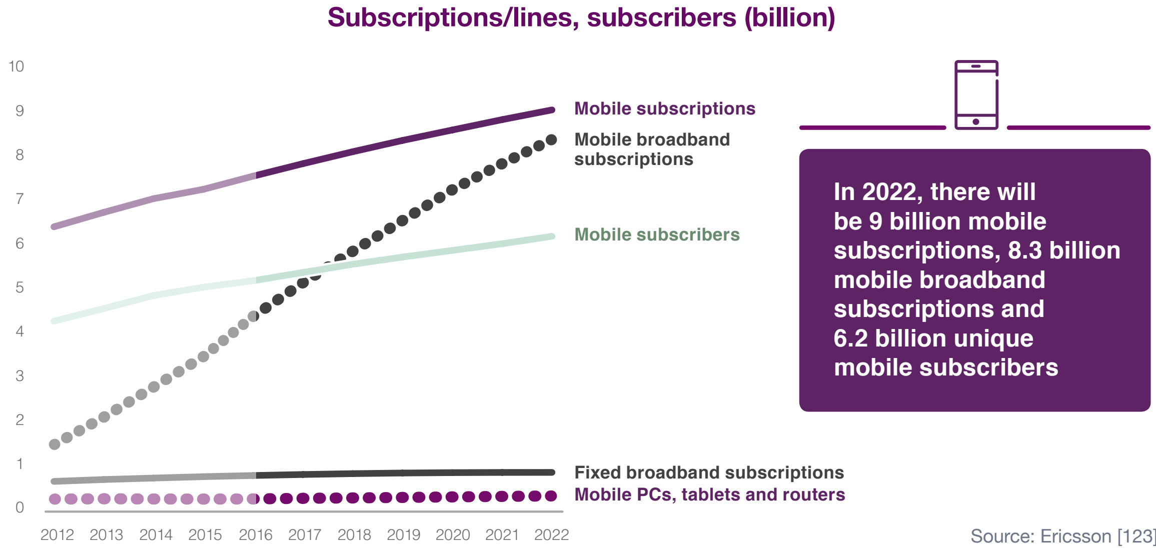


Source: Ericsson [123]

The creation of data will remain exponential over the next several years, driven by the Internet of Things and M2M applications, Open data and derived insights, autonomous agents, and not least a doubling of users of the internet as it becomes more and more available to all citizens. Therefore, appropriate planning for network capacitates is of utmost importance. A second space race is currently being battled out by private industry consortiums to connect the remaining half of population that are not yet on the internet. Service delivery will be via innovative LEO satellites, stratospheric balloons, solar drones and other technologies.

Telecommunications companies are starting to work on 5G wireless networks with immensely faster network speeds to cater for the data deluge that will pass through their infrastructures (Figure 69 shows Ericsson's predictions on the expected increase, in particular for mobile broadband subscriptions until 2022).

FIGURE 69: SUBSCRIPTIONS (IN BILLION)



Source: Ericsson [123]

By 2022, more than 90% of mobile data traffic will likely be from smartphones. Around 75% of mobile data traffic will be caused by video (including video embedded in social media) [123]. Cisco also estimates a 53% CAGR for mobile data traffic between 2015 and 2020.

3.1.2 INTERNET CONNECTION

The average global internet connection speed (IPv4) is 7.2 Mbps. South Korea ranks first with 28.6 Mbps, and Australia ranks 50th with an average connection speed of 11.1 Mbps [124]. See Figure 70.

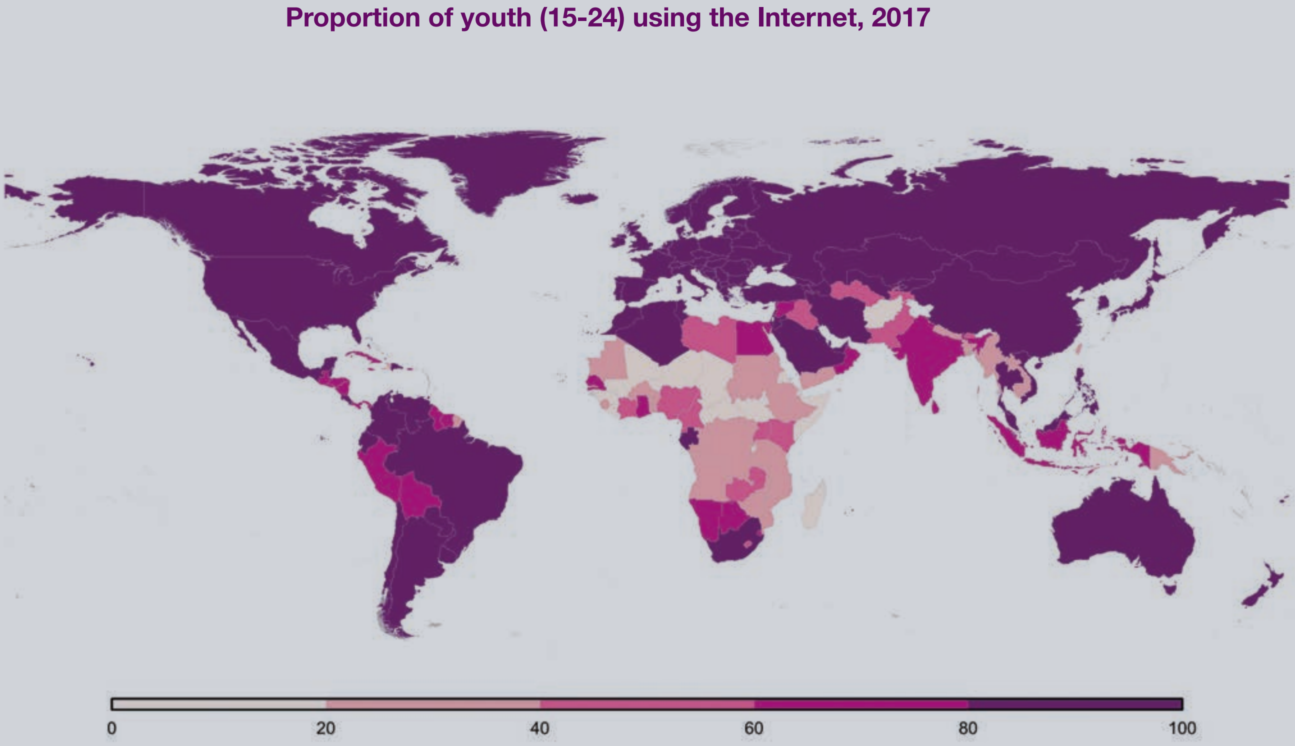
FIGURE 70: AVERAGE CONNECTION SPEED (IPV4) BY COUNTRY/ REGION

Global Rank	Country /Region	Q1 2017 Avg. Mbps	QoQ Change	YoY Change
-	Global	7.2	2.3%	15%
1	South Korea	28.6	9.3%	-1.7%
2	Norway	23.5	-0.4%	10%
3	Sweden	22.5	-1.3%	9.2%
4	Hong Kong	21.9	-0.2%	10%
5	Switzerland	21.7	-2.1%	16%
6	Finland	20.5	-0.7%	15%
7	Singapore	20.3	0.8%	23%
8	Japan	20.2	3.1%	11%
9	Denmark	20.1	-2.9%	17%
10	United States	18.7	8.8%	22%
27	New Zealand	14.7	14%	40%
50	Australia	11.1	9.6%	26%

Source: Akamai [124]

It is interesting to note that the young generation is digitally literate and on the forefront of internet adoption. In 104 countries, more than 80% of youth are online (94% in developed countries).

FIGURE 71: PROPORTION OF YOUTH USING THE INTERNET, 2017



Source: ITU [125]

In Australia, there are about 13.7 million internet subscribers (June 2017) [120]. Of the 86% of households using the internet, Australian teenagers in the age bracket 15-17 have the highest percentage of internet users (99%); they spend about 18 hours per week on the internet [13].

In June 2017 31% of Australians accessed the internet by DSL, 7% by cable, 16% by fibre, 1% by fixed wireless, 45% by mobile wireless and under 1% by satellite [120]. Remote rural Australians benefit from the NBN's ambition of ‘no Australian left behind’ which connects them primarily via communication satellites Muster 1 and 2 (launched in October 2015 & 2016).

Australia’s National Broadband Network (NBN) program has been rolled out more slowly than expected [11]. A sample of a weekly update is given in Figure 72 [126]:

FIGURE 72: SUMMARY TABLE OF NBN ROLLOUT, WEEKLY STATUS REPORT

National Broadband Network – Rollout Information

The data contained in this document reflects NBN Co's position for the week ending 15 February 2018

Weekly Summary

This weekly report by NBN Co of network rollout progress reflects the Government's requirements for greater transparency as set out in the Statement of Expectations to NBN Co.This shows rollout progress as of last Thursday 15 February 2018

A total of 9,204 additional lots/premises were passed/covered by the network during the week. This included an increase of 6,491 in Brownfield areas, an increase of 2,048 in New Development areas and an increase of 665 premises in fixed wireless and satellite areas.

During the week an additional 28,952 premises had services activated on the network, including 27,411 on fixed line services and 1,541 using satellite and fixed wireless technologies.

	Brownfields				New Developments (Greenfields)		Satellite		Wireless		Totals		
Week ending	Premises in RFS Areas	Ready to Connect	Not Yet Ready to Connect	Premises Activated	Ready to Connect	Premises Activated	Ready to Connect	Premises Activated	Ready to Connect	Premises Activated	Premises in RFS Areas	Ready to Connect	Premises Activated
	(A)	(B)	(C)=(A-B)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(A+E+G+I)	(B+E+G+I)	(D+F+H+J)
ACT	95,771	95,076	695	38,635	16,524	10,952	379	66			112,674	111,979	49,653
NSW	1,782,428	1,467,839	314,589	930,516	134,001	89,787	127,315	30,312	161,319	62,107	2,205,063	1,890,474	1,112,722
NT	67,638	67,443	195	44,512	6,907	4,355	12,379	2,288	4,784	2,160	91,708	91,513	53,315
QLD	1,159,752	953,479	206,273	599,545	109,317	61,683	96,516	17,915	120,675	46,586	1,486,260	1,279,987	725,729
SA	495,641	410,852	84,789	249,151	14,947	8,217	34,159	5,852	54,847	17,255	599,594	514,805	280,475
TAS	209,492	206,865	2,627	138,346	3,020	1,206	15,374	4,039	42,020	17,823	269,906	267,279	161,414
VIC	1,323,384	996,422	326,962	630,400	144,402	97,645	75,921	13,208	153,191	62,982	1,696,898	1,369,936	804,235
WA	667,224	600,084	67,140	313,354	63,974	38,509	63,567	11,965	36,733	11,083	831,498	764,358	374,911
15-Feb-18	**5,801,330**	**4,798,060**	**1,003,270**	**2,944,459**	**493,092**	**312,354**	**425,610**	**85,645**	**573,569**	**219,996**	**7,293,601**	**6,290,331**	**3,562,454**
08-Feb-18	5,794,839	4,794,217	1,000,622	2,919,123	491,044	310,279	425,345	85,217	573,169	218,883	7,284,397	6,283,775	3,533,502
01-Feb-18	5,763,438	4,762,257	1,001,181	2,892,883	488,197	307,956	425,073	84,819	571,591	217,715	7,248,299	6,247,118	3,503,373
25-Jan-18	5,757,366	4,750,609	1,006,757	2,874,826	484,637	305,982	424,817	84,550	568,604	216,684	7,235,424	6,228,667	3,482,042
18-Jan-18	5,713,896	4,705,718	1,008,178	2,849,122	482,513	303,872	424,728	84,176	567,059	215,609	7,188,196	6,180,018	3,452,779
11-Jan-18	5,711,273	4,702,822	1,008,451	2,824,025	481,198	301,971	424,525	83,796	566,273	214,482	7,183,269	6,174,818	3,424,274
04-Jan-18	5,677,358	4,670,853	1,006,505	2,801,979	477,573	299,690	424,267	83,473	565,669	213,388	7,144,867	6,138,362	3,398,530
28-Dec-17	5,630,445	4,625,726	1,004,719	2,789,416	475,915	298,068	424,160	83,414	565,515	212,917	7,096,035	6,091,316	3,383,815

Source: NBN [126]

3.1.3 COMMUNICATION SATELLITES

Communication satellites become increasingly prevalent as satellites miniaturize, and become cheaper to build and launch. It is estimated that the developing world will be connected to the internet within the next decade via LEO communication. Figure 73 shows a range of selected communication satellite constellations.

FIGURE 73: COMMUNICATION SATELLITES

Selected satellite telecommunications constellations in lower and medium Earth orbit

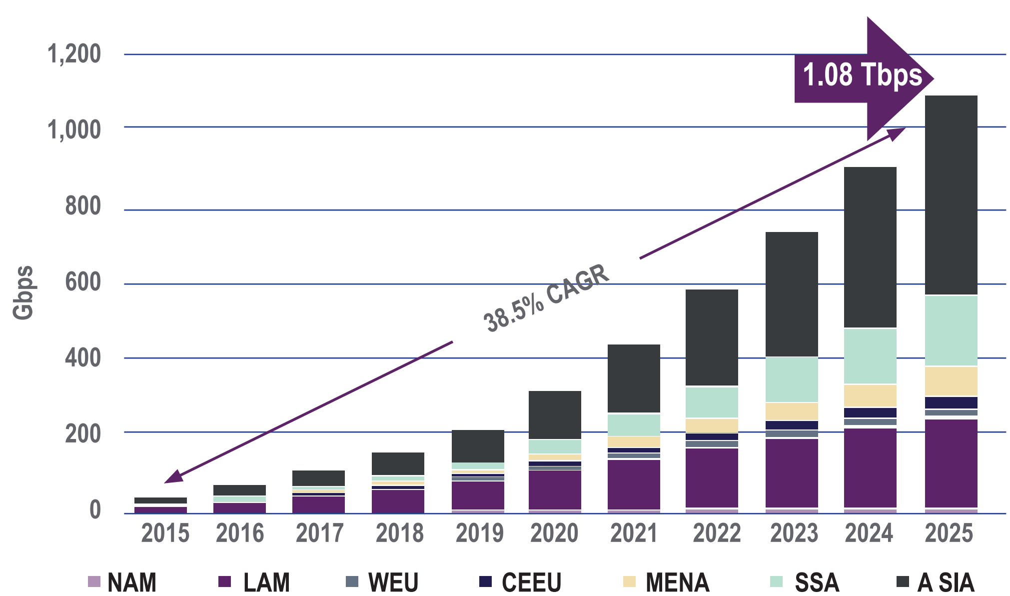
System/ operator	Status	Number of satellites	Orbit[1]	Main applications (radio spectrum frequency)
ORBCOMM	Operational	30	LEO	Narrowband data communications (e.g. e-mail, two-way paging, simple messaging)
Globalstar	Operational	45	LEO	Wideband mobile voice telephony and data services (L- and S-band)
Iridium	Operational	71	LEO	Wideband mobile voice telephony and data services (L- and S-band)
O3B (SES)	Operational	12	MEO	Broadband high-speed data services (Ka-band). Cellular backhaul and trunking, connectivity to mobile and maritime industries
One Web	Planned launches in 2017-19	600-900	LEO	Broadband high-speed data services (Ka- and Ku-band). Direct customers, cellular backhaul and enterprise connectivity to mobile and maritime industries
SpaceX	Uncertain (launch within five years)	4 000	LEO	Broadband high-speed data services (spectrum not yet allocated)
Boeing	Uncertain (filed for FCC license in June 2016)	1 300-3 000	LEO	Broadband high-speed data services N- and C-band)
Leosat	Uncertain (feasibility study with Thales Alenia Space)	80-120	LEO	Broadband high-speed data services

1. LEO: low-Earth, orbit (160 krn-2 000 km altitude), MEO: medium-Earth orbit (2 000 km-35 000 km altitude).

Source: OECD [127]

Northern Star Research estimates the Global Satellite Backhaul Capacity demand to grow by CAGR 38.5% for the decade until 2025.

FIGURE 74: GLOBAL COMMUNICATION SATELLITE BACKHAUL DEMAND



Source: NSR [128]

3.1.4 ALTERNATIVE NETWORKS

The rapid increase in data traffic creates enormous demands on networks. Low Power WANs (LPWAN) networks are dedicated to the Internet of Things. As the number of 'things' that need to be connected challenge the conventional mobile networks, LPWAN is essential for smart cities to be operated in a cost-effective manner [129]:

- NB-IoT: backed by Huawei, Nokia, Ericsson, Cisco Jasper, and the mobile operators. This runs on top of the existing mobile networks.
- LoRa: Unlicensed spectrum that is inexpensive to deploy. It can be used to cover specific cities, but some operators are deploying nationwide networks (e.g. KPN in the Netherlands, SK Telecom in Korea, Tata Comms in India).
- Sigfox: French startup that uses an alternative unlicensed spectrum. Their model requires that a Sigfox Network Operator (SNO) be created to deploy a nationwide network, with 32 countries deployed to date and they will hit 60 countries in 2018. This is a good "global" alternative.

Subject to the distance and amount of data that need to be transported the most common networks are:

FIGURE 75: NETWORKS

Standard	Frequency	Range	Data Rates
Bluetooth 4.2 core specification	2.4GHz (ISM)	50-150m (Smart/BLE)	1Mbps (Smart/BLE)
ZigBee 3.0 based on IEEE802.15.4 **Z-Wave Alliance ZAD12837 / ITU-T G.9959**	2.4GHz 900MHz (ISM)	10-100m 30m	250kbps 9.6/40/100kbit/s
6LoWPAN RFC6282	(adapted and used over a variety of other networking media including Bluetooth Smart (2.4GHz) or ZigBee or low-power RF (sub-1GHz)	N/A	N/A
Thread, based on IEEE802.15.4 and 6LowPAN	2.4GHz (ISM)	N/A	N/A
WIFI Based on 802.11n (most common usage in homes today)	2.4GHz and 5GHz bands	Approximately 50m	600 Mbps maximum, but 150-200Mbps is more typical, depending on channel frequency used and number of antennas (latest 802.11-ac standard should offer 500Mbps to 1Gbps)
Celluar GSM/GPRS/EDGE (2G), UMTS/HSPA (3G), LTE (4G)	900/1800/1900/2100MHz	35km max for GSM; 200km max for HSPA	(typical download): 35-170kps (GPRS), 120-384kbps (EDGE), 384Kbps-2Mbps (UMTS), 600kbps-10Mbps (HSPA), 3-10Mbps (LTE)
NFC ISO/IEC 18000-3	13.56MHz (ISM)	10cm	100–420kbps
Sigfox	900MHz	30-50km (rural environments), 3-10km (urban environments)	10-1000bps
Neul	900MHz (ISM), 458MHz (UK), 470-790MHz (White Space)	10km	Few bps up to 100kbps
LoRaWAN	Various	2-5km (urban environment), 15km (suburban environment)	0.3-50 kbps.

Source: DesignSpark [130]

3.2 SENSOR NETWORKS

3.2.1 INTERNET OF THINGS MARKET

Wireless sensor networks are a key enabler for the Internet of Things [131].

The Internet of Things market size is estimated to grow from USD $157.05 billion in 2016 to USD $661.74 billion by 2021, at a CAGR of 33.3% (2016 to 2021) [132]. Considerations for IoT are connectivity, security, data storage, system integration, device hardware, and application development.

Sensor networks rely on IT services and systems to talk to each other. Cisco's Jasper IoT network and Salesforce and Microsoft's IoT cloud services are examples. These Mesh APP and Service architectures (MASA) are expected to generate USD $661.74 billion by 2021, predicts Markets and Markets [133].

A comprehensive list of companies in the Internet of Things landscape can be found in reference [134].

3.2.2 SENSORS

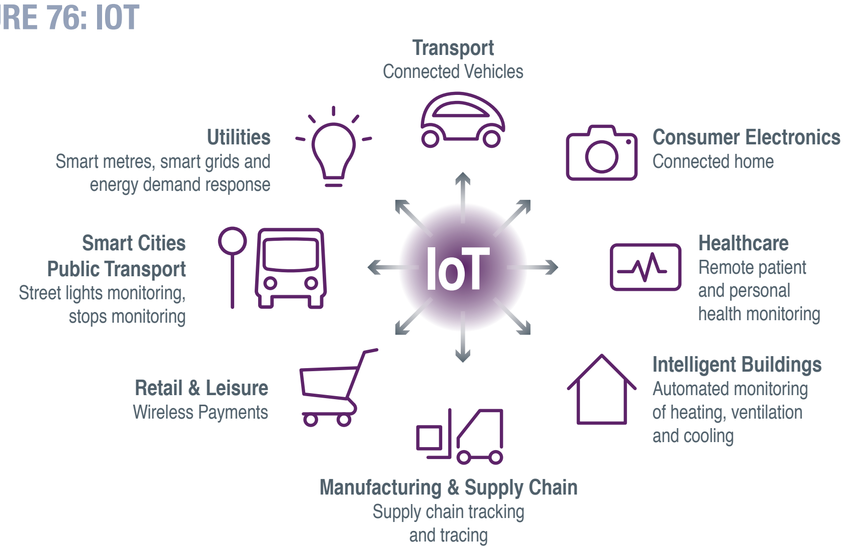
Sensors are essential in enabling smart cities, smart transport, smart infrastructure, and brain-computer interfaces amongst many other uses. It is estimated there will be 75 (IHS) -100 (CISCO) billion connected devices in 2025. Most devises will be invisible, embedded into physical objects, or worn on the body as part of clothing, jewellery. An example of a sensor application in clothing is produced by Auckland-based IMeasureU, a solution for elite athletes that provide insights into training and performance. It is likely that over the next few years more and more sensors will be implanted in the body, to shift medicine from reactive to proactive [135].

Sensors will develop further to use advanced technologies, such as optical frequency comb technologies; i.e. the SCOUT program detects multiple types of substances such as chemical (i.e. explosives) or biological (i.e. human breath) agents, even at extended distances [136]. Sensor networks will partially compute data at the site of the sensor and connect to cloud computing capabilities. Computing in the next decade will include optical, Quantum [137] and DNA [138] computing increasing facilitated by machine learning and artificial intelligence.

3.2.3 SENSOR NETWORKS EXAMPLES

Sensor networks have many applications, as described in Figure 76.

FIGURE 76: IOT



Source: GSA [72]

FIGURE 77: EXAMPLES FROM SENSOR NETWORKS IN AGRICULTURE

NAME & TYPE OF PROJECT	PARTNERS INVOLVED	DATA COLLECTION	VISUALISATION MECHANISM	RETURN ON INVESTMENT
VINEYARD HEALTH MONITORING Switzerland	Dolphin Engineering with University and government funding input from scientific research institutes, engineers, vintners, disease experts	Sensors from Waspmote Plug & Sense! Smart Agriculture monitor air temperature, humidity, leaf wetness and rainfall	PreDiVine dashboard displays messages with predicted dates of insect pest activities; this allows the growers to make ready and apply insecticides precisely when needed	Improved grape quality, management, lower costs; advice on just-in-time intervention; extend system to other areas
VINEYARD HEALTH MONITORING Slovenia	Elmitel with help from European private and public start-up accelerators	Sensors from Waspmote Plug & Sense! Smart Agriculture that collect environmental data including temperature and soil humidity	Elmitel's eViti application combines Elmitel Sensing and Libelium technology for a complete Cloud-based solution for managing vineyards.	Growers are more confident as to the best time for spraying; as a result, spraying has been reduced by around 20 percent from the previous season
OLIVE TREE MONITORING Italy	Team Dev working with Assoprol Umbria, a consortium of Italian olive producers	Through Waspmote Plug & Sense! Smart Agriculture specific weather conditions in each plot such as temperature, humidity, rainfall, atmospheric pressure, wind direction and speed, soil moisture and leaf wetness were measured	Waspmote Plug & Sense! Sensor Platform is connected by Meshlium to a cloud service of ArcGIS Online, an ESRI geographic platform, that collects all data and geolocates them in maps. Software creates the model of fly diffusion based on weather conditions	Better control of olive fruit fly pest through understanding of growing and environmental conditions; technology investment recovered in the course of one year
TOBACCO PLANTS MONITORING Italy	TeamDev in partnership with farmer association	Sensors from Waspmote Plug & Sense! Smart Agriculture collect key parameters including ambient temperature, humidity, rainfall, atmospheric pressure, wind direction, wind speed, soil moisture or leaf wetness	Waspmote Plug & Sense! Sensor Platform is connected by Meshlium to a cloud service of ArcGIS online, an ESRI geographic platform, that collects all data and geolocates them in maps. All data converge in a software for mananaging tobacco's crops which is part of AGRICOLUS suite	Project provided guidance as to how to adapt conditions for growing tobacco in Europe, as well as growing to comply with EU regulations to reduce toxicity to smokers
COCOA PLANTATION MONITORING Indonesia	Singapore-based solution provider in conjunction with various researchers and scientists located remotely. The project was part of Indonesia's Sustainable Cocoa Production Program	Temperature, humidity, photo-synthetically active radiation (PAR) and soil water potential were monitored through Waspmote Plug & Sense! Smart Agriculture	Because Internet connectivity in the rural site was unreliable, the collected data were sent to the Cloud for off-site researchers and collaborators to visualise and analyse the data from the on-going experiments	Project showed multiple Benefits including such as reducing visits to remote site, developing pest resistant cocoa, rehabilitation of old trees and counteracted deforestation
STRAWBERRY PLANT MONITORING Italy	Famosa, specialist in crop management, worked with farmers growing strawberries in greenhouses	Sensors from Waspmote Plug & Sense! Smart Agriculture collect temperature and soil water content	The Web service portal esiFarm is the solution that combined collection and monitoring of parameters; both were connected via wireless system	Some of the benefits were losses reductions and better fruit quality; savings of money and energy; reducing water daily supply up to the 30% after planting and around the 15% during harvesting; more rapid time to market and constant production made possible stable pricing of the fruit
ENVIRONMENTAL IMPACT IN WASTEWATER IRRIGATION AREA Australia	AJ Bush Meat Manufacturer commisioned Pacific Environment to provide sensor network in a wastewater irrigation area	Soil moisture was measured through Waspmote Plug&Sense! Smart Agriculture and electrical conductivity, temperature and dissolved oxygen through Waspmote Plug & Sense! Smart Water	EnviroSuite software platform comprising monitoring, forecasting and reporting tools converted data into information as to what was happening in the soil and waterways	The real time system enabled effective management of operations and adherence to compliance processes The investment was recovered in 18 months, through reduced grab monitoring, improved labour efficiencies and laboratory costs and waiting time

Source: Beecham Research [139]

Figure 77 shows several application examples in agricultural case studies.

To enable the Internet of Things in remote Australia, current technologies need to be upgraded further. Communication equipment for connections is too bulky and power-hungry for most applications. The Australian company Myriota is developing an affordable solution that uses low-earth orbit satellites for two-way data connectivity, utilizing miniaturisation and low power operation. This makes IoT applications far more viable for remote rural Australian farm uses [140].

3.3 VISUALISATION AND INTERFACES

3.3.1 AUGMENTED REALITY

Augmented Reality (AR) overlays the real world with digital data. Typically, this is achieved by using a smartphone screen to overlay digital information on real-world cues (places, patterns, sounds etc.). Mid 2016, the game 'Pokémon go' created substantial awareness for location-enabled augmented reality applications. For augmented reality uses to become truly transformative they need to be coupled with smart wearable technology- eyewear.

Augmented reality wearable devices are an interface that enables interaction with a smart world. But according to Gartner's Hype Cycle (Figure 4) of emerging technologies, augmented reality is currently in the trough of disillusionment.

Much noted Google Glass ceased sales to the public in 2015 (but is now again available for commercial applications), and the currently available glasses (ODG, Vuzix, Sony, Recon Jet etc.) are considered so ugly by some that they are unsuitable for daily wear for the majority of the population. Intel has developed 'Vaunt' smart glasses and it is anticipated for developers to have access in late 2018. Innovega ioptic (combined smart contact lenses and glasses) and Magic Leap (which attracted USD $1.4 billion in venture capital funds [20]) are much talked about, but their products are still unavailable to the consumer market. Microsoft's HoloLens (holographic computing) might have potential in the future, but to date is still bulky and the current developer version disappoints in normal daylight settings. Apple purchased augmented reality glass manufacturer Metaio and is preparing for the time 'after the screens'; yet to date no AR system that would have technical performance and social acceptance is on the market. Thus the transformative augmentation of the real world with digital data appears held back by the lack of available consumer-focused smart eyewear.

3.3.2 VIRTUAL REALITY

Virtual Reality (VR) is fully immersive; typically, users strap on virtual reality goggles, headsets and stay in a confined space. Applications reach from gaming to scenario exercises for real-world missions. Virtual reality can play a significant role in spatial data visualization and will see exponential uptake by users in the next few years. Spatial applications to date include Google Earth (truly impressive in VR), visualization of 3D city models, architectural plans, geological models and more. Hardware available to consumers for an immersive viewing experience (goggles with built-in head tracker functions) is more advanced than augmented reality glasses. VR devices include HTC Vive (about AUD $1400), Oculus Rift, and PlayStation VR. There are also basic contraptions on the market that turn a smartphone into virtual reality goggles (i.e. Google cardboard, under AUD $15).

Business Insider Intelligence estimates VR head-mounted displays growth to have a CAGR of 99% between 2015- 2020 driven by the rapid adoption this technology will see.

Creating a virtual reality experience once required considerable time and programming knowledge. The rise of Virtual Reality Modelling Language (VRML) standards, together with software tools has advanced the field. Autodesk Stingray now has a one-button rendering to Revit. BIM, CAD or GIS models allow VR visualisation via the Gaming engines 'Unity' or 'Unreal'. Another tool is Fuzor, that also instantly transforms a Revit or Sketchup model into a virtual reality experience. Esri's CityEngine allows users to create VR visualisation (VRGIS) without programming [141]. A paper by Boulos describes the wide range of applications for virtual reality GIS (VRGIS) and augmented reality GIS (ARGIS) [142].

3.3.3 VIRTUAL SENSING

Research is also working on virtual 'senses'. The Virtual Human Interaction Lab at Stanford University is investigating VR and the use of smell on the perception that people have of food. Japanese company Vaqso has designed an odor-emitting attachment for VR headsets. Olorama offers a wide range of smells, a dispenser, and software to synchronize smells with the VR experience. Feelreal has hot air, and water mist experiences in the sensory VR mask, as well as scents. Even taste buds can be tricked into thinking that one has a cocktail when only consuming water [143].

Advances in sound transfer will see more of bone conduction speakers, i.e. headsets or via glasses/sunglasses. 'Sgnl' Bluetooth connected wristband enables users to hear callers of mobile phones by simply holding a finger to the ear. 'Orii' is a smart ring with similar capabilities. Another sound technology: directional speakers, paired with face recognition, directing sound only to the listener's ears (i.e. by Noveto [144]).

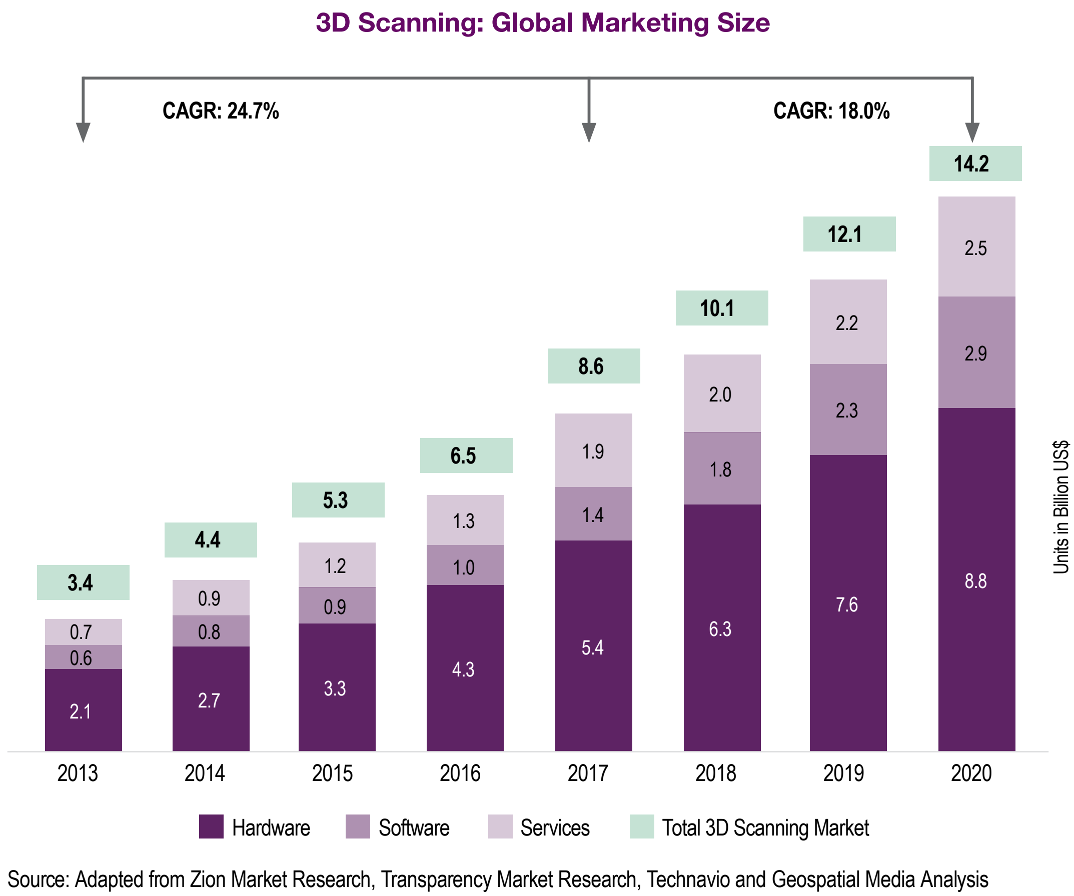
Tools such as VR, AR and holographic projectors will become compelling for users in the Virtual Worlds of the future. The next decade will see a great shift away from keyboards and screen-based interaction; augmented and virtual reality will be fully operational and an essential tool for most jobs, as well as for how we play and live. Computer inputs will be either automatic through the use of sensors, or by voice, gestures, and even thoughts. It is anticipated that Holographic telepresence is becoming more and more widely accepted, and promises to be transformative to how people interact, live and travel. Computers and input interfaces will become invisible, and 'part of us', i.e. in our jewellery ring or glasses [145], [146].

3.4 SCANNING AND MAPPING SYSTEMS

3.4.1 3D SCANNING

3D scanning technology captures a 3D representation of physical objects. It is used in digital mapping, architecture, construction, engineering, precise manufacturing, and autonomous systems. It is growing with CAGR 18% from 2017- 2020 and expected to then reach a global market size of USD $14.2 billion. Figure 78 shows the market development over time until 2020 [25].

FIGURE 78: 3D SCANNING GLOBAL MARKET SIZE



Source: Geospatial Media and Communications [25]

3.4.2 MOBILE MAPPING

Mobile mapping systems are driven by the need for bulk data generation derived from 3D modelling and LIDAR technology. They provide accurate and time-saving data capture for assets and inventory management. It is expected to grow from USD $10.28 billion in 2015 to USD $39.8 billion in 2022 (CAGR 21.3%) [147].

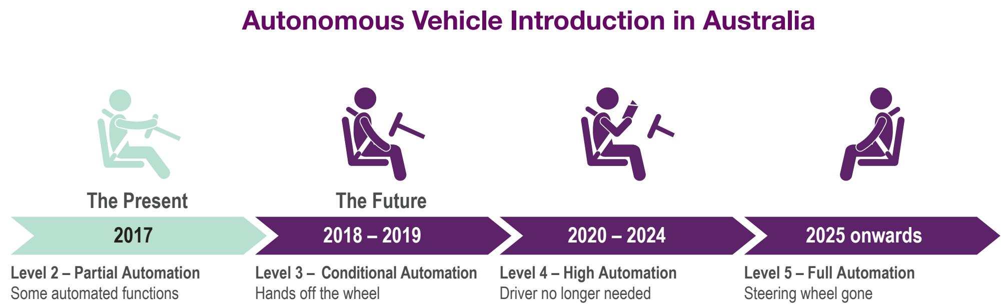
3.5 AUTONOMOUS TRANSPORT

3.5.1 AUTONOMOUS CARS

Self-driving cars and surrounding infrastructures (location being one of them) are now so advanced that technically level 5[4] fully autonomous vehicles can be operated. In February 2018 the Victorian Government passed a law [148], [149] to allow permits for fully autonomous cars on certain roads under test conditions following the lead of South Australia which gave permission in June 2016. A nationally consistent legislative model is expected to allow autonomous vehicles on roads within the next two or three years (Figure 79). More than 700 laws and regulations need to be amended [150].

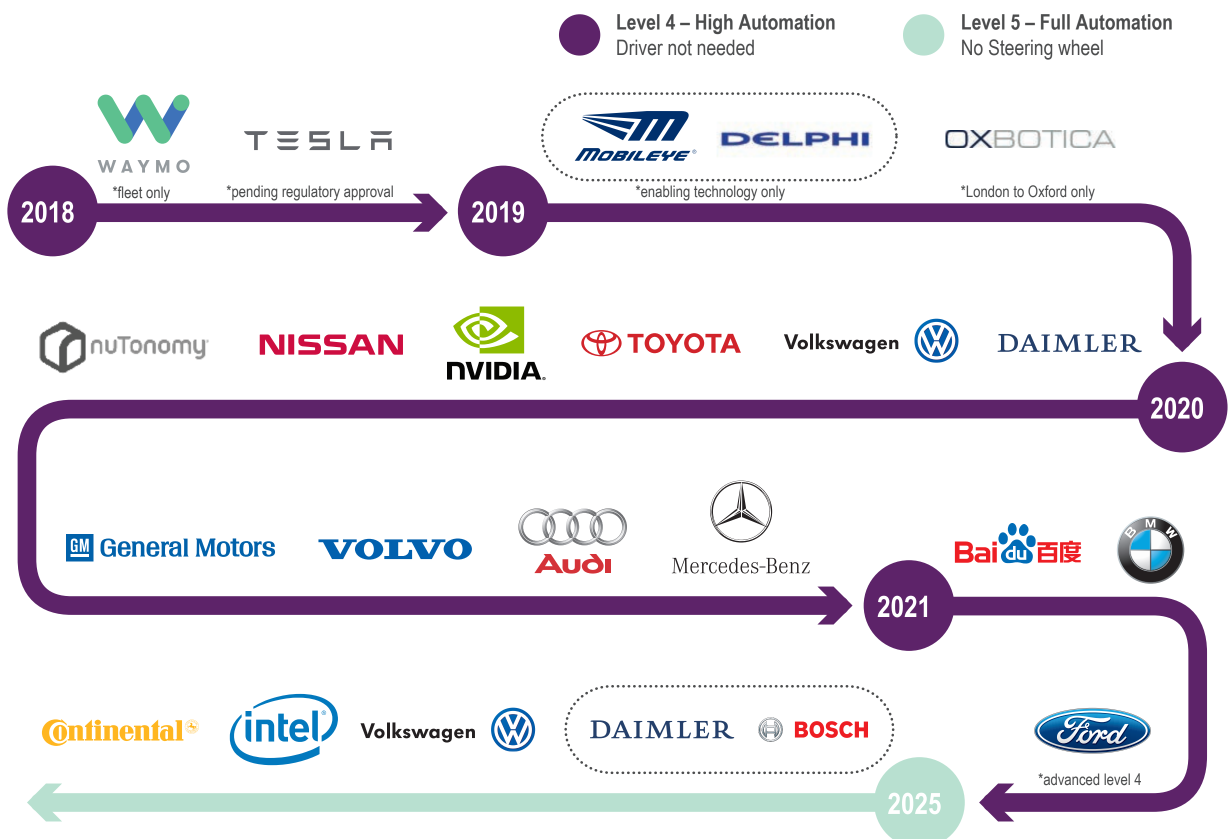
[4]Level 5 is the highest level in autonomous cars with complete automation. Cars are fully self driving and require no human attention.

FIGURE 79: AUTONOMOUS VEHICLE INTRODUCTION IN AUSTRALIA



Source: NRMA [150]

FIGURE 80: TIMELINE TO FULL CAR AUTOMATION



Source: NRMA [150]

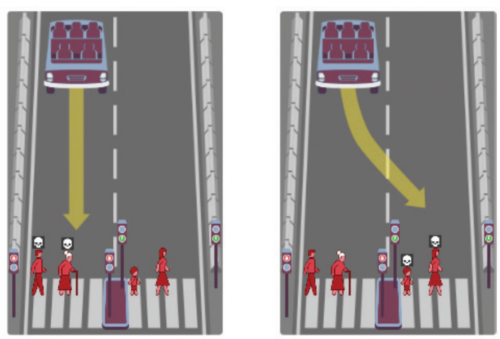
Vehicles that need no drivers are expected to be commercially available in the 2020s [148]. Figure 80 gives a roadmap to full automation including involved companies.

To be widely adopted, the population needs to be comfortable with driverless cars on the road. The tolerance of the public for a person being killed by robotic vehicles (autonomous vehicle) is very low [151]. With the widely reported first death[5] caused by a self-driving car (one of Uber's) in Tempe, Arizona, USA, there will be detailed investigations that may result in regulatory modifications and perhaps changes to public perception. Figure 81 shows ethical dilemmas that will need be solved by in-charge machines in the future, possibly including choosing which lives to sacrifice in conflicting situations.

Transport has become safer with autosteer (see Figure 82), with Tesla vehicle accidents dropping by 40%. It is essential that connected, autonomous vehicles are safe, and cannot be manipulated by hackers. Software 'upgrades' for the rich (which ensure that their vehicle always has the optimal accident outcome at the expense of others) need to be technically impossible.

FIGURE 81: CRASH ETHICS

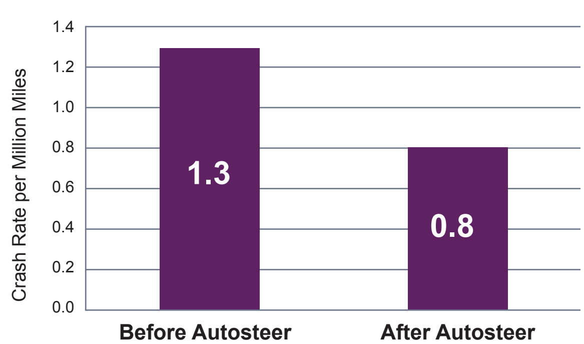
What should the self-driving car do?



Source: Myers [152]

FIGURE 82: CRASH STATISTICS RELATED TO AUTOSTEER

Tesla Crashes Drop 40% With Autopilot installed



Crash rates in model years 2014-2016 Model S and Model X vehicles

Source: Randall [153]

[5] A self driving car fatally injured a cyclist on 18 March 2018

3.5.2 DRONES

Drones[6] can play a significant role in socially beneficial developments; however, there is concern that the public might reject drones due to their association with military applications [154].

Challenges for drone uptake:

- More flexible 'beyond visual line of sight' regulations
- Harmonised legal regulations across countries
- Integration of drones with manned aircraft in non-segregated airspace
- Advanced Detect & Avoid (DAA) technologies
- Robust Command & Control (C2) communication links
- Implementation of Concept of Operation (CONOPS) proportionate to the risk of an operation
- Improved airworthiness
- Pilot training (certification, international recognition)
- Contingency aspects

It was suggested to enhance drone safety to have [155]:

- operators self-registration on a web-based application
- chip, SIM-card, transponder installation on the platform
- standardized tools to inform the public about local regulations and temporary restrictions
- registration and announcement of operations in controlled airspace
- mandatory insurances

In the USA drones weighing between 0.55 and 55 pounds need to be registered with FAA. [156], [157]

FIGURE 83: FAA DRONE REGISTRATION AGREEMENTS

Acknowledgement of Safety Guidance

I will fly below 400 feet

I will fly within visual line of sight

I will be aware of FAA airspace requirements: www.faa.gov/go/uastfr

I will not fly directly over people

I will not fly over stadiums and sports events

I will not fly near emergency response efforts such as fires

I will not fly near aircraft, especially near airports

I will not fly under the influence

---

[6] Are also known as Remotely Piloted Aircraft (RPA) or Unmanned Aerial Vehicles (UAV's) or Unmanned Aircraft System (UAS). These terms are often used interchangeably.

There are issues around controlling potentially harmful drone payloads. The company Droneshield provides anti-drone solutions [158]. In the USA Verizon is partnering with PrecisionHawk, Digital Globe and Harris Corporation's nationwide automatic dependent surveillance-broadcast network to build a system that can track drones, apply geo-fencing and help with obstacles via the Verizon cell towers [159]. There are also still major issues regarding the integration of drones into the National Airspace. The Joint Authorities for Rulemaking for Unmanned Systems (JARUS) (Australia is a member thereof) has several working groups, addressing issues such as:

- WG 1 – Flight Crew Licencing
- WG 2 – Operations
- WG 3 – Airworthiness
- WG 4 – Detect and Avoid
- WG 5 – Command and Control
- WG 6 – Safety and Risk Management
- WG 7 – Concepts of Operation

The table in Figure 84 lists conditions for drones in various countries. However, there are many legal changes being worked on, i.e. the Australian Senate referred a drone law review to the Rural and Regional Affairs and Transport References Committee for inquiry and report by April 2018 [160].

FIGURE 84: PARAMETERS FOR DRONES IN SELECTED COUNTRIES

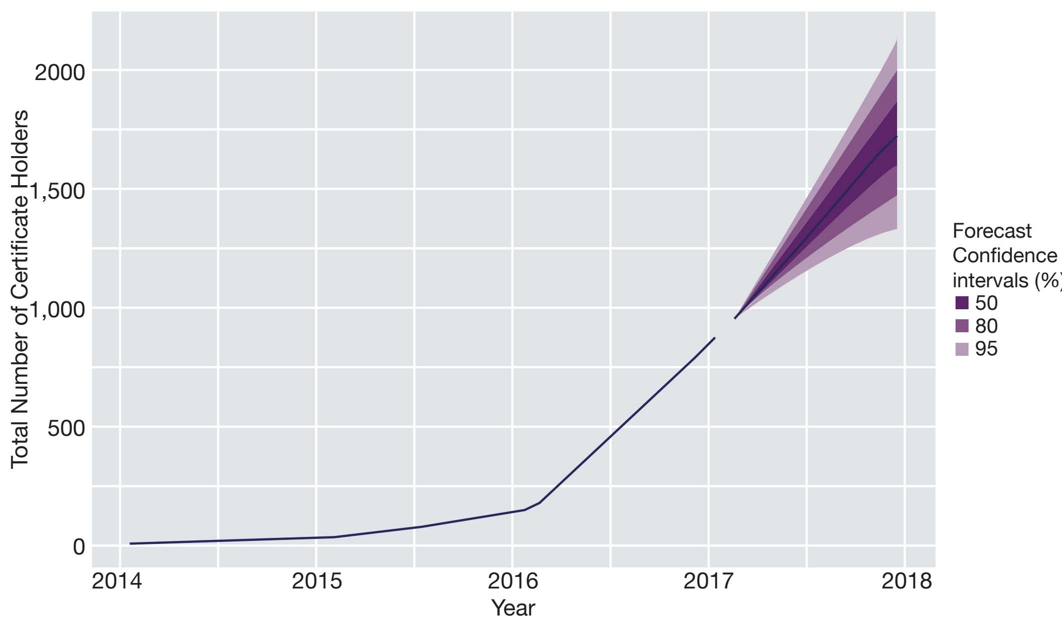
Applicability				Technical Requirements		Operational Limitations (Distances)							Administrative Procedures			
Country Issued and/or Last Updated	Applicable for MA/UAVs	Classification (Weight, Purpose, Area, Visibility)	Weight Limits(Max)	Special Technical Requirements	Collision Avoidance Capability	Airports/ Strip	People	Congested Areas	Additional	Max Height	VLOS/Lateral Distance	BVLOS	Application and Operational Certificate	Need for Registration	Insurance	Qualification of Pilots
United Kingdom 05/2002 03/2015	MA/UAV	W,P	7/20/ 150 kg		for special operations		50m	150m	N/A	122m	500m, EVLOS possible	need for special approval	various approval requirements for different flight operations	N/A	N/A	pilot competency
Australia 07/2002 09/2016	MA/UAV	W,P	2/25/ 150 kg	N/A	N/A	5.5km	30m		emergency situation	120m		need for special approval	>2/25kg	N/A	recommended	license>2 kg
Malaysia 02/2008	no distinction	W,P	20kg	Request equivalent level of compliance with rules for manned aircraft			N/A	N/A	N/A	122m		if ATC capable	flight authorization and air worthiness certification	>20kg		license for pilot and commander
United States 08/2008 06/2016	MA/UAV	W,P	0,25/25/ 150 kg	N/A	N/A	8km		N/A	N/A	122m	EVLOS possible	need for special approval	>25kg	registration number	depending on purpose	certificate
Canada 2010 05/2015	MA/UAV	W,P	2/25kg	N/A	>25kg	9km	150 m		forest fires	90m		N/A	>25kg	N/A	depending on weight	pilot competency
France2012 12/2015	MA/UAV	W,A,V	2/8/ 150 kg	>2kg	in populated areas and BVLOS		not over crowds	N/A	emergency situation	150m	100m/200 m/EVLOS		for specific operation procedures	depending on flight scenario		depending on flight scenario
The Netherlands 2012 07/2016	MA/UAV	W,P	1/4/25/ 150 kg	N/A	N/A	nofly zones	50m		moving cars	120m	100/500m	N/A	operational certificate			license
Germany 12/2013 07/2016	UAV	W	10/ 25 kg	>10kg	May help toget BVLOS permission		not over crowds	N/A	emergency situation	100m		need for special approval	general permission, single operational approval for >10–25kg	N/A		pilot competency
Italy12/2013 12/2015	UAV	W,A	2/25/ 150 kg	For critical flights	N/A	5km	50m	150m	N/A	150m	500 m/EVLOS	in segregated airspace	for critical operations and/or>25kg	plateand electronic ID		0–25kg certificate, >25kg license
Austria 01/2014 08/2015	no distinction and if > 500m from pilot	W,A	5/25/ 150 kg	depending on scenario	depending on scenario		not over crowds	N/A	N/A	150m		need for special approval	general permission, single approval for risky operations	registration needed		depending on scenario

Source: Stöcker [161]

In Australia, commercial drone pilots need a Part 101 UAS operator certificate. It is interesting to note the increase of certificates issued by CASA (See Figure 85).

FIGURE 85: NUMBER OF CASA DRONE OPERATOR CERTIFICATES

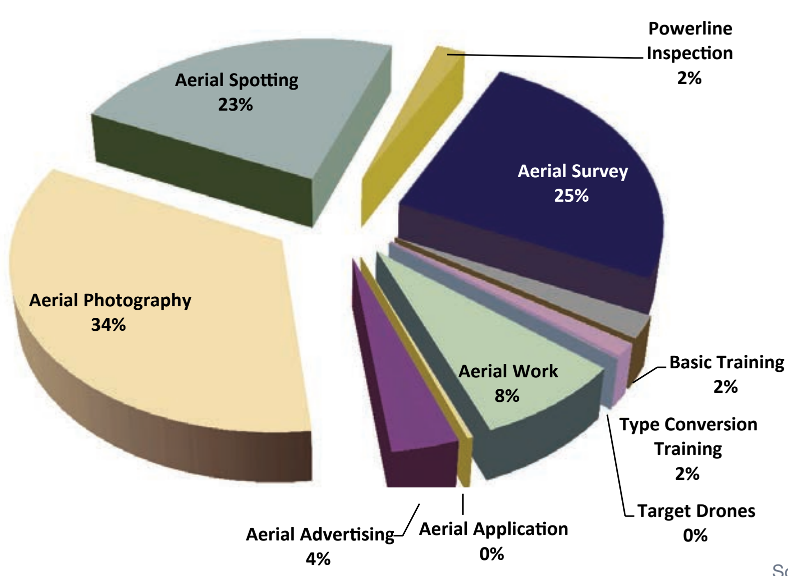
Total Number of CASA registered RPAS certificate holders (Jan 2014 to Jan 2017). The purple regions are the 50th, 80th and 95th per cent confidence intervals for the forecasts (up to December 2017) calculated using the weighted average of ARIMA and exponential smoothing state space models



Source: ATSB, 'A safety analysis of remotely piloted aircraft systems: A rapid growth and safety implications for traditional aviation 2012 to 2016'.

A list of companies with RPA's certificates can be found on CASA's website [162].

FIGURE 86: USES OF COMMERCIAL DRONES

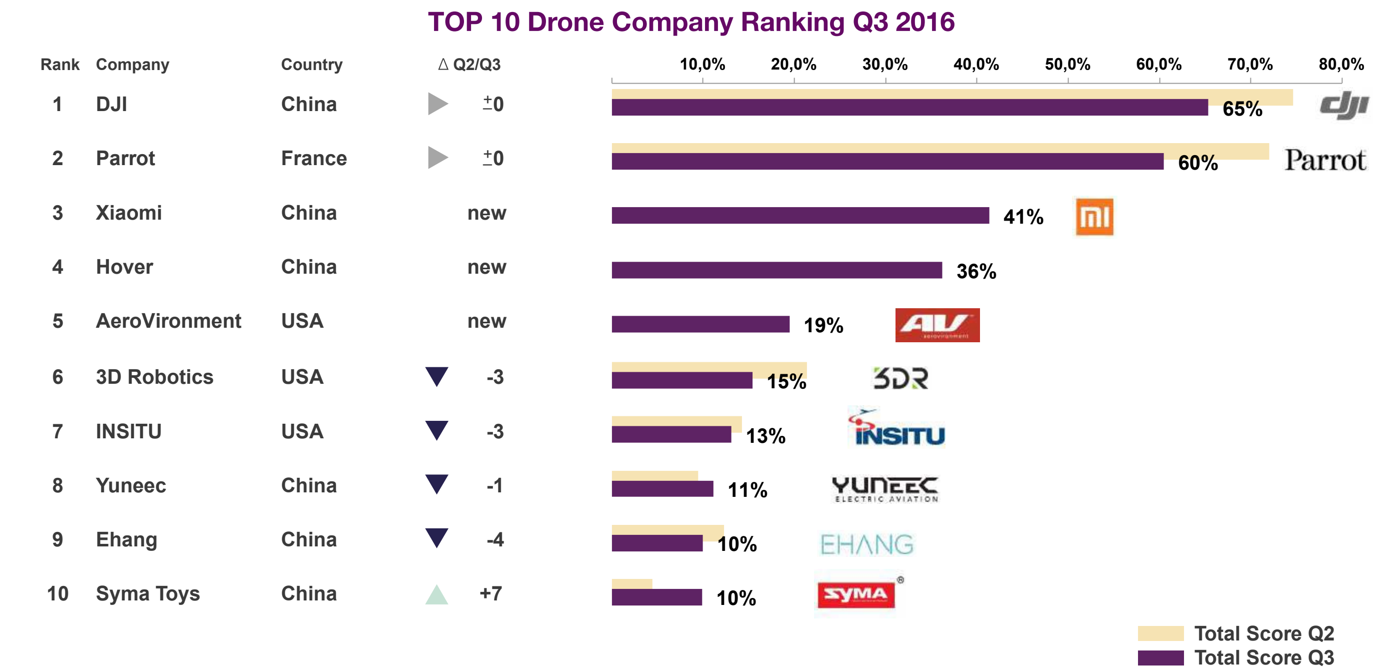


Source: CASA [163]

Figure 86 shows the drone application uses registered with CASA.

The following graph (Figure 87) looks at the drone ecosystem, assessing the top ten platforms; a summary of drone partnerships, investments and acquisitions are detailed in a further report by Droneii in [164].

FIGURE 87: TOP 10 DRONE COMPANIES (Q3/2016)



Sep. 2016, Sources:
Number of Google searches: How often people search for the companies on Google in conjunction with “drone” and “UAV”;
Number of News items: How often newspapers and blogs mention the companies in conjunction with “drone” and “UAV”;
Number of Drone Company employees: How many company employees carry the tag “drone” or “UAV” on LinkedIn;
The highest scoring company in each dimension receives a rating of 100%, with all other drone companies receiving a lower percentage in linear relation to the score of the highest ranking company. The total score is an average of all four measured dimensions. A company can reach an index of 100% if he leads all considered sources.

Source: Droneii [165]

Amazon has a patent for an ‘intermodal vehicles, facilitating last mile delivery’; these are in effect drone launching shipping containers, which can be moved around by truck, train, and trailer [166].

Express delivery of life-saving medicines, blood and devices are most likely to pave the way for drone deliveries to become part of normal modern life. The applications are being tested around the world, for example, Zipline delivering urgent medical supplies in Rwanda (overcoming complications of poor road infrastructure) [167]. Matternet is delivering medicines in remote areas in Switzerland [168]. In a three-month trial in 2017, Australian Chemist Warehouse tested deliveries of over the counter medicines in Royalla [169].

3.5.3 FLYING CARS

Flying cars have been a science fiction dream for a very long time. Gliding above congested roads is what many frustrated commuters hope to soon be a reality. As far back as 1926, Henry Ford was working on a Model T of the air, (Air Flivver/ Aircar) which due to crashes and death of key personnel did not go beyond prototype into production. With the advances in positioning technology, AI and vehicle technology (including electric batteries) it is expected (i.e. by Zach Lovering, the leader of Airbus Project ‘Vahana’) that the transport industry will be revolutionised in as little as 10 years [170]. Figure 88 gives an overview of selected flying vehicles.

FIGURE 88: OVERVIEW - FLYING CARS

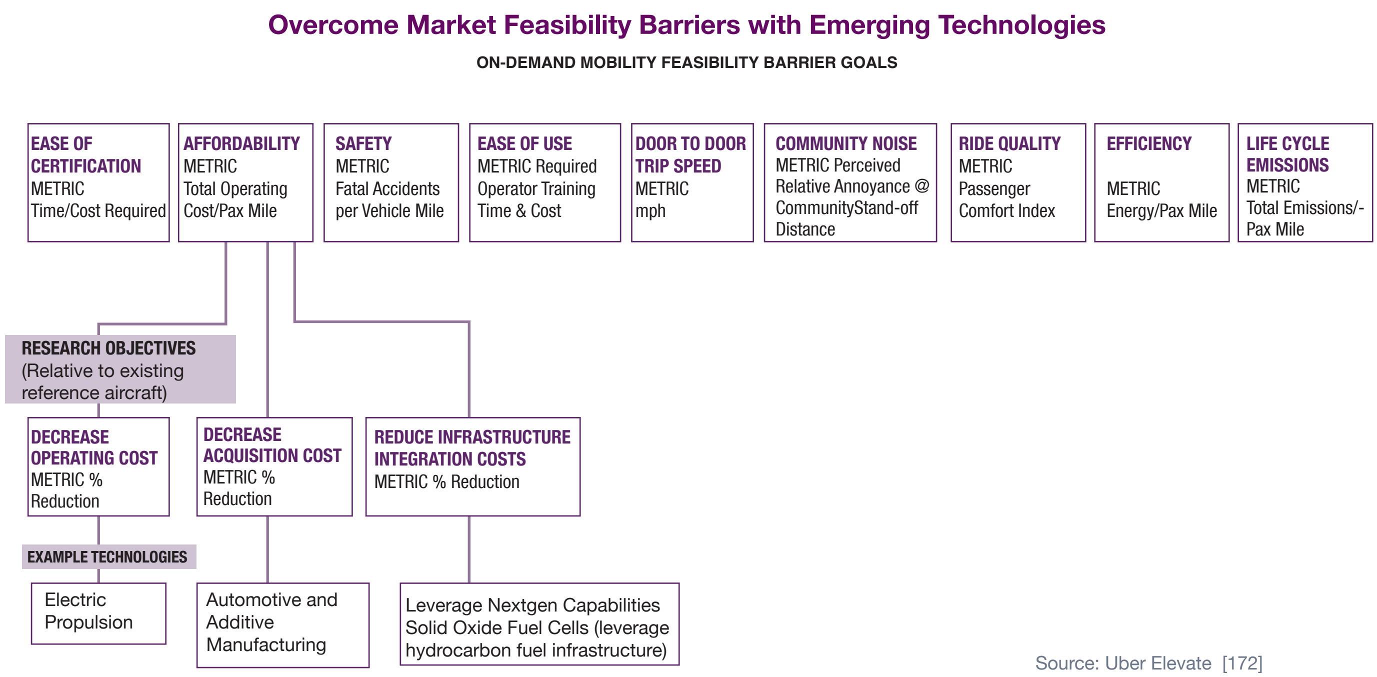
Country	CHINA	FRANCE	FRANCE	GERMANY	GERMANY	SLOVAKIA	USA	USA	USA	USA	USA	USA
Company	EHANG	AIRBUS	PAL-V	E-VOLO	LILIUM	AEROMOBIL	AIRBUS	AURORA FLIGHT SCIENCES	JOBY AVIATION	MOLLER INT.	TERRAFUGIA	ZEE.AERO
Name	184	PopUp[1]	Pal-V	Volocopter V200	Lilium	Flying Car	Vahana	eVTOL	S2	Skycar	Transition	Zee
Project started in	2014	2016	2001	2012	2014	2010	2016	1989	2009	1983	2006	2010
Funding [Mio USD]	52	undisclosed	-	1.2	11.4	3.2	undisclosed	15	undisclosed	undisclosed	5.56	100[2]
Investors	GGV Capital	undisclosed	-	Crowdfunding	Atomico	Patrick Hessel	undisclosed	Enlightenment Capital	undisclosed	undisclosed	Transendent Holdings	Larry Page
VTOL[3]	✓	✓	✓	✓	✓	-	✓	✓	✓	✓	-	✓
Battery	✓	✓	-	✓	✓	-	✓	✓	✓	-	✓	✓
Gasoline	-	-	✓	-	-	✓	-	-	-	-	✓	-
Hybrid[4]	-	-	-	-	-	-	-	-	-	✓	-	-
Prototype + Permit	✓	-	✓	✓	✓	✓	-	✓	-	✓	✓	✓
Number of rotors	8	4	2	18	36	1	8	9	12	4	1	5
Max. speed [km/h]	100	?	180	100	300	360	?	?	320	450	185	?
Max. range [km]	30	?	350	100	300	750	200	?	320	850	640	?
Seats	1	2	1	2	5	2	1	2	2	2	2	2

[1] Airbus PopUp: represents an extensive mobility concept not a sole flying platform
[2] Source: Bloomberg – “welcome to Larry Pages secret flying car factories”
[3] VTOL: Vertical Takeoff and Landing – all other platforms require a runway/airport
[4] Hybrid propulsion: electrically powered VTOL, gasoline powered horizontal flight April 2017

Source: Droneii [171]

Uber released a white paper in October 2016, detailing ‘Uber Elevate’ (on demand aviation service) [172]. Figure 89 gives an overview of the major barriers that need to be addressed.

FIGURE 89: UBER ELEVATE MARKET FEASIBILITY BARRIERS TECH SOLUTIONS



Source: Uber Elevate [172]

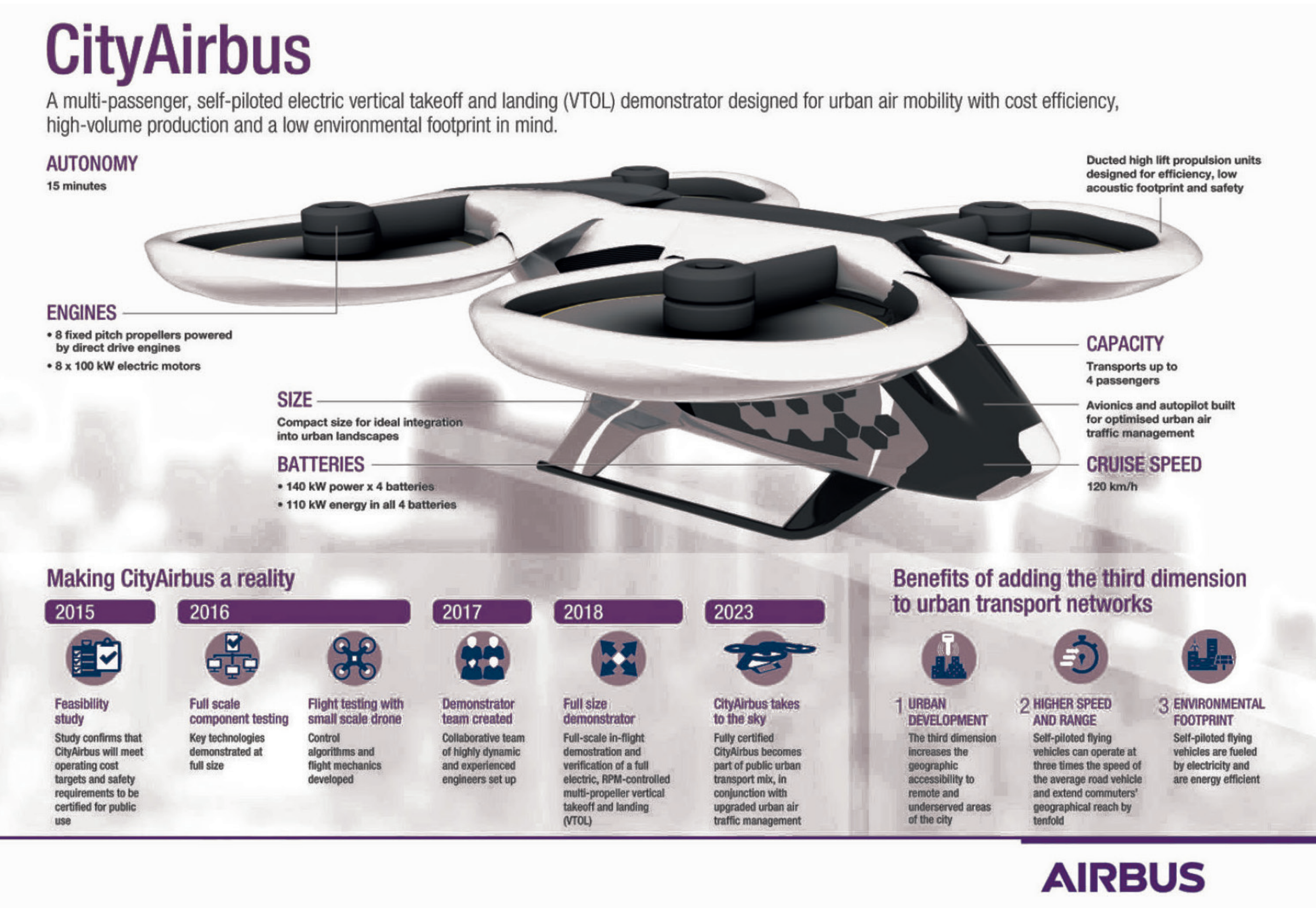
The city of Dubai permitted the first test flight of an uncrewed two-seater drone (from German manufacturer Volokopter), called ‘autonomous air taxi’ (AAT). Plans are to make the service available to the public via a smartphone APP:

Over the next five years, the RTA will collaborate with the UAE General Civil Aviation Authority and the Dubai Civil Aviation Authority to ensure that the operational requirements for implementing AAT services are put in place. These requirements include developing laws and policies governing certification of the aircraft and AAT operations at an Emirate and Federal level, defining aerial routes and corridors, designing and locating take-off and landing points, setting standards for official operators of AAT services in Dubai, identifying the roles and responsibilities of stakeholders, and specifying security and safety standards for the AAT [173].

Volokopter has a strategic partnership with Intel [174].

In October 2017 Airbus announced it was on track to put its flying taxi into the air by 2018. It can transport up to 4 passengers on short city trips at speeds of up to 130 km/h [175]. See Figure 90 for more on its concept.

FIGURE 90: AIRBUS FLYING TAXI CONCEPT



Source: Etherington [175]

In Paris, a 'flying water taxi' was tested mid-2017. Built by Seabubble, it glides 70cm above the water on four foils (up to 30km/h), has zero emissions and is powered by a solar-recharged electric motor. Founder Thebault hopes for Uber (already operating water taxis in Croatia) to engage with Seabubble to speed up Paris inner-city transport. The initiative is supported by the French government and the Mayor of Paris [176].

Shanghai UVS Intelligence System is planning to bring to market the first commercial drone (U650) that is able to take off and land on water; the 20-metre-long Chinese drone can stay in the air for up to 15hrs, fly up to 2000km and carry a maximum weight of 550 pounds of cargo. Uses are business and military applications [177].

4 DATA AND SMART SYSTEMS

4.1 SPATIAL DATA INITIATIVES

Noteworthy initiatives and proposals in Australia for spatial enablement are the Foundation Spatial Data Framework (FSDF), the Nation-wide Single Data Infrastructures (NSDI), the Australian Geoscience DataCube (AGDC) [178] and reforms to the datum (Figure 43) and land registries. Figure 91 details some of these initiatives as described in the Australian 2026 Spatial Industry Transformation and Growth Agenda [179]. The Action Plan for the 2026 Agenda has 32 initiatives including:

FIGURE 91: AGENDA 2026 SPATIAL INFRASTRUCTURES, PARTIAL INFORMATION OF PILLAR A

A1. Develop and publish a nationwide framework and roadmap setting out all major public spatial infrastructure developments and supporting analytical capabilities for the next five years

The framework will create nationwide collaboration and coordination, which will streamline processes and remove duplication. This initiative will identify priorities for investment and set a specific and coordinated plan for implementation of all proposed infrastructures.

Foundational Spatial Data Framework (FSDF)

- Foundation data is spatial data of national importance that supports evidence-based decisions across government, industry and the community. Current themes under which foundational datasets can be grouped are: geocoded addressing, administrative boundaries, positioning, place names, land parcel and property, imagery, transport, water, elevation and depth and land cover.
- This framework simplifies access to spatial data and allows for consistency across state borders to standardise data analysis across the country.
- The FSDF is needed to deliver national coverage of the best available, most current, authoritative source of foundation spatial data that is standardised and quality controlled. The FSDF is coordinated by ANZLIC.

Nationwide Spatial Data Infrastructure (NSDI)

- Today the nation has nine spatial data infrastructures (SDIs) being managed by the federal, state and territory governments, with a 10th being maintained by the PSMA. ANZLIC has estimated that the total annual expenditure on these 10 SDIs is $152 million involving 650 FTEs.

- It is estimated that a single nationwide SDI (NSDI) may cost around one-third of current expenditure, potentially saving up to $50 million per annum. An NSDI would, in addition, facilitate needed transformations such as the move from the 2D environment to 3D, and the creation of a 4D cadastre underpinned by a coordinate system with a dynamic datum, to take into account the 7.5cm movement each year of Australia's tectonic plate.
- The future prospect of an NSDI is to deliver the capabilities required at a national level to underpin the property market through development of best-of-breed systems to collate and deliver the fundamental data services, analytics and knowledge required by organisations who operate borderless and do not have the ongoing flexibility to discover, access, integrate and generate the information they require, which is estimated to use 70% of a resources investment each time a national view of data is required.

Australian Geoscience Data Cube(s) (AGDC)

- Without satellites of its own, Australia is 100% dependent on overseas data capture to retrieve nation-relevant earth observation data. The Australian Geoscience Data Cube (Data Cube), a new approach for organising and analysing vast quantities of satellite imagery and other Earth observations, has made it quicker, easier, and more cost-effective to provide information on issues that affect all Australians.
- Scaling the current AGDC into a consistent national infrastructure for hosting, processing and analysing earth observation data, that is open and easily accessible to Australians would significantly increase the impact of earth observation on a range of sectors and provide greater benefits to Australian society.

Land Registries Reform

- Australia's residential property market is valued at $6.2 trillion and represents an under-utilised asset class which is ready to drive economic growth.
- The development of a National Land Registry Service Provider would align the current eight different land administration systems to create a national, digitally enabled land register that achieves annual recurrent savings of more than $250 million in the provision of land registry services, and avoids capital costs (estimated in more than $500 million) and risks in migrating land titling. This initiative would be linked to a cadastral reform.

Visualisation Engines and Globes

- Being able to properly visualise spatial data, and the information and knowledge derived from it is paramount to ensuring an accurate decision-making scenario is provided to customers and users.
- Globe technologies have considerable untapped potential for analysing and communicating knowledge on economic and development patterns, risk and hazards, human health, city and regional planning, and resource management.

Source: 2026Agenda

4.2 OPEN DATA

In 2017, Australia ranked first on the Global Open Data Index (GODI), that measures open data access.

FIGURE 92: OPEN DATA ACCESS INDEX GODI

Source: Open Knowledge Network, as quotes in [180]

In Australia, Geospatial datasets on data.gov.au and from other spatial indexes are now available through the National Map; here citizens can access geospatial information.

In the Australian state of New South Wales, the government is initiating "NSW Live" (with real-time data feeds) as an application that lets the public access developments in a real-time. Data feed allow discovery of "exactly what is going on across NSW on a map in real-time." The public will also be encouraged to contribute data to the platform which supports the NSW Government's spatially digital agenda. Other initiatives, such as dMarketplace, a sharing place for data, includes a rating scheme for data sources [181].

EuroGeographics, which represents National Mapping, Cadastral and Land Registry Authorities from the whole of geographical Europe, is providing its 1:1 million scale topographic open dataset, EuroGlobalMap, to assist the projects aim of compiling global administrative boundaries data from authoritative sources.

Governmental data are being combined with citizen produced data- i.e. social media, mobile phone, CCTV, drone, satellite and IoT data to give insights and produce early warning systems. For example, UAE extreme weather APP detects and predicts sandstorms, and in the Netherlands, the Police and Fire Department uses Twitcident to better respond to emergencies [182].

Radiant.Earth is an initiative aiming to connect people with earth observation and geospatial data, tools, and knowledge to solve the world's most critical challenges. In September 2017 a UN study found that 41% of disasters over the past two decades were caused by natural hazards in the Asia-Pacific region. Data61 have announced their intention to cooperate with Radiant.Earth by sharing existing resources, facilities and networks for real-time modelling, machine learning, and visualisation [183].

4.2.1 OPEN DATA CUBE

The objective of the open source Open Data Cube (ODC) is to increase the impact of satellite data by providing an open and freely accessible exploitation tool and to foster a community to develop, sustain, and grow the breadth and depth of applications [184]. Its key objectives include building the capacity of users to apply EO satellite data and to support global priority agendas, such as those found in the United Nations Sustainable Development Goals (UN-SDG) and the Paris and Sendai Agreements. The Open Data Cube (ODC) was born out of the need to better manage satellite data. It has evolved to support interactive data science and scientific computing. ODC will always be 100% open source software, free for all to use and released under the liberal terms of the Apache 2.0 licence.

Technologies such as the Australian Geoscience Data Cube (AGDC) and Google Earth Engine (GEE) have transformed the EO satellite data user community. In response to user demand, such technological solutions remove the burden of data preparation, yield rapid results, and foster an active and engaged global community of contributors. The Committee on Earth Observation Satellites (CEOS) is a founding partner of the Open Data Cube (ODC).

4.2.2 DIGITAL EARTH AUSTRALIA

Digital Earth Australia (DEA) builds on the Geoscience Australia Data Cube (supported by CSIRO, the National Computational Infrastructure (NCI), and the National Collaborative Research Infrastructure Strategy). In May 2017 it received an allocation of AUD $15.3 million in the federal budget. When completed it will provide 10 metres resolution image data nationwide permitting multi-temporal analyses throughout the stack of co-registered data for as far back as the imagery goes, which in the case of Landsat is to the 1970s for epochs of every 16 days. The NCI is a super-computer and ensures super fast processing. It is a world-leading analysis platform for satellite imagery and other Earth observation imagery [185].

Australia has been maintained excellent image repositories for decades. DEA is being used to unlock new insights about the changing Australian landscape and coastline, providing a ground-breaking approach to organising, analysing, and storing vast quantities of data. It facilitates access to businesses, researchers, and governments. To fully realise the benefits of DEA once operational, the platform and products will be open and freely available to any user [185].

4.2.3 FOUNDATION SPATIAL DATA

There are a number of countries and groups of countries that maintain foundation datasets including:

- The European Union INSPIRE Directive with 13 core reference data sets;
- The United Nations Economic Commission for Africa (UNECA) recommends 12 "candidate" fundamental datasets for Africa in its ‘Determination of Fundamental Datasets for Africa: Geoinformation in Socio-Economic Development’;
- ANZLIC (Australia and New Zealand Land Information Council) have recognised users’ recurring need for a defined number of spatial datasets, identifying 10 foundation data themes [186].

4.3 GLOBES

Keyser has built on previous work [187] and reports updates in a more recent Globe review paper [188]. A categorisation of 23 existing unique virtual globe platforms and some associated visualisation applications were assessed. Four virtual globes were included that are visualisation applications only. Figure 93 summarises the platforms, visualisation capability, whether they are open or closed source, their public availability and cost of access, if any. A summary of their operating system and capabilities is given in Figure 94.

FIGURE 93: GLOBES

	Unique Platform	Visualisation Application	Closed / Open Source	Public / Restricted Access	Free / Paid
1	Google Earth	Google Earth	Closed	Public	Free
		QLD Globe	Closed	Public	Free
		QLD G20 Globe	Closed	Public	Free
2	ESRI ArcGIS Earth	ArcGIS Earth	Closed	Public	Free
3	Bing Maps 3D	Bing Maps 3D	Closed	Public	Free
4	PYXIS WorldView Studio	WorldView Studio & Gallery	Closed	Public	Free & Paid
5	Cesium	Cesium	Open	Public	Free
		Australian National Map	Open	Public	Free
		Bhuvan-3D	Open	Public	Free
		QLD Cube Globe	Open	Public	Free
6	World Wind	World Wind	Open	Public	Free
		3D Data Viewer	Open	Public	Free
7	Marble	Marble	Open	Public	Free
8	SkylineGlobe	SkylineGlobe	Closed	Public	Paid
		Army Geospatial Enterprise (AGE) GeoGlobe	Closed	Restricted (US Army)	Restricted
9	EV-Globe	Unknown (Chinese)	Unknown (Chinese)	Unknown (Chinese)	Unknown (Chinese)
10	SuperMap GIS	SuperMap GIS	Closed	Public	Paid
11	Digital Earth Science Platform	Digital Earth Science Platform (DESP/CAS)	Closed	Restricted (Chinese Government)	Restricted
12	osgEarth	-	Open	n/a as platform only	Free
13	CitySurf Globe	CitySurf Globe	Closed	Public	Paid
14	Earth 3D	Earth 3D	Open	Public	Free (donations taken)
15	EarthBrowser	EarthBrowser	Closed	Public	Paid (cheap)
16	OpenWebGlobe	OpenWebGlobe	Open	Public	Free
17	Glob3 Mobile	Glob3 Mobile	Open	Public	Free
18	WebGL Earth 2	WebGL Earth 2	Open	Public	Free (donations taken)
19	VirtualGeo	VirtualGeo	Closed	Public	Paid
20	OssimPlanet	OssimPlanetViewer	Open	Public	Free
21	Norkart Virtual Globe	Norkart Virtual Globe	Open	Public	Free
22	GeoBrowser3D	GeoBrowser3D	Closed	Public	Paid
23	Microsoft Visual Experience Engine	World Wide Telescope	Open	Public	Free
24	-	*NASA's Eyes	Closed	Public	Free
25	-	*Kaspersky Cyberthreat	Closed	Public	Free
26	-	*Pokémon GO	Closed	Public	Free & Paid
27	-	*Science On a Sphere	Closed	Public	Free & Paid

*Not a platform as does not allow the user to add any data or make any customisations
(Note that the information was gathered online and from limited testing of globes and its accuracy is not guaranteed)

Source: ODEF/ Keysers [188]

FIGURE 94: VIRTUAL GLOBE USER FUNCTIONALITY OVERVIEW

Virtual Globe	Operating System	Basemaps & Data	Place Search	3D Navigation	Add Data	3D Objects	Terrain	Distance Measure	Annotate	Symbology Control	Analysis	Extensible
Google Earth	Windows, Mac, Linux, Android, iOS	Yes (only basemap is imagery)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Limited	No	No
ArcGIS Earth	Windows	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Limited	No	No
Bing Maps 3D	Windows	Yes	Yes	Yes	No	Yes	Yes	No	Yes (pin only)	No	No	No
PYXIS WorldView	Windows	No (none loaded by default but provided via Gallery)	Yes	Yes	Yes	Limited	Yes	No	No	Yes	Yes	No (has some widgets)
Cesium	Any browser that supports WebGL including mobile	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
World Wind	All platforms including Android and iOS	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Marble	Linux, Windows, Mac, Android	Yes	Yes	No	Yes	No	Yes	Yes	No	No	No	Yes
SkylineGlobe	Windows	Yes (high-res US imagery & streets, lower-res elsewhere)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
EV-Globe	Windows	unknown	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
SuperMap GIS	Windows, Linux, AIX, K-UX, Android and iOS	Yes (For China)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
DESP/CAS	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown
osgEarth	Linux, Mac, Windows	Yes (example Earth files)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes (e.g. line of sight)	Yes
CitySurf Globe	Windows	Yes (For Turkey)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Earth 3D	Linux, Windows, Mac	Yes (Imagery)	No	Yes	Yes	No	Yes	No	No	No	No	Yes
EarthBrowser	Windows or Mac	Yes	Yes	No	Yes	No	No	No	Yes (placemark only)	Yes (for placemark)	No	No
OpenWeb Globe	Cross-platform	unknown	Yes	Yes	unknown	unknown	Yes	unknown	unknown	unknown	unknown	Yes
Glob3 Mobile	Android, iOS, HTML5 browsers	Yes (imagery only by default)	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes
WebGL Earth2	Android, iOS, HTML5 browsers	Yes (basemaps)	Yes	Yes	Yes	No	No	No	No	Yes	No	Yes
VirtualGeo	Windows, Mac, Linux, LTS, HTML5 browsers	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
OssimPlanet	Windows, Mac	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No	Yes
Norkart Virtual Globe	Windows	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes
GeoBrowser3D	Windows, Mac, Linux	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
World Wide Telescope	Windows, HTML5	Yes	Yes	Yes	Yes	Yes	No (could be added)	Yes	Yes (constell-ation lines)	Yes (added data)	No	Yes
*NASA's Eyes	Windows, Mac, Android, iOS	Yes	No	No	No	No	Yes	No	No	No	No	No
*Kaspersky Cyberthreat	Any browser that supports WebGL	Yes	No	No	No	Yes	No	No	No	No	No	No
*Pokémon GO	iOS and Android	Yes	No	Yes	No	Yes	No	No	No	No	No	No
*Science On a Sphere Explorer	Windows, Mac	Yes (16 datasets in Lite version, 100 in Explorer)	No	Yes (limited in Lite version)	No (only from library but not in Lite)	Yes (satellite)	Yes	Yes	Yes	No	Yes (graph)	No

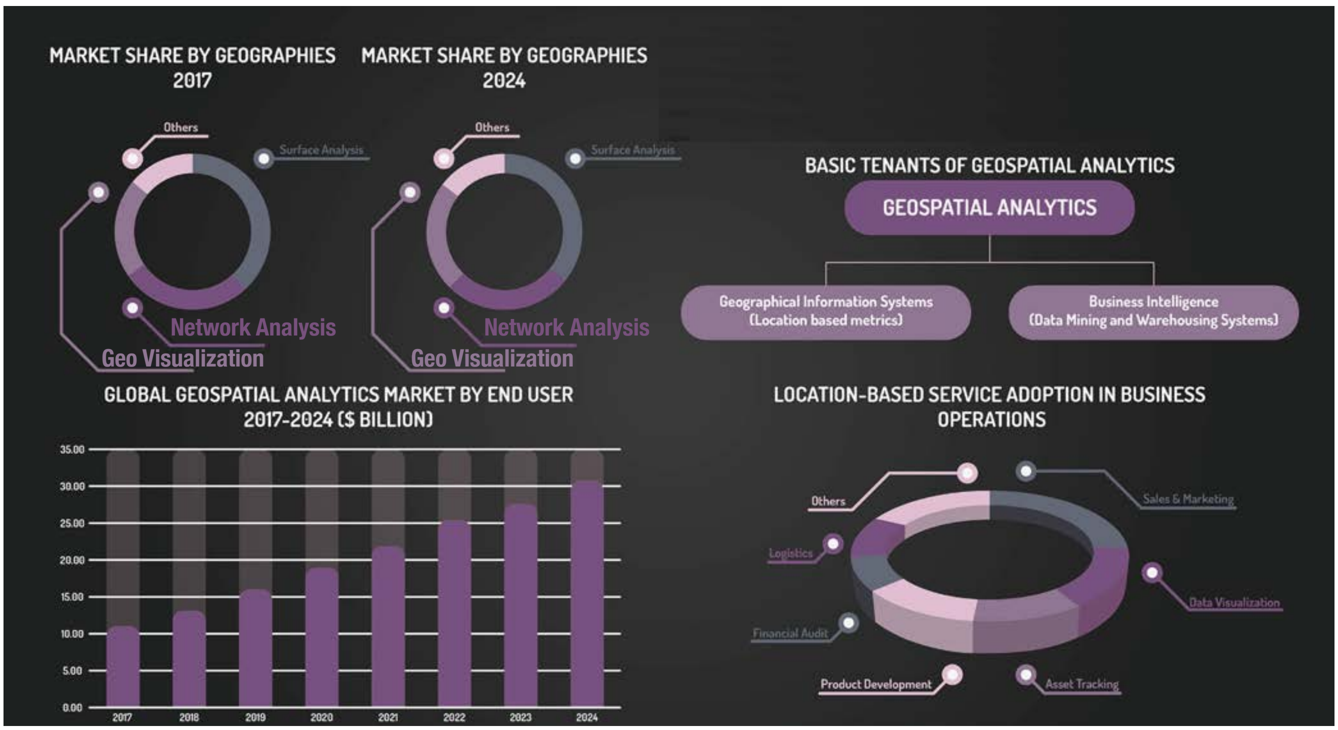
Source: ODEF/ Keysers [188]

4.4 GEOSPATIAL ANALYTICS

4.4.1 MARKET

The Geospatial Analytics market in 2017 was valued at USD $37.20 billion and expected to grow with a CAGR of 17.06% between 2018 and 2024 to be worth USD $112.06 billion [189]. Drivers include the development and utilisation of Global Positioning System (GPS) empowered gadgets, the convergence of technologies and the demand to reduce operational and logistics costs. Major players in the geospatial analytics market are Esri, Hexagon AB, Trimble Geospatial, Fugro, MDA Corporation, Bentley Systems, Harris Corporation, General Electric, Critigen, and Atkins.

FIGURE 95: GLOBAL GEOSPATIAL ANALYTICS MARKET FORECAST



Source: Inkwood Research [189]

4.4.2 WORKFLOWS AND PROCESS

Open Web Analytics (OWA) is open source web analytics software that can track and analyze how people use websites and applications. OWA is licensed under General Public License (GPL) and provides website owners and developers with easy ways to add web analytics to their sites using simple Javascript, PHP, or REST based APIs. OWA also comes with built-in support for tracking websites made with popular content management frameworks such as WordPress and MediaWiki [190].

'Distributed GIS' is an integrated framework to combine multiple geographic information system (GIS) resources and GIS workstations and servers located in different physical places for high-level interoperability and federation of GIS operations and user tasks. Distributed GIS can provide various geographic information, spatial analytical functions, and GIS Web services by linking multiple GIS and geographic information services together via wired or wireless networks [191].

4.4.3 FROM SPATIAL DATA INFRASTRUCTURE TO SPATIAL KNOWLEDGE INFRASTRUCTURE

The next generation Spatial Knowledge Infrastructure (SKI) progresses from traditional Spatial Data Infrastructure concepts to automatically create, share, curate, deliver and use knowledge (not just data or information). Knowledge-based solutions are the delivery of data and information in real time applying machine-to-machine communications and on-the-fly predictive analytics.

SKI will support the emerging digital economy, and enable smarter transportation networks, responsive and resilient cities, and intelligent infrastructure planning for spatially-aware and equipped citizens [192].

FIGURE 96: SDI

SPATIAL 'DATA' INFRASTRUCTURE TO SPATIAL 'KNOWLEDGE' INFRASTRUCTURE			
KEY RESEARCH AND INNOVATION AREAS			
	Data Perspective	**Information Perspective**	**Knowledge Perspective**
Sharing	• Open data principles • Spatial transactioning • Data warehouses	• Mechanisms for capturing and sharing spatial analytics • Cloud-based platforms	• Automation of human tasks • Encapsulating and sharing knowledge using domain ontologies
Versatility	• 3-D, 4-D moving objects and event-based models • Crowdsourced and social media data • Dynamic datum transformations	• Automated or semi-automated data conflation and fusion • Distributed and decentralised processing	• Responding to questions via visual and natural query languages • Responding to questions via visual and natural query languages
Process	• Value activities that contribute to 'fit for purpose' data • Automated capture and use of data quality • Communizing 'fit for purpose'	• Ubiquitous access to analytical tool sets • Automatic orchestration of scientific workflows • Tighter integration of spatial and non-spatial analytics	• Scenario exploration • Knowledge-service/ interface suitable for the masses • Trustworthiness: Automatic extraction of provenance and trust modelling
Usability	• Removing supply chain duplication and redundancy • Smart search: Find information in distributed supply chains	• Innovative mapping platforms • Multi-platform access, including virtual reality, augmented reality, mobile users	• Scenario exploration, predictive models, data assimilation • Collaborative decision support • Rapid feedback

Source: CRCSI [192]

To maximise the benefits of spatial knowledge, current SDI activity must be extended to include four key areas: sharing, versatility, process and usability (see Figure 97). These activities are necessary to achieve a successful transition to an SKI [192].

FIGURE 97: FROM SDI TO SKI

	Today (2017)	Benefits of success (2022)	Value proposition
Sharing	Spatial experts dominate use and analysis of spatial data	Non-experts and domain experts dominate spatial data use and analytics	Significant time and effort saved through improved access, sharing and collaboration on data curation; analytics; broader inclusion of domain experts in collaborative teams leads to more effective use of spatial data; reliance on spatial data increased, driving increased productivity.
	Data is shared and reused, but analysis and data fusion procedures are bespoke	Government and industry rely on automated fusion and routinely share and adapt analytics processes	
	Data analytics largely done in desktop GIS or isolated web portals	Spatial analytics easy to automatically embed in a myriad of cloud-based, distributed, and mobile tools and applications	
	Collaboration on analytics only within co-located and established groups	Broad collaborative teams with diverse expertise solve problems	
Versatility	Spatial data and analytics typically 2D "flatland"	Seamless analytics of 2D, 3D and 4D metric data	Comprehensive spatial data available for decisions across all areas of government and industry analytics, including incorporation of 3D and 4D, dynamic, sensor-based, multisource imagery, IoT data reflecting physical measurements and crowdsourced data intimating human judgments and views.
	Significant duplication of data within government and wider industries that is manually collected and combined	Tools to deliver consistent and seamless datasets, with data fit for analytics purpose drawn from a variety of sources (federated)	
	Underlying reference framework is static	Underlying reference based on dynamic datum	
	Spatial data derived from relatively narrow range of authoritative data sources	Spatial data routinely from IoT, RPAS, sensors, crowd sourcing and social media, and mobile devices	
Process	Domination of suppliers providing users with data and describing how they can use the data	Users using the data they want, when they want and how they want it with automated understanding of use parameters and machine readable guidelines associated with usage	Increased integration of analytics and business workflows; protection from adverse effects of data misapplication; increased confidence in data and analytics; range and use of spatial data in the marketplace increased. Increased confidence in automated information and knowledge creation.
	Data quality based largely on provider reputation and known uses	Machine generated documentation of uses, production and provenance of data that can be understood by non-spatial specialists	
	Undocumented or bespoke analytics run on trusted foundational spatial data	Warrantability and trust of data, enabling scrutiny and replication of analytics from a broad range of data sources supported by fitness for purpose statements (from accuracy statements to caveat emptor)	
Usability	Data visualisation tools patchy, mutually incompatible and largely desktop-driven	Intuitive visualisation and analytics that adapt to a user's expertise, context and devices, in open and online environment	More real-time usable, mobile, graphical and natural language interfaces; increase user base for spatial data, thus increasing efficiency; evidence-based decision-making supported by data and predictive analytics; time and costs of searching for data and using sub-optimal data and analytics reduced. Fast, efficient and cost effective spatial processes incorporated into workflows.
	Difficulty in locating most appropriate spatial data for specific applications	Intelligent search capabilities leveraging natural language eases the task of finding the most appropriate data from a diversity of options, while multidimensional ranking provides increased relevancy, supported by both text and geographic search capabilities	
	Limited and costly support for data exploration and "what if?" hypothesis testing	Ability to plan based on "what is there" and "what might happen"	
	Lack of ability to find appropriate, cost effective processes	Discovery and use of appropriate process standards with spatial workflows using plain language querying from any source	

Source: CRCSI [192]

4.5 ARTIFICIAL INTELLIGENCE AND COGNITIVE COMPUTING

4.5.1 AI MARKET

In 2017, the Artificial Intelligence (AI) market was thought to be worth USD $16.06 billion, with a CAGR of 36.62% from 2018 to 2025 [193]. AI uses cutting-edge technologies[7] that develop products that work in a similar way to human intelligence. A study looking at publications over the last 30 years [195] found that interest in AI (started 1956) has sharply increased since 2009, with the public perception being more optimistic than pessimistic. Specific areas of concern, however, are a loss of control of AI, ethical concerns for AI and the negative impact of AI on work.

4.5.2 AI PROGRESS

AI has made substantial progress in the last few years. It can now lip read and recognize speech for transcription more accurately than humans, win air battles against human pilots, and consistently beat the (human) world champion in Go (a major AI achievement) [196].

Advances in artificial intelligence will be very influential processing large amounts of data, including spatial data. Approaches such as machine learning, deep learning, and neural networks will extract insights hidden in data. Several companies are working on turning large-scale spatial data archives and feeds into actionable intelligence, i.e. Orbital Insights, and Descartes Labs. [197], [198]. South Australia based machine intelligence company Consilium Technology has partnered with Digital Globe to leverage the Digital Globe's big data platform (GBDX) with over 100 Petabyte of high-resolution satellite imagery [199]. Amazon Web Services has been active in developing AI for over a decade.

4.6 SECURITY

4.6.1 BLOCKCHAIN

Blockchain capabilities have gained a lot of public attention in the last year as the technology that stands behind some cryptocurrencies. The underlying principle is that a digital, decentralized ledger, in which transactions (a list of records, called blocks) are recorded chronologically and made publicly[8] available makes it very difficult to defraud the system. Each block has a cryptographic hash of the previous block, the transaction date, and a timestamp. Each node (computer) gets a copy of the blockchain, which is downloaded automatically; the records are verifiable and permanent and cannot be altered retroactively. The World Economic Forum reports that by 2027 10% of the world's GDP could be stored on blockchain technology [200].

Blockchains have many applications beyond cryptocurrencies, i.e. for supply chain management (smart contracts) and land registry/ title offices. The global blockchain technology market is expected to grow from USD $210.2 million to USD $2,312.5 million by 2021 (61.5% CAGR) [201].

---

[7] According to Forrester Research AI technologies include: Natural Language Generation, Speech Recognition, Virtual Agents, Machine Learning Platforms, AI-optimized Hardware, Decision Management, Deep Learning Platforms, Biometrics, Robotic Process Automation, Text Analytics and NLP [194]

[8] In private blockchains users need permission to join the network

4.6.2 CYBERSECURITY THREATS AND INCIDENCES

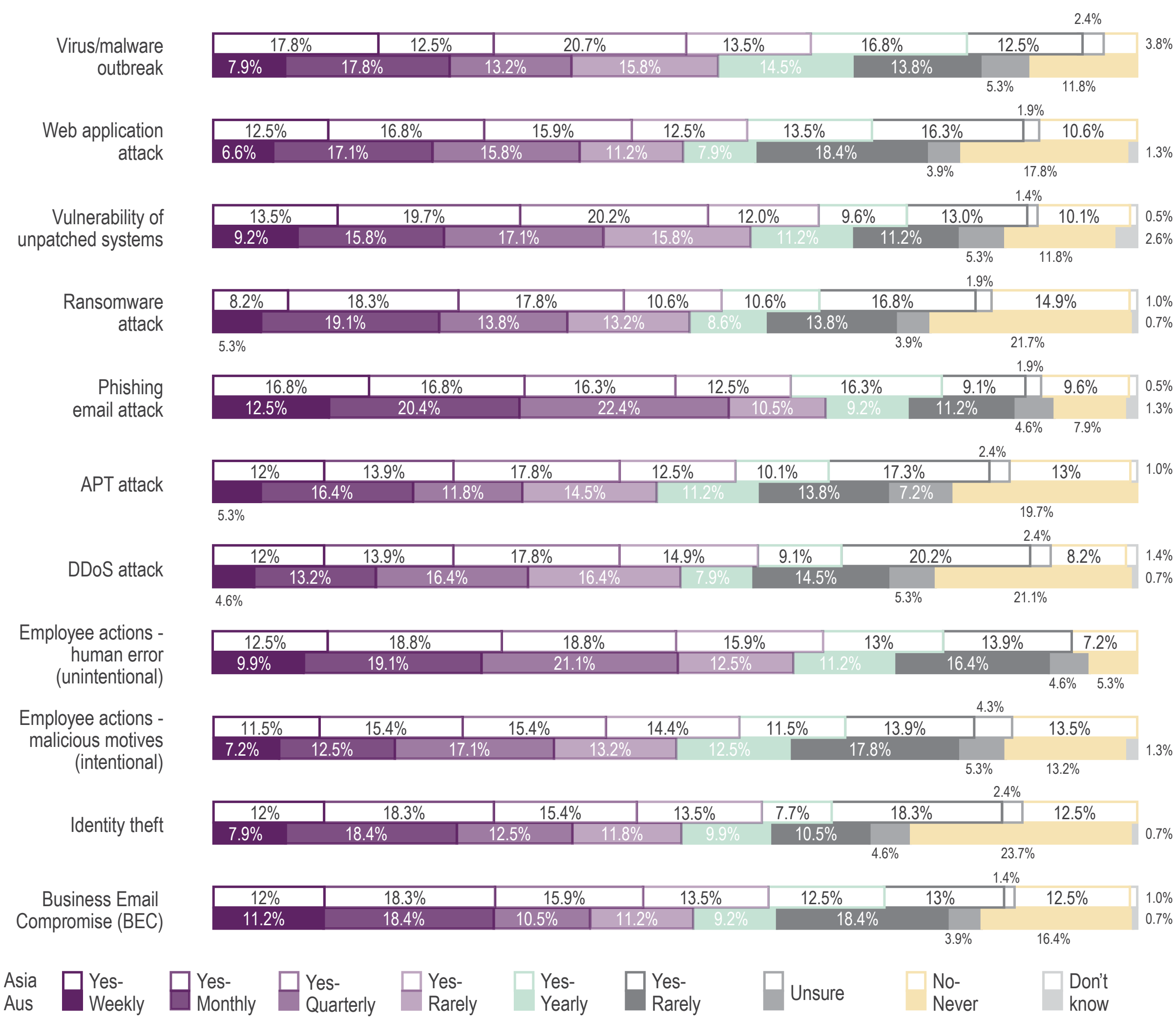
With the advent of quantum computing, most encryption algorithms will become obsolete as a means for safe communication. The Australian Capital Territory (ACT) government has funded the University of New South Wales (UNSW) for a world class space mission design centre, including a jointly developed ground station for quantum encrypted satellite communication. The Australian Government is planning on spending AUD $17 billion over the next decade for intelligence, surveillance, and reconnaissance, space, electronic warfare, and cybersecurity [202].

The global cybersecurity market is worth USD $100 billion and expected to more than double by 2020.

In early 2017 the Australian Cyber Security Growth Network (ACSGN) became operational.

Figure 98 shows type and frequency and occurrence of impacting security incidences in Asia and Australia.

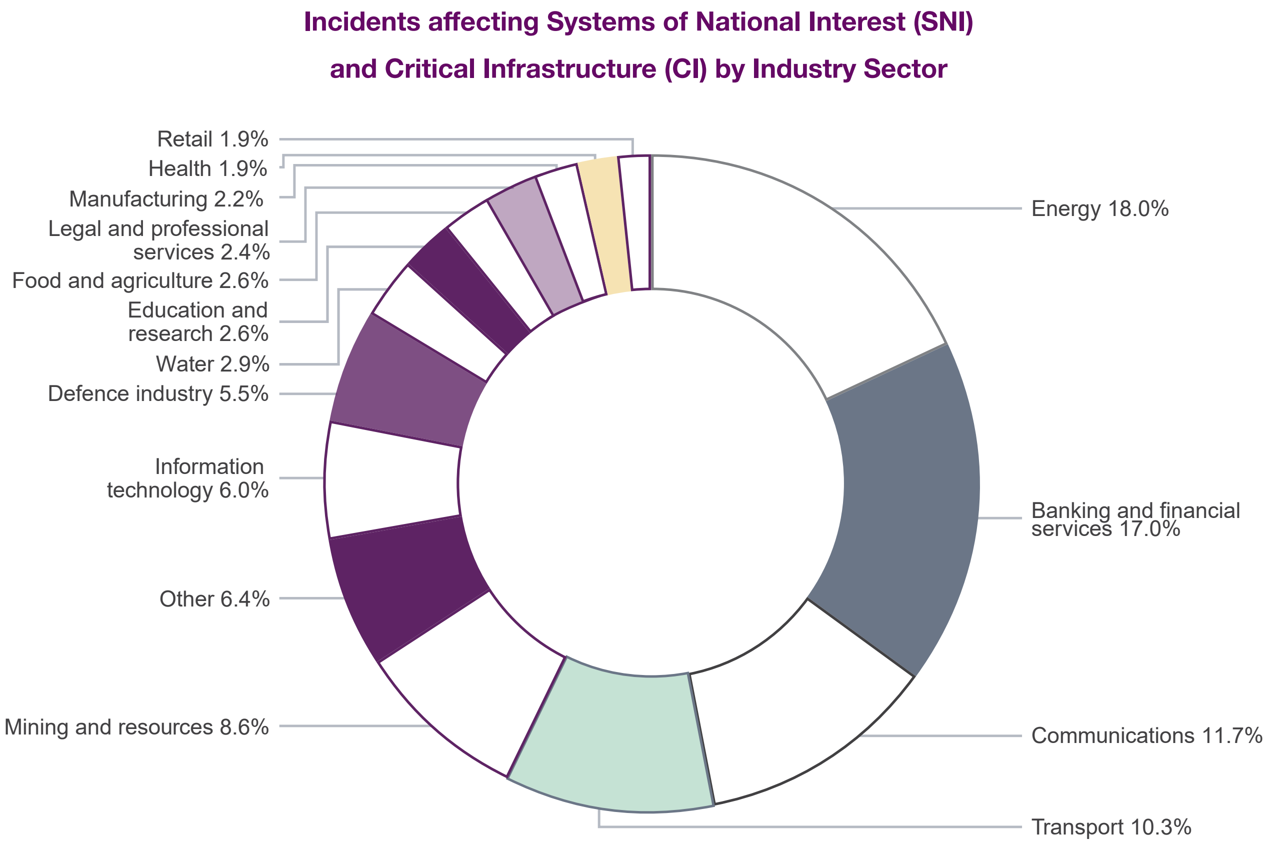
FIGURE 98: CYBERSECURITY INCIDENCES AUSTRALIA AND ASIA



Source: Telstra [203]

In the 18 months prior to June 2016, the Australian CERT (Computer Emergency Response Team) responded to 14,804 cybersecurity incidences affecting Australian businesses, 418 involved systems of national interest and critical infrastructure. The energy and communication sector had the highest amount of reported compromised systems, while the banking, finance and communication services had the highest amount of Distributed Denial of Service (DDoS) activities [203]. Figure 99 shows details.

FIGURE 99: CYBERSECURITY INCIDENCES AFFECTING SNI AND CI

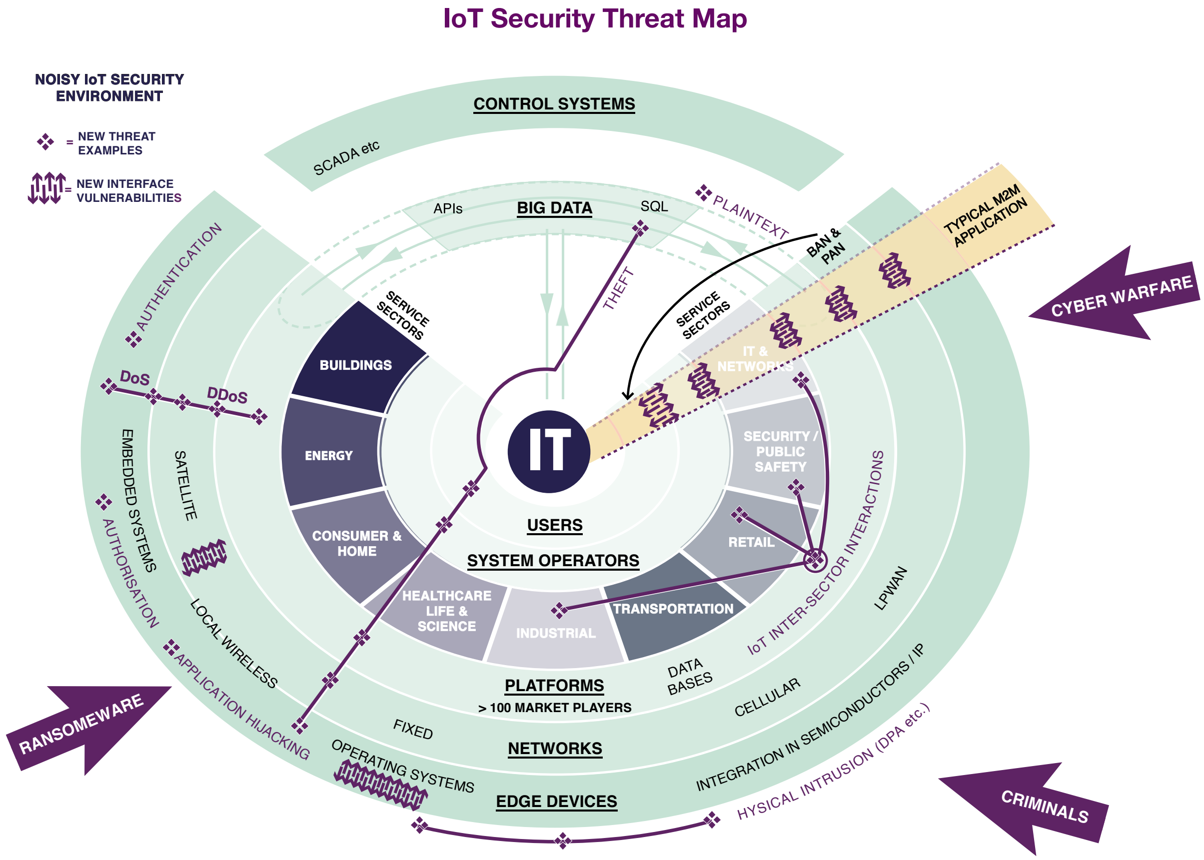


Source: ACSC, as quoted in Telstra [203]

Traditional M2M systems (see Figure 100) typically use focused edge[9] devices. With the many IoT sensors and systems coming online it is essential to have strong security in place. IoT sensors are still considered to be a weak link between users and platforms. Blockchain might be the solution to secure the IoT. There are platforms such as Filament and the ADEPT proof-of-concept from IBM [204]. Further security advances could be achieved with the implementation of Edge computing, making computations on the edge of a system (i.e. sensor nodes) rather than at the core (thus no need for transporting masses of data back and forth) [205]. Figure 100 maps security threats to the Internet of Things.

[9] An edge device is a device that provides an entry point into enterprise or service provider core networks, i.e. routers, routing switches, integrated access devices (IADs), multiplexers, and a variety of metropolitan area network (MAN) and wide area network (WAN) access devices. Edge devices also provide connections into carrier and service provider networks. (Wikipedia).

FIGURE 100: IOT SECURITY THREAT MAP



Source: Beecham Research [206]

5 SOCIAL AND HUMAN ASPECTS

5.1 PRIVACY

5.1.1 USE OF PRIVATE DATA

Vast amounts of data that are being created by the technologies currently in use and this will very much increase as sensors become more prevalent in connected devices. The Internet of Things is a major driver underpinning this development. It is a goldmine of information, mostly collected by companies and organisations unrelated to the users that produce the data. Data is being analysed and exploited in places users are not even aware of, i.e. by professional data agglomeration companies meshing information together from a multitude of sources (with legal access because of the fine print in smartphone APPs and permissions are unwittingly given when signing up to shopping loyalty cards etc.). Sometimes these data and user profiles resurface through data breaches (no data are truly secure) and are abused. Marc Goodman's book 'Future Crimes' has some interesting case studies [207].

Risks to privacy stand out as the most perceived downside in the rise of personal technology to 52% (even 64% in developed nations) of participants of a Microsoft /WEF survey (conducted during 2014) [208].

Virtual assistants are always listening for a ‘wake up' command, and Alexa/Echo, for example, a second before and after a command is sensed, sends it to Amazon's cloud. Everything is hackable, and it will not be too long before uninvited observers are listening in on conversations in private homes [209]. Other technologies such as ultrasonic beacons can also monitor users without their knowledge [210]. A paper from Ikram et al. (2016) reviews privacy breaches on Android APPs using VPN connections and raises particular concerns that APPs insert JavaScrip programs for tracking, advertising, or redirecting e-commerce traffic to external partners [211].

Data breaches become all the more concerning when biometric data are involved. Legislation lags behind and is furthermore complicated by inconsistent laws in various jurisdictions [212].

5.1.2 PRIVACY LAWS

Governments are recognizing that they need to be more proactive to protect their citizen’s privacy and have started to legislate; however, this is a complex issue needing global standards and cooperation and still, more work needs to be done.

In Australia, in February 2018 the Privacy Amendment (Notifiable Data Breaches) Act 2017 commenced. It requires organisations (including the Australian Government Agencies) to notify individuals likely to be at risk of serious harm by a data breach [213].

The EU’s General Data Protection Regulation (GDPR) will come into effect in May 2018 [214]. The GDPR has been likened (major change to IT) to Y2K, requiring significant work from organisations to comply with required user privacy protections.

In 2017 the USA government voted to alter prior approved privacy protections, thus allowing internet service provider companies to collect and sell web browsing, location and other personal details [215].

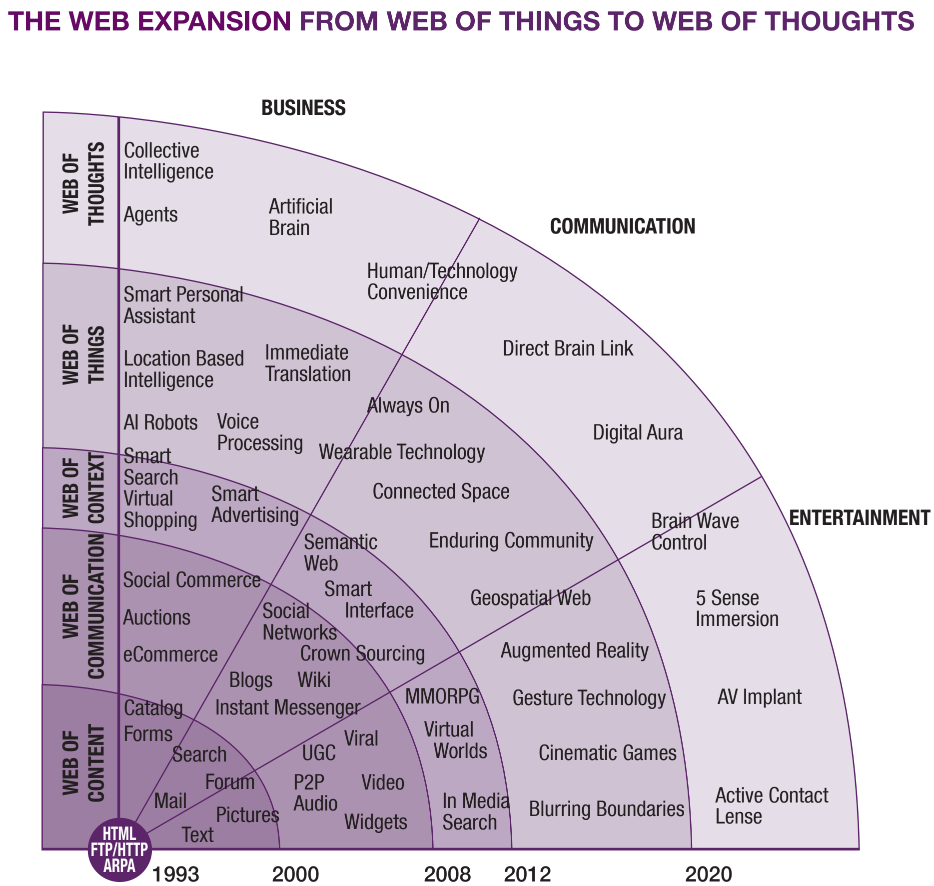
In the future citizens will become more and more aware that their data are being commoditized without them receiving a benefit; consequently, companies offering ‘privacy as a service' will boom.

5.2 MACHINE- HUMAN INTERACTIONS

Interactions between humans and machines are becoming increasingly integrated. Traditionally humans used tools/ and machines to assist with processes. With the advance of technology, humankind now has the rapidly improving capabilities to directly connect humans to machines, be it for artificial body parts (insulin pumps, pacemakers, artificial limbs and more) or connecting brains to computers (Brain-Computer-Interfaces [BCIs], i.e. to operate exoskeletons). Renown authorities, such as Futurist Ray Kurzweil, and Elon Musk even speak of the future evolution of mankind: humans merging with super-smart machines [216], [217].

Figure 101 shows the progression of the internet from content in the early 1990' via the internet of things (this decade) to the web of thoughts (anticipated in the next decade).

FIGURE 101: CONNECTIVITY TOWARDS THE WEB OF THOUGHTS



Source: Trendone as quoted in [218]

The following sections look at virtual assistance, robots, brain-computer interfaces. Spatial sciences will underpin a wide selection of the technologies involved- from imaging, (extraction of information and intelligence from these images), to location related matters for virtual/ real world interactions.

5.2.1 VIRTUAL ASSISTANTS

Virtual Assistants (VA) perform a task or service for an individual. There are two versions of Virtual Assistants:

a) traditional humans, that are employed 'virtually' via the internet (i.e. Upwork, Fiverr, Fancy Hands, and Zirtual amongst others), and could be anywhere in the world while they assist, or

b) a software agent. Digital Virtual Assistants typically observe the behaviour and habits of their user and then use artificial intelligence to assist with music preferences, shopping and so on [219]. VA in the pocket in the form of a smartphone have the smarts to help owners with location-relevant information (i.e. up-to-date travel times, prompts with reminders at certain locations etc.) Virtual assistants currently on the market include Cortana, Siri, Google Assistant, and Alexa. Typical functionalities of Virtual Assistance include launching APPs, retrieving weather forecasts, making calls, sending texts and emails, setting alarms, recognizing and playing music, and searching the web. It is anticipated that functionalities will vastly improve in the next few years; access to super-smart assistants will give people an advantage for future jobs.

The global Intelligent Virtual Assistant (IVA) market is expected to be worth USD $12.28 billion by 2024 (according to Grand View Research) [133], experiencing rapid growth over the next few years.

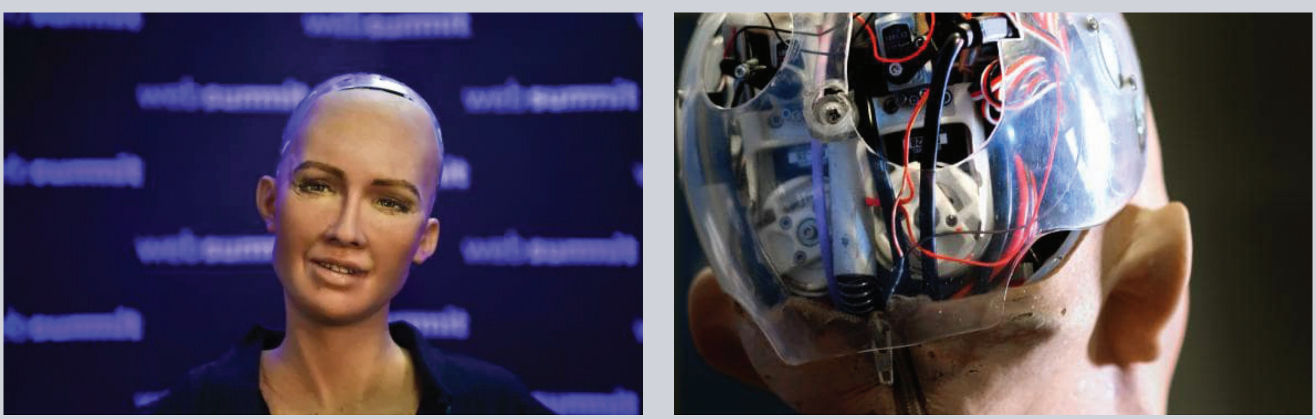
5.2.2 ROBOTS

'Archinaut' is a design for a space-based 3D printer that can print structures larger than the printer itself and then assemble the parts with its robotic arm in orbit. The initial test phase will be completed in 2018 with the actual assembly of structures in space [220].

In a major report on RoboLaw [221], the European Union suggested the create an insurance fund for damages caused by robots.

In October 2017, Saudi Arabia bestowed (world-first) citizenship on a humanoid robot 'Sophia'. Sophia was developed by Hong Kong company Hanson Robotics [222]. Sophia can hold a conversation and has gained publicity with the controversy over her citizenship, a twitter exchange with Elon Musk, expressing the view that she wants to start a family, and wishing to use crowdfunding and AI to make herself smarter.

FIGURE 102: ROBOT SOPHIA



Sophia is not pre-programmed with answers but instead uses machine learning algorithms to form her responses. Picture: Patricia de Melo/AFP Source:AFP

Source: [223]

There is discussion that robots could develop consciousness and legal rights might need to be adjusted to give robots rights but also to keep them responsible. The European Union is one of the governing bodies that is working on robolaws [224].

In his thesis, ter Wijlen (2017) looks at differences between humanoid robots and cyborgs [225] and assesses:

Currently, the prospect of technological development regarding robotics looks in two directions. On one hand, there is a development of creating humanoid robots, which ultimately will house the capacity for human-level sentience, consciousness, and intelligence. On the other hand, there is a development of mechanizing the human being, resulting in a cyborg, which refers to the belief that the human being can evolve beyond the current physical and mental limitations through the use of technology [225].

5.3 BRAIN-COMPUTER INTERFACES

A brain-computer-interface (BCI) connects a brain to an external device and facilitates the communication between the two. There are invasive BCIs where an electrode is implanted in the brain; this method produces the highest quality signal, but signal degradation can be caused by scar tissue build-up. Partially invasive BCIs are implanted in the skull, but not within the grey matter of the brain. Signals are still better than non-invasive methods and have the benefit of not being deteriorated by scar tissue.

Non-invasive BCI methods register the electromagnetic transmission of neurons via wearable devices, but the resolution is lower due to the interference of the skull with the signals. Hans Berger, a German neuroscientist, discovered in 1924 neuro-electrical activity using electroencephalogram (EEG). Reflecting on progress in BCI development, DARPA commenced EEG research in 1970. In 1998 the first brain implant was used to enable a locked-in[10] patient to communicate via BCI. A monkey's brain succeeded in controlling a robotic arm in 2005. In 2014 direct brain-to-brain communication between two people was successful via the internet [226].

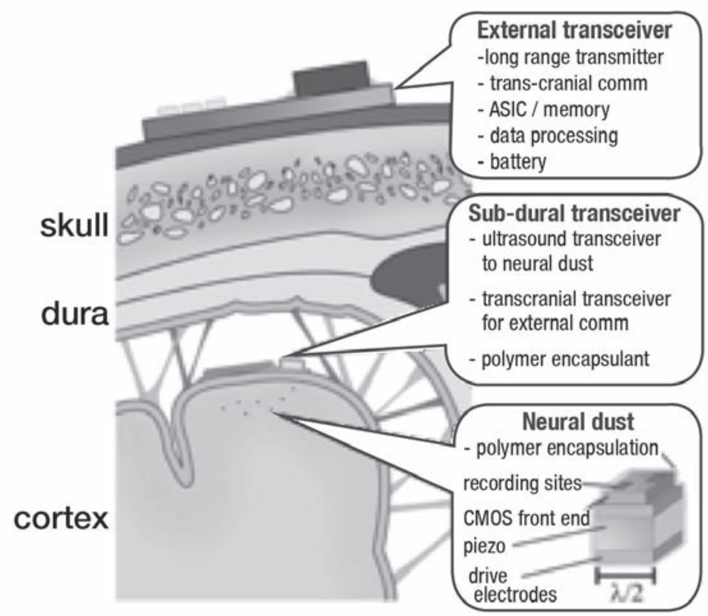
Connecting brains to machines has a vast array of applications from synthetic telepathy (human-to-human covert communications, and new levels of real teamwork), linking humans to robotic machines (i.e. smart prosthetics for the disabled) or remote operations of telerobots (performing surgery, handling dangerous materials or operating in inaccessible locations). There is the potential to give humans super-hero-like abilities. Cross-species information exchange could also be useful (i.e. using a dog's smelling capability, connecting dog and human brains). It also enables memory extension, downloading skills (as seen in 'The Matrix' movie) and uploading memories to the cloud. Neuro-gaming and operating in virtual worlds/ VR environment will create some major applications for these advances [226]. In this respect, BCIs will be key for interaction with spatial datasets in virtual worlds.

[10] Locked-in patients have lost the ability to voluntarily control their body; often patients can only move their eyes

5.3.1 BCI SYSTEMS

Serious endeavours are underway to develop BCI devices that are estimated to become available in about 8-10 years. Elon Musk [217] is the co-founder of Neuralink, a company that works on brain-computer interfaces, envisioning a mesh that creates a neural lace and wirelessly connects the brain with a computer. Another company, Kernel (started by Bryan Johnson) is working on neuro-prostheses, to upgrade human cognition [227]. UC Berkley Researchers propose neural dust for Brain-computer interfaces [228], see Figure 103.

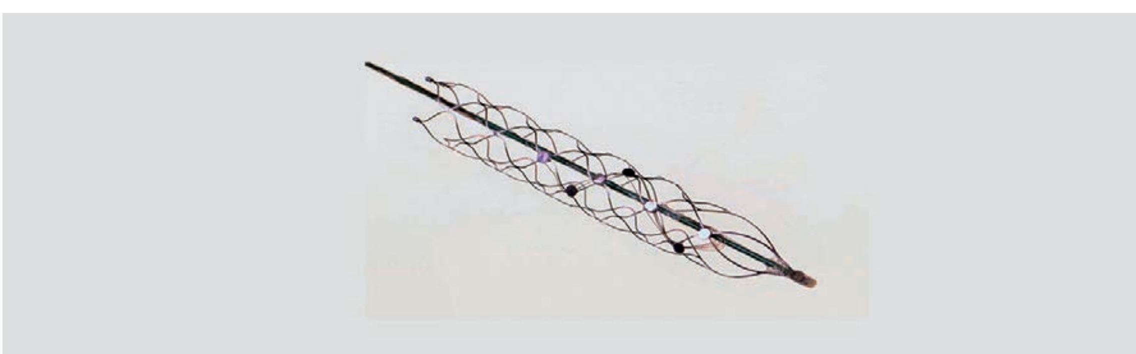
FIGURE 103: NEURAL DUST



Neural dust system diagram showing the placement of ultrasonic interrogator under the skull and the independent **neural dust** sensing nodes dispersed throughout the brain.

Source: Seo [228]

FIGURE 104: STENTRODE



Source: DARPA [229]

DARPA has several programs as part of the Brain Initiative [230], i.e. Reliable Neural-Interface Technology (RE-NET) working on BCI: The initiative 'Minimally Invasive "Stentrode" (see Figure 104) builds on work from Thomas Oxley, Vascular Bionics Laboratories, Melbourne University [231] converting off-the-shelf stent-technology into sensors monitoring motor cortex activities (responsible for voluntary movement). The device has been trialled in sheep and was scheduled for human trials in late 2017.

5.3.2 LEGAL CONSIDERATIONS FOR BCIS

Brain-computer interfaces will revolutionize the way people work, play and live. There are ethical, legal and societal issues related to BCI that need to be progressed before this technology becomes widely adopted. There is no legislation in most countries regulating informed consent or protecting personal data extracted via BCIs [232].

There are concerns around mind-reading, mind-control, use of the technology in advanced interrogation techniques, side-effects (i.e. neuro-feedback affecting sleep quality), issues around personality and personhood, selective enhancements and social stratifications. There are also concerns about 'brain-jacking'- hacking a brain, through unauthorized access to brains via BCIs [233]. Legislation and law enforcement need to prepare to detect and counter-act criminal hackers.

In the paper 'Towards new human rights in the age of neuroscience and neurotechnology' [234], the authors observe that existing human rights might not be sufficient to respond to these emerging issues. They identified the need to address the following four rights:

- the right to cognitive liberty,
- the right to mental privacy,
- the right to mental integrity, and
- the right to psychological continuity.

Concerns also exist when connecting two brains together via Brain-to-Brain Interfaces (BTBI) [232]. Issues can be grouped into two broad components: (a) extracting neural information, and (b) delivering neural information. Complications also arise when combined brains come up with new ideas - who rightfully owns these ideas; who is responsible for damage created by combined brains. It also opens the question of the definition of a 'person' when brains are wired between individuals [232].

5.4 HEALTH

Immense progress has been achieved in the health field, in particular in recent years. Many medical breakthroughs are happening such as:

- Cancer research, i.e. out-smarting tumours [235]
- Grow human body parts from stem cells, i.e. eyes [236]
- Removing diseases with gene-therapy, i.e. genetic blindness [237]
- Reverse aging [238] [239]

5.4.1 LOCATION IN HEALTH STUDIES

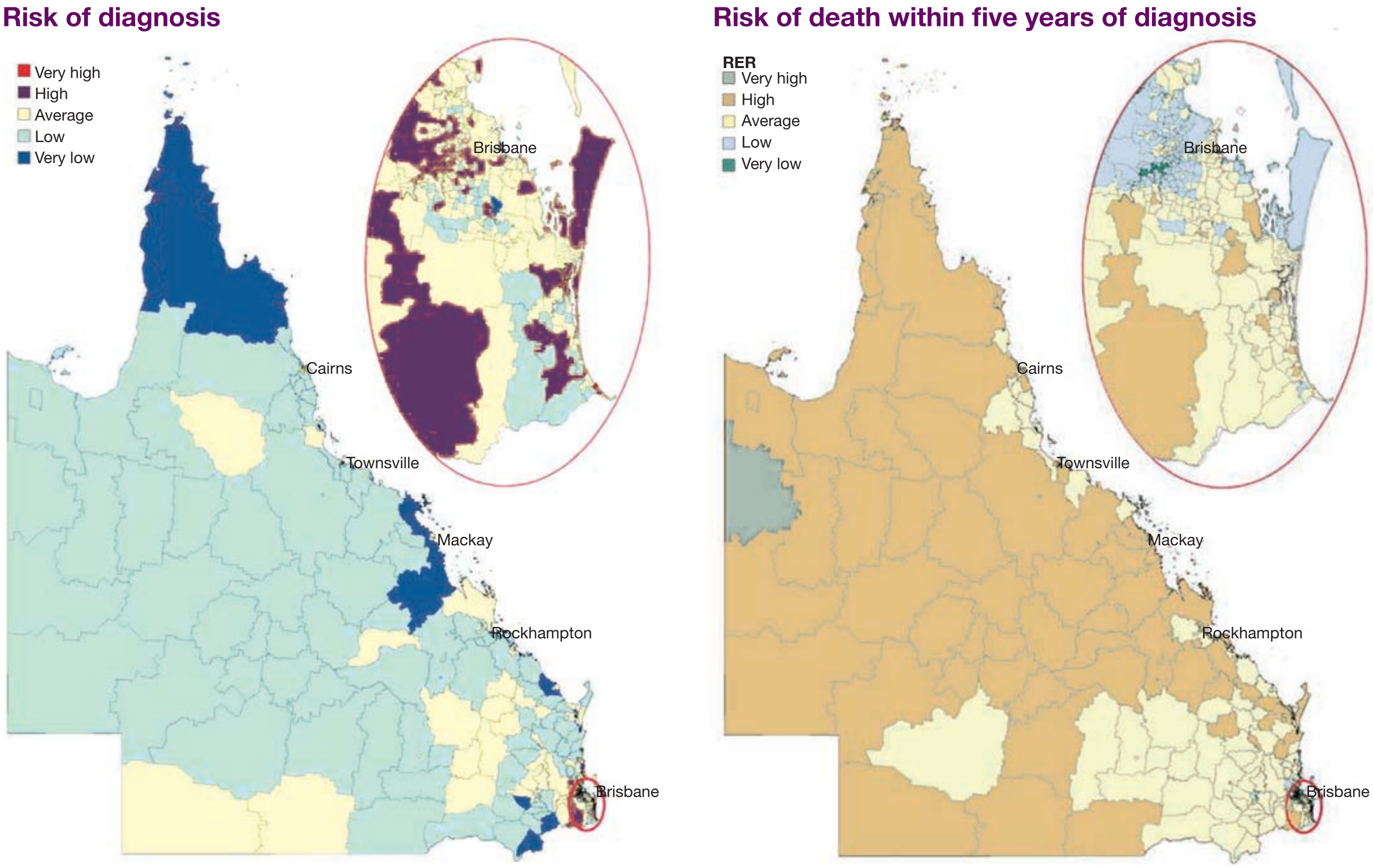
Location is a significant factor when it comes to surviving cancer. An Australia and New Zealand Cooperative Research Centre for Spatial Information project mapped risk of cancer diagnosis and 5-year survival rates in Queensland [240] (see Figure 105). Spatio-temporal modelling leads to insights into inequality of cancer treatment and survivability. Using the release of the Atlas of Cancer in Queensland as a foundation, Queensland University of Technology together with the Queensland Cancer Council developed new Spatio-temporal modelling techniques to examine cancer incidence and survival within small areas, which together with health service data, provided novel insights to inform service priorities and planning, guide advocacy, and stimulate further research, each with a common purpose of reducing population-level inequities.

This research produced a picture of how cancer incidence and survival varies across the 478 Statistical Local Areas in Queensland. The Atlas of Cancer in Queensland published in 2011 demonstrates clear survival inequalities, influencing factors, and how it changes over time.

The Atlas has been widely used to inform Government Agencies and Health Policy makers leading to additional support staff in regional and rural areas to assist rural and remote cancer patients. The research also led to the reform in public policy including a landmark doubling of the Queensland Governments Patient Travel Subsidy Scheme which offsets the costs of travelling for medical treatment. Governmental policies like travel cost allowances for remote citizens are expected to shift cancer outcomes.

The Australia and New Zealand Cooperative Research Centre for Spatial Information is currently working on a nationwide cancer atlas.

FIGURE 105: QUEENSLAND CANCER ATLAS



Source: Cancer Council Queensland [241]

5.4.2 SPATIAL TECHNOLOGIES TOOLS FOR HEALTH

Smartphone APPs such as Third eye, KNFB reader (Kurzweil National Federation of the Blind), Aira, and the OpenGlass project use image processing technology to assist blind people navigating daily life better.

Wearable devices monitor health parameters and have been found to even predict when a wearer is about to become sick [242]. Smart tattoos [243] and (more invasive) implants (i.e. dissolvable biosensors [244]) notify[11] carers or doctors if the patient is unwell. MIT researchers, with the WiGait system, analysed how low power radio signals reflect off people's bodies. They monitored people's walking speed and stride length, associated with conditions such as kidney failure, certain lung diseases, heart failure, and stroke. A similar analysis showed breathing and heart rate. This technology has interesting uses for monitoring the health of seniors to security applications [245].

[11] some notifications include last monitored location

6 CONCLUSIONS

Spatial technologies are set to be increasingly enabled by an ever growing variety of complex technologies and analytics techniques including: cloud computing, augmented reality and wearable technologies, multilevel customer interaction and profiling, big data analytics and advanced algorithms, smart sensors, 3D printing, authentication and fraud detection, advanced human-machine interfaces, the Internet of Things platforms, block chains, drones, robots, Artificial Intelligence, autonomous vehicles, solutions to cyber threats, advanced sensor technologies, space and satellite developments including micro, nano and cube sats, and satellite constellations of dozens or hundreds of satellites functioning together in pre-designed synchronisation.

Most of these technologies and their markets are covered in this report. Many are accompanied by estimates of compound annual growth rates that exceed 10% per annum, some significantly more, and whilst estimated growth rates and forecasts should always be scrutinised carefully, it is clear that the spatial technologies, operating in harness with these other enabling technologies and analytics are set to offer substantial value adding and new applications, many of which are yet to be conceived and realised, most of which will be disruptive. The rate of change in the spatial marketplace is set to accelerate and the breadth of coverage and adoption to expand.

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APPENDIX A: 2026 AGENDA

TRANSFORMATION AND GROWTH INITIATIVES

The Australian spatial sector has determined that this suite of high priority initiatives will make an essential contribution to the transformation and growth of the Australian economy and accelerate the realisation of benefits to the wider community over the next decade.

A. PUBLIC INFRASTRUCTURE AND ANALYTICS

A1. Develop and publish a nationwide framework and roadmap setting out all major public spatial infrastructure developments and supporting analytical capabilities for the next five years, including:

- National Positioning Infrastructure (NPI)
- Foundational Spatial Data Framework (FSDF)
- Nationwide Spatial Data Infrastructure (NSDI)
- Australian Geoscience Data Cube(s) (AGDC)
- Land Registries Reform
- Visualisation Engines and Globes

A2. Prioritise the collection of, and access to, public datasets of national importance to focus investment and publish the plans for their maintenance, upgrading and availability

A3. Complete the implementation of the development of the dynamic datum including the move to 3D

A4. Publish the plan for future improvements to the National Elevation Data Framework

A5. Develop a National Spatial Analytics Capability (NSAC) to provide government, business and consumers with a simpler, coordinated and collaborative means to access, process and add value to open data

B. INNOVATION AND ENTREPRENEURSHIP

B1. Open location technologies and services to new sectors through the analysis of their problems, challenges and value chains.

- The high priority growth sectors are: transport, agriculture, health, defence and security, energy, mining and the built environment. The natural environment should also be given special consideration.

B2. Create nationwide location innovation ecosystems that allow entrepreneurs, start-ups and researchers to access real-world data for fast prototyping and development of business expertise to facilitate the transition from idea to commercialisation

B3. Establish and grow relationships between the spatial sector and the investment community, including the venture capital industry and growth funds

B4. Publish information about existing programs and organisations that can support the export of products and services from Australian-based spatial businesses

B5. Undertake pilot exercises with jurisdictions and/or organisations that are already offering innovative procurement programs so that the benefits of new procurement approaches can be showcased using spatial and location examples

B6. Create a program to develop and deploy low-cost dedicated Australian earth observation sensors and satellites to supply nation-critical data

B7. Implement a pilot international exchange program for professionals from Australia and overseas who can accelerate Australian-based spatial innovation

B8. Promote the adoption of the use of digital location information in legislation and progressively replace the use of analogue map-based information in current legislation

B9. When the time is right, develop a bid to create a Space and Spatial Growth Centre

C. OUTREACH

C1. Grow relationships with peak industry bodies from the priority growth sectors (B1) and with key international organisations

C2. Arrange for the spatial peak bodies and their members to specifically target conferences and forums in the priority growth sectors (B1) and to ensure a spatial presence

C3. Develop and run an awareness campaign promoting the benefits to the economy and society provided by location-related technologies, ensuring the message and language are accessible to the Australian public

C4. Regularly publish information about the size, composition, impact and value of the spatial sector in Australia

C5. Create a Location Young Professionals Engagement Program targeting spatial and STEM graduates

C6. Re-purpose the Locate Conference to: 1) include streams specifically focussed on the priority growth sectors (B1) to promote cross-sectoral participation; 2) report on progress with the implementation of this Action Plan; and 3) seek advice on improvements and updates to the Action Plan

D. RESEARCH AND DEVELOPMENT

D1. Develop a nationwide, nation-building research agenda that sets out the major spatial challenges in the short, medium and long term

D2. Identify, implement and showcase at least one transformative R&D initiative for each priority growth sector (B1)

D3. Publish a plan setting out the incentives that will ensure the supply of industry-ready spatial PhDs for the next decade

D4. Publish information on available mechanisms and benefits that can reward businesses that invest in spatial R&D

E. EDUCATION, TRAINING AND CAPACITY BUILDING

E1. Develop a strategic framework to coordinate the management of education, training and capacity building (K1-12, TAFE and universities), comprising:

- A nationwide plan to maintain high priority spatial disciplines at the tertiary education level including geodesy, surveying, photogrammetry, spatial analysis and new future-fit competences including business subjects
- A plan to include fundamental spatial knowledge in cross disciplines where location-related technologies and skills are gaining importance (e.g. data science, ICT, statistics)
- Scaling up the nationwide spatial curriculum in primary and secondary schools

E2. Implement a program of training offering upskilling opportunities in spatial disciplines to existing employees in the workforce, including both technical and management streams

E3. Develop and facilitate a spatial professionals exchange program across government, business and academia

E4. Establish and grow relationships with Regional Development Australia and the Regional Australia Institute, amongst others, to grow location-related regional capacity

E5. Design and implement a nationwide action plan to mitigate the forecasted shortage of surveyors and geospatial specialists in Australia over the next 10 years

E6. Identify and facilitate the implementation of initiatives that will improve diversity in the spatial sector workforce

F. REPRESENTATION

F1. The two peak bodies (SSSI and SIBA) to form one spatial organisation

F2. Align strategies and roadmaps of representative organisations in the spatial sector

F3. Prepare and publish a single explanatory statement of the roles of the key peak bodies across the spatial sector and how they complement each other

F4. Consolidation of a group to drive the 2026Agenda, with the key responsibility to promote and develop innovative leadership across all areas of the spatial sector

APPENDIX B: LIST OF EARTH OBSERVATION SATELLITES AS OF 31 AUGUST 2017

(Source: Union of Concerned Scientists)

COSPAR Number	NORAD Number	Name of Satellite\Alternate Names	Country	Operator/Owner	Date of Launch
2016-025E	41460	AAUSat-4	Denmark	University of Aalborg	25/04/2016
1998-029A	25336	Advanced Orion 2 (Mentor, NROL 6, USA 139)	USA	National Reconnaissance Office (NRO)	09/05/1998
2003-041A	27937	Advanced Orion 3 (Mentor, NROL 19, USA 171)	USA	National Reconnaissance Office (NRO)	09/09/2003
2009-001A	33490	Advanced Orion 4 (Mentor, NRO L-26, USA 202)	USA	National Reconnaissance Office (NRO)	18/01/2009
2010-063A	37232	Advanced Orion 5 (Mentor, NRO L-32, USA 223)	USA	National Reconnaissance Office (NRO)	21/11/2010
2012-034A	38528	Advanced Orion 6 (Mentor, NRO L-15, USA 237)	USA	National Reconnaissance Office (NRO)	29/06/2012
2016-036A	41584	Advanced Orion 7 (Mentor, NRO L-37, USA 268)	USA	National Reconnaissance Office (NRO)	11/06/2016
2007-015A	31304	AIM (Aeronomy of Ice in Mesosphere)	USA	Center for Atmospheric Sciences, Hampton University/ NASA	25/04/2007
2016-059D	41786	Alsat 2B	Algeria	Algerian Space Agency (ASAL)	26/09/2016
2016-059C	41785	Alsat-1B	Algeria	Algerian Space Agency (ASAL)	26/09/2016
2010-035D	36798	Alsat-2A (Algeria Satellite 2A)	Algeria	Algerian Space Agency (ASAL)	12/07/2010
2014-070A	40298	ASNARO 1 (Advanced Satellite with New system Architecture for Observation)	Japan	Ministry of Economy, Trade and Industry	06/11/2014
2015-009A	40420	BARS-M (Cosmos 2503)	Russia	Ministry of Defense	27/02/2015
2016-020A	41394	BARS-M (Cosmos 2515)	Russia	Ministry of Defense	24/03/2016
2005-043A	28890	BeijinGalaxy-1 (Beijing 1 [Tsinghua], Tsinghau-2, China DMC+4)	China	Beijing Landview Mapping Information Technology Co. Ltd (BLMIT)	27/10/2005
2016-040F	41604	BIROS (Bispectral Infrared Optical System)	Germany	German Aerospace Center (DLR)	22/06/2016
2012-039B	38708	BKA 2 (BelKA 2)	Belarus	National Academy of Sciences	22/07/2012
2016-059E	41787	BlackSky Pathfinder 1	USA	BlackSky Global	26/09/2016
2005-017A	28649	CartoSat 1 (IRS P5)	India	Indian Space Research Organization (ISRO)	05/05/2005
2007-001B	29710	CartoSat 2 (IRS P7, CartoSat 2AT)	India	Indian Space Research Organization (ISRO)	10/01/2007
2008-021A	32783	CartoSat 2A	India	Indian Space Research Organization (ISRO)	28/04/2008
2010-035A	36795	CartoSat 2B	India	Indian Space Research Organization (ISRO)	12/07/2010
2016-040A	41599	CartoSat 2C	India	Indian Space Research Organization (ISRO)	22/06/2016
2017-008A	41948	CartoSat 2D	India	Indian Space Research Organization (ISRO)	15/02/2017
2017-036C	42767	CartoSat 2E	India	Indian Space Research Organization (ISRO)	22/06/2017

COSPAR Number	NORAD Number	Name of Satellite\Alternate Names	Country	Operator/Owner	Date of Launch
2014-079A	40336	CBERS 4 (China-Brazil Earth Resources Satellite 4)	China/Brazil	China National Space Administration (China)/National Institute for Space Research (Brazil)	07/12/2014
2008-056B	33434	Chuangxin 1-2 (Innovation 1-2)	China	Chinese Academy of Sciences	05/11/2008
2011-068A	37930	Chuangxin 1-3 (Innovation 1-3)	China	Chinese Academy of Sciences	20/11/2011
2014-051B	40137	Chuangxin 1-4 (Innovation 1-4)	China	Chinese Academy of Sciences	04/09/2014
2017-042C	42827	Cicero-1	USA	GeoOptics Inc.	14/07/2017
2017-042M	42836	Cicero-2	USA	GeoOptics Inc.	14/07/2017
2017-042AA	42849	Cicero-3	USA	GeoOptics Inc.	14/07/2017
2017-036AE	42793	Cicero-6 (Community Initiative for Cellular Earth Remote Observation-6)	USA	GeoOptics Inc.	23/06/2017
2006-016A	29107	Cloudsat	USA	National Aeronautics and Space Administration (NASA)/ Colorado State University	28/04/2006
2014-084A	40353	Condor E2	South Africa	Armed Forces	19/12/2014
2003-001A	27640	Coriolis (Windsat)	USA	US Air Force/ US Navy/NASA	06/01/2003
2017-042Y	42847	Corvis-BC-1 (Landmapper BC)	USA	Astro Digital	14/07/2017
2017-042X	42846	Corvis-BC-2 (Landmapper BC)	USA	Astro Digital	14/07/2017
2006-011A	29047	COSMIC-A (Formosat-3A, Constellation Observing System for Meteorology, Ionosphere and Climate)	Taiwan/USA	National Space Program Office (NSPO)/University Corporation for Atmospheric Research (UCAR) Boulder, CO	15/04/2006
2006-011B	29048	COSMIC-B (Formosat-3B, Constellation Observing System for Meteorology, Ionosphere and Climate)	Taiwan/USA	National Space Program Office (NSPO)/University Corporation for Atmospheric Research (UCAR) Boulder, CO	15/04/2006
2006-011D	29050	COSMIC-D (Formosat-3D, Constellation Observing System for Meteorology, Ionosphere and Climate)	Taiwan/USA	National Space Program Office (NSPO)/University Corporation for Atmospheric Research (UCAR) Boulder, CO	15/04/2006
2006-011E	29051	COSMIC-E (Formosat-3E, Constellation Observing System for Meteorology, Ionosphere and Climate)	Taiwan/USA	National Space Program Office (NSPO)/University Corporation for Atmospheric Research (UCAR) Boulder, CO	15/04/2006
2006-011F	29052	COSMIC-F (Formosat-3F, Constellation Observing System for Meteorology, Ionosphere and Climate)	Taiwan/USA	National Space Program Office (NSPO)/University Corporation for Atmospheric Research (UCAR) Boulder, CO	15/04/2006
2007-023A	31598	COSMO-Skymed 1 (Constellation of small Satellites for Mediterranean basin Observation)	Italy	Italian Space Agency/Ministry of Defense	08/06/2007
2007-059A	32376	COSMO-Skymed 2 (Constellation of small Satellites for Mediterranean basin Observation)	Italy	Italian Space Agency/Ministry of Defense	09/12/2007
2008-054A	33412	COSMO-Skymed 3 (Constellation of small Satellites for Mediterranean basin Observation)	Italy	Italian Space Agency/Ministry of Defense	25/10/2008
2010-060A	37216	COSMO-Skymed 4 (Constellation of small Satellites for Mediterranean basin Observation)	Italy	Italian Space Agency/Ministry of Defense	06/11/2010
2015-003E	40380	CP-10 (Exocube)	USA	California Polytechnic State University/NASA JPL	31/01/2015
2010-013A	36508	Cryosat-2	ESA	European Space Agency (ESA)	08/04/2010
2016-078D	41887	CYGNSS FM01 (Cyclone Global Navigation Satellite System)	USA	University of Michigan/NASA Earth Science Technology Office	15/12/2016

COSPAR Number	NORAD Number	Name of Satellite\Alternate Names	Country	Operator/Owner	Date of Launch
2016-078C	41886	CYGNSS FM02 (Cyclone Global Navigation Satellite System)	USA	University of Michigan/NASA Earth Science Technology Office	15/12/2016
2016-078H	41891	CYGNSS FM03 (Cyclone Global Navigation Satellite System)	USA	University of Michigan/NASA Earth Science Technology Office	15/12/2016
2016-078B	41885	CYGNSS FM04 (Cyclone Global Navigation Satellite System)	USA	University of Michigan/NASA Earth Science Technology Office	15/12/2016
2016-078A	41884	CYGNSS FM05 (Cyclone Global Navigation Satellite System)	USA	University of Michigan/NASA Earth Science Technology Office	15/12/2016
2016-078F	41889	CYGNSS FM06 (Cyclone Global Navigation Satellite System)	USA	University of Michigan/NASA Earth Science Technology Office	15/12/2016
2016-078G	41890	CYGNSS FM07 (Cyclone Global Navigation Satellite System)	USA	University of Michigan/NASA Earth Science Technology Office	15/12/2016
2016-078E	41888	CYGNSS FM08 (Cyclone Global Navigation Satellite System)	USA	University of Michigan/NASA Earth Science Technology Office	15/12/2016
2014-029A	39766	Daichi-2 (Advanced Land Observing Satellite-2, ALOS 2 2)	Japan	Japan Aerospace Exploration Agency (JAXA)	24/05/2014
2009-041A	35681	Deimos 1	Spain	Deimos Imaging/DMC International Imaging (DMCII)	29/07/2009
2014-033D	40013	Deimos 2	Spain	Deimos Imaging/DMC International Imaging (DMCII)	19/06/2014
2015-032A	40715	DMC 3-1 (Disaster Monitoring Constellation)	United Kingdom	Surrey Satellite Technologies Ltd.	10/07/2015
2015-032B	40716	DMC 3-2 (Disaster Monitoring Constellation)	United Kingdom	Surrey Satellite Technologies Ltd.	10/07/2015
2015-032C	40717	DMC 3-3 (Disaster Monitoring Constellation)	United Kingdom	Surrey Satellite Technologies Ltd.	10/07/2015
1997-012A	24753	DMSP 5D-2 F14 (Defense Meteorological Satellites Program, USA 131)	USA	DoD/NOAA	04/04/1997
1999-067A	25991	DMSP 5D-3 F15 (Defense Meteorological Satellites Program, USA 147)	USA	DoD/NOAA	12/12/1999
2003-048A	28054	DMSP 5D-3 F16 (Defense Meteorological Satellites Program, USA 172)	USA	DoD/NOAA	18/10/2003
2006-050A	29522	DMSP 5D-3 F17 (Defense Meteorological Satellites Program, USA 173)	USA	DoD/NOAA	04/11/2006
2009-057A	35951	DMSP 5D-3 F18 (Defense Meteorological Satellites Program, USA 210)	USA	DoD/NOAA	18/10/2009
2014-033T	40027	Dove 1c-1 (0 Flock 1C-1 0903)	USA	Planet Labs, Inc.	19/06/2014
2014-033P	40023	Dove 1c-10 (0 Flock 1C-10 090C)	USA	Planet Labs, Inc.	19/06/2014
2014-033Z	40033	Dove 1c-11 (0 Flock 1C-11 090D)	USA	Planet Labs, Inc.	19/06/2014
2014-033V	40029	Dove 1c-2 (0 Flock 1C-2 0904)	USA	Planet Labs, Inc.	19/06/2014
2014-033AH	40041	Dove 1c-3 (0 Flock 1C-3 0905)	USA	Planet Labs, Inc.	19/06/2014
2014-033X	40031	Dove 1c-4 (0 Flock 1C-4 0906)	USA	Planet Labs, Inc.	19/06/2014
2014-033AE	40038	Dove 1c-5 (0 Flock 1C-5 0907)	USA	Planet Labs, Inc.	19/06/2014
2014-033AC	40036	Dove 1c-6 (0 Flock 1C-6 0908)	USA	Planet Labs, Inc.	19/06/2014
2014-033S	40026	Dove 1c-7 (0 Flock 1C-7 0909)	USA	Planet Labs, Inc.	19/06/2014
2014-033AG	40040	Dove 1c-8 (0 Flock 1C-8 090A)	USA	Planet Labs, Inc.	19/06/2014
2014-033AB	40035	Dove 1c-9 (0 Flock 1C-9 090B)	USA	Planet Labs, Inc.	19/06/2014

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1998-067JD	41483	Dove 2e-1 (0 Flock 2E-1 0C37)	USA	Planet Labs, Inc.	17/05/2016
1998-067JW	41572	Dove 2e-10 (0 Flock 2E-10 0C82)	USA	Planet Labs, Inc.	01/06/2016
1998-067JY	41574	Dove 2e-11 (0 Flock 2E-11 0C13)	USA	Planet Labs, Inc.	01/06/2016
1998-067JX	41573	Dove 2e-12 (0 Flock 2E-12 0C79)	USA	Planet Labs, Inc.	01/06/2016
1998-067JE	41484	Dove 2e-2 (0 Flock 2E-2 0C78)	USA	Planet Labs, Inc.	17/05/2016
1998-067JG	41486	Dove 2e-3 (0 Flock 2E-3 0C60)	USA	Planet Labs, Inc.	17/05/2016
1998-067JH	41487	Dove 2e-4 (0 Flock 2E-4 0C41)	USA	Planet Labs, Inc.	17/05/2016
1998-067JN	41564	Dove 2e-5 (0 Flock 2E-5 0C43)	USA	Planet Labs, Inc.	30/05/2016
1998-067JM	41563	Dove 2e-6 (0 Flock 2E-6 0C75)	USA	Planet Labs, Inc.	30/05/2016
1998-067JP	41565	Dove 2e-7 (0 Flock 2E-7 0C24)	USA	Planet Labs, Inc.	31/05/2016
1998-067JQ	41566	Dove 2e-8 (0 Flock 2E-8 0C2B)	USA	Planet Labs, Inc.	31/05/2016
1998-067JV	41571	Dove 2e-9 (0 Flock 2E-9 0C14)	USA	Planet Labs, Inc.	01/06/2016
1998-067HZ	41479	Dove 2ep-1 (0 Flock 2EP-1 0D05)	USA	Planet Labs, Inc.	17/05/2016
1998-067KA	41576	Dove 2ep-10 (0 Flock 2EP-10 0C65)	USA	Planet Labs, Inc.	03/06/2016
1998-067KB	41577	Dove 2ep-11 (0 Flock 2EP-11 0C27)	USA	Planet Labs, Inc.	03/06/2016
1998-067KC	41578	Dove 2ep-12 (0 Flock 2EP-12 0C81)	USA	Planet Labs, Inc.	03/06/2016
1998-067KH	41761	Dove 2ep-13 (0 Flock 2EP-13 0C45)	USA	Planet Labs, Inc.	15/09/2016
1998-067KJ	41762	Dove 2ep-14 (0 Flock 2EP-14 0C56)	USA	Planet Labs, Inc.	15/09/2016
1998-067KL	41764	Dove 2ep-15 (0 Flock 2EP-15 0C54)	USA	Planet Labs, Inc.	15/09/2016
1998-067KK	41763	Dove 2ep-16 (0 Flock 2EP-16 0C0B)	USA	Planet Labs, Inc.	15/09/2016
1998-067KN	41776	Dove 2ep-17 (0 Flock 2EP-17 0C12)	USA	Planet Labs, Inc.	15/09/2016
1998-067KM	41769	Dove 2ep-18 (0 Flock 2EP-18 0C44)	USA	Planet Labs, Inc.	16/09/2016
1998-067KQ	41782	Dove 2ep-19 (0 Flock 2EP-19 0C62)	USA	Planet Labs, Inc.	15/09/2016
1998-067JB	41481	Dove 2ep-2 (0 Flock 2EP-2 0C1B)	USA	Planet Labs, Inc.	17/05/2016
1998-067KP	41777	Dove 2ep-20 (0 Flock 2EP-20 0C38)	USA	Planet Labs, Inc.	17/09/2016
1998-067JA	41480	Dove 2ep-3 (0 Flock 2EP-3 0D06)	USA	Planet Labs, Inc.	17/05/2016
1998-067JC	41482	Dove 2ep-4 (0 Flock 2EP-4 0C22)	USA	Planet Labs, Inc.	17/05/2016
1998-067JR	41567	Dove 2ep-5 (0 Flock 2EP-5 0C59)	USA	Planet Labs, Inc.	01/06/2016
1998-067JS	41568	Dove 2ep-6 (0 Flock 2EP-6 0C46)	USA	Planet Labs, Inc.	01/06/2016
1998-067JT	41569	Dove 2ep-7 (0 Flock 2EP-7 0C42)	USA	Planet Labs, Inc.	01/06/2016
1998-067JU	41570	Dove 2ep-8 (0 Flock 2EP-8 0C76)	USA	Planet Labs, Inc.	01/06/2016
1998-067JZ	41575	Dove 2ep-9 (0 Flock 2EP-9 0C19)	USA	Planet Labs, Inc.	03/06/2016
2017-042AD	42852	Dove 2k-1 (0 Flock 2K-1 0F1A)	USA	Planet Labs, Inc.	14/07/2017
2017-042BY	42895	Dove 2k-10 (0 Flock 2K-10 0F32)	USA	Planet Labs, Inc.	14/07/2017
2017-042BX	42894	Dove 2k-11 (0 Flock 2K-11 0F33)	USA	Planet Labs, Inc.	14/07/2017
2017-042BW	42893	Dove 2k-12 (0 Flock 2K-12 0F36)	USA	Planet Labs, Inc.	14/07/2017
2017-042BU	42891	Dove 2k-13 (0 Flock 2K-13 0F37)	USA	Planet Labs, Inc.	14/07/2017
2017-042BV	42892	Dove 2k-14 (0 Flock 2K-14 0F3B)	USA	Planet Labs, Inc.	14/07/2017
2017-042BT	42890	Dove 2k-15 (0 Flock 2K-15 0F3C)	USA	Planet Labs, Inc.	14/07/2017
2017-042BS	42889	Dove 2k-16 (0 Flock 2K-16 0F3D)	USA	Planet Labs, Inc.	14/07/2017

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2017-042BR	42888	Dove 2k-17 (0 Flock 2K-17 0F40)	USA	Planet Labs, Inc.	14/07/2017
2017-042BQ	42887	Dove 2k-18 (0 Flock 2K-18 0F44)	USA	Planet Labs, Inc.	14/07/2017
2017-042BP	42886	Dove 2k-19 (0 Flock 2K-19 0F46)	USA	Planet Labs, Inc.	14/07/2017
2017-042AE	42853	Dove 2k-2 (0 Flock 2K-2 0F1E)	USA	Planet Labs, Inc.	14/07/2017
2017-042BN	42885	Dove 2k-20 (0 Flock 2K-20 0F47)	USA	Planet Labs, Inc.	14/07/2017
2017-042AM	42860	Dove 2k-21 (0 Flock 2K-21 0F49)	USA	Planet Labs, Inc.	14/07/2017
2017-042AN	42861	Dove 2k-22 (0 Flock 2K-22 0F4A)	USA	Planet Labs, Inc.	14/07/2017
2017-042AL	42859	Dove 2k-23 (0 Flock 2K-23 0F4B)	USA	Planet Labs, Inc.	14/07/2017
2017-042AJ	42857	Dove 2k-24 (0 Flock 2K-24 0F4F)	USA	Planet Labs, Inc.	14/07/2017
2017-042BM	42884	Dove 2k-25 (0 Flock 2K-25 0F4D)	USA	Planet Labs, Inc.	14/07/2017
2017-042BL	42883	Dove 2k-26 (0 Flock 2K-26 0F53)	USA	Planet Labs, Inc.	14/07/2017
2017-042BK	42882	Dove 2k-27 (0 Flock 2K-27 0F54)	USA	Planet Labs, Inc.	14/07/2017
2017-042BH	42880	Dove 2k-28 (0 Flock 2K-28 1047)	USA	Planet Labs, Inc.	14/07/2017
2017-042AY	42871	Dove 2k-29 (0 Flock 2K-29 1048)	USA	Planet Labs, Inc.	14/07/2017
2017-042AB	42850	Dove 2k-3 (0 Flock 2K-3 0F21)	USA	Planet Labs, Inc.	14/07/2017
2017-042AZ	42872	Dove 2k-30 (0 Flock 2K-30 1049)	USA	Planet Labs, Inc.	14/07/2017
2017-042AW	42869	Dove 2k-31 (0 Flock 2K-31 104A)	USA	Planet Labs, Inc.	14/07/2017
2017-042AX	42870	Dove 2k-32 (0 Flock 2K-32 104B)	USA	Planet Labs, Inc.	14/07/2017
2017-042BG	42879	Dove 2k-33 (0 Flock 2K-33 104C)	USA	Planet Labs, Inc.	14/07/2017
2017-042BF	42878	Dove 2k-34 (0 Flock 2K-34 104D)	USA	Planet Labs, Inc.	14/07/2017
2017-042BE	42877	Dove 2k-35 (0 Flock 2K-35 104E)	USA	Planet Labs, Inc.	14/07/2017
2017-042BD	42876	Dove 2k-36 (0 Flock 2K-36 104F)	USA	Planet Labs, Inc.	14/07/2017
2017-042AU	42867	Dove 2k-37 (0 Flock 2K-37 1050)	USA	Planet Labs, Inc.	14/07/2017
2017-042AV	42868	Dove 2k-38 (0 Flock 2K-38 1051)	USA	Planet Labs, Inc.	14/07/2017
2017-042AT	42866	Dove 2k-39 (0 Flock 2K-39 1052)	USA	Planet Labs, Inc.	14/07/2017
2017-042AC	42851	Dove 2k-4 (0 Flock 2K-4 0F24)	USA	Planet Labs, Inc.	14/07/2017
2017-042AS	42865	Dove 2k-40 (0 Flock 2K-40 1053)	USA	Planet Labs, Inc.	14/07/2017
2017-042BC	42875	Dove 2k-41 (0 Flock 2K-41 1054)	USA	Planet Labs, Inc.	14/07/2017
2017-042BB	42874	Dove 2k-43 (0 Flock 2K-43 1056)	USA	Planet Labs, Inc.	14/07/2017
2017-042BA	42873	Dove 2k-44 (0 Flock 2K-44 1020)	USA	Planet Labs, Inc.	14/07/2017
2017-042AH	42856	Dove 2k-45 (0 Flock 2K-45 100D)	USA	Planet Labs, Inc.	14/07/2017
2017-042AK	42858	Dove 2k-46 (0 Flock 2K-46 103F)	USA	Planet Labs, Inc.	14/07/2017
2017-042AF	42854	Dove 2k-47 (0 Flock 2K-47 1043)	USA	Planet Labs, Inc.	14/07/2017
2017-042AG	42855	Dove 2k-48 (0 Flock 2K-48 101C)	USA	Planet Labs, Inc.	14/07/2017
2017-042AR	42864	Dove 2k-5 (0 Flock 2K-5 0F29)	USA	Planet Labs, Inc.	14/07/2017
2017-042CA	42897	Dove 2k-6 (0 Flock 2K-6 0F2A)	USA	Planet Labs, Inc.	14/07/2017
2017-042AP	42862	Dove 2k-7 (0 Flock 2K-7 0F2B)	USA	Planet Labs, Inc.	14/07/2017
2017-042AQ	42863	Dove 2k-8 (0 Flock 2K-8 0F2D)	USA	Planet Labs, Inc.	14/07/2017
2017-042BZ	42896	Dove 2k-9 (0 Flock 2K-9 0F2E)	USA	Planet Labs, Inc.	14/07/2017
2016-040U	41617	Dove 2p-1 ((0 Flock 2P-1 0E0D)	USA	Planet Labs, Inc.	22/06/2016

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2016-040P	41612	Dove 2p-10 (0 Flock 2P-10 0E2F)	USA	Planet Labs, Inc.	22/06/2016
2016-040K	41608	Dove 2p-11 (0 Flock 2P-11 0E30)	USA	Planet Labs, Inc.	22/06/2016
2016-040R	41614	Dove 2p-12 (0 Flock 2P-12 0E3A)	USA	Planet Labs, Inc.	22/06/2016
2016-040L	41609	Dove 2p-2 (0 Flock 2P-2 (0e0E)	USA	Planet Labs, Inc.	22/06/2016
2016-040V	41618	Dove 2p-3 (0 Flock 2P-3 (0E0F)	USA	Planet Labs, Inc.	22/06/2016
2016-040N	41611	Dove 2p-4 (0 Flock 2P-4 0E14)	USA	Planet Labs, Inc.	22/06/2016
2016-040T	41616	Dove 2p-5 (0 Flock 2P-5 0E16)	USA	Planet Labs, Inc.	22/06/2016
2016-040H	41606	Dove 2p-6 (0 Flock 2P-6 0E19)	USA	Planet Labs, Inc.	22/06/2016
2016-040S	41615	Dove 2p-7 (0 Flock 2P-7 0E1F)	USA	Planet Labs, Inc.	22/06/2016
2016-040Q	41613	Dove 2p-8 (0 Flock 2P-8 0E20)	USA	Planet Labs, Inc.	22/06/2016
2016-040M	41610	Dove 2p-9 (0 Flock 2P-9 0E26)	USA	Planet Labs, Inc.	22/06/2016
2017-008V	41967	Dove 3p-1 (0 Flock 3P-1 1000)	USA	Planet Labs, Inc.	14/02/2017
2017-008AC	41974	Dove 3p-10 (0 Flock 3P-10 1022)	USA	Planet Labs, Inc.	14/02/2017
2017-008AD	41975	Dove 3p-11 (0 Flock 3P-11 101F)	USA	Planet Labs, Inc.	14/02/2017
2017-008AA	41972	Dove 3p-12 (0 Flock 3P-12 1010)	USA	Planet Labs, Inc.	14/02/2017
2017-008CW	42040	Dove 3p-13 (0 Flock 3P-13 1016)	USA	Planet Labs, Inc.	14/02/2017
2017-008BS	42012	Dove 3p-14 (0 Flock 3P-14 1018)	USA	Planet Labs, Inc.	14/02/2017
2017-008CV	42039	Dove 3p-15 (0 Flock 3P-15 101D)	USA	Planet Labs, Inc.	14/02/2017
2017-008BR	42011	Dove 3p-16 (0 Flock 3P-16 100E)	USA	Planet Labs, Inc.	14/02/2017
2017-008Q	41962	Dove 3p-17 (0 Flock 3P-17 1023)	USA	Planet Labs, Inc.	14/02/2017
2017-008K	41957	Dove 3p-18 (0 Flock 3P-18 102B)	USA	Planet Labs, Inc.	14/02/2017
2017-008H	41955	Dove 3p-19 (0 Flock 3P-19 1024)	USA	Planet Labs, Inc.	14/02/2017
2017-008U	41966	Dove 3p-2 (0 Flock 3P-2 1001)	USA	Planet Labs, Inc.	14/02/2017
2017-008C	41950	Dove 3p-20 (0 Flock 3P-20 1029)	USA	Planet Labs, Inc.	14/02/2017
2017-008M	41959	Dove 3p-21 (0 Flock 3P-21 102A)	USA	Planet Labs, Inc.	14/02/2017
2017-008L	41958	Dove 3p-22 (0 Flock 3P-22 1028)	USA	Planet Labs, Inc.	14/02/2017
2017-008BY	42018	Dove 3p-23 (0 Flock 3P-23 1025)	USA	Planet Labs, Inc.	14/02/2017
2017-008J	41956	Dove 3p-24 (0 Flock 3P-24 1026)	USA	Planet Labs, Inc.	14/02/2017
2017-008S	41964	Dove 3p-25 (0 Flock 3P-25 102F)	USA	Planet Labs, Inc.	14/02/2017
2017-008P	41961	Dove 3p-26 (0 Flock 3P-26 102D)	USA	Planet Labs, Inc.	14/02/2017
2017-008R	41963	Dove 3p-27 (0 Flock 3P-27 1030)	USA	Planet Labs, Inc.	14/02/2017
2017-008N	41960	Dove 3p-28 (0 Flock 3P-28 102C)	USA	Planet Labs, Inc.	14/02/2017
2017-008DB	42045	Dove 3p-29 (0 Flock 3P-29 1033)	USA	Planet Labs, Inc.	14/02/2017
2017-008W	41968	Dove 3p-3 (0 Flock 3P-3 1002)	USA	Planet Labs, Inc.	14/02/2017
2017-008AR	41987	Dove 3p-30 (0 Flock 3P-30 102E)	USA	Planet Labs, Inc.	14/02/2017
2017-008DF	42049	Dove 3p-31 (0 Flock 3P-31 1032)	USA	Planet Labs, Inc.	14/02/2017
2017-008CD	42023	Dove 3p-32 (0 Flock 3P-32 1035)	USA	Planet Labs, Inc.	14/02/2017
2017-008AU	41990	Dove 3p-33 (0 Flock 3P-33 103C)	USA	Planet Labs, Inc.	14/02/2017
2017-008AS	41988	Dove 3p-34 (0 Flock 3P-34 103B)	USA	Planet Labs, Inc.	14/02/2017
2017-008AT	41989	Dove 3p-35 (0 Flock 3P-35 103D)	USA	Planet Labs, Inc.	14/02/2017

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2017-008AQ	41986	Dove 3p-36 (0 Flock 3P-36 103A)	USA	Planet Labs, Inc.	14/02/2017
2017-008F	41953	Dove 3p-37 (0 Flock 3P-37 1037)	USA	Planet Labs, Inc.	14/02/2017
2017-008CT	42037	Dove 3p-38 (0 Flock 3P-38 1036)	USA	Planet Labs, Inc.	14/02/2017
2017-008CU	42038	Dove 3p-39 (0 Flock 3P-39 103E	USA	Planet Labs, Inc.	14/02/2017
2017-008T	41965	Dove 3p-4 (0 Flock 3P-4 1003)	USA	Planet Labs, Inc.	14/02/2017
2017-008BQ	42010	Dove 3p-40 (0 Flock 3P-40 1039)	USA	Planet Labs, Inc.	14/02/2017
2017-008BJ	42004	Dove 3p-41 (0 Flock 3P-41 1031)	USA	Planet Labs, Inc.	14/02/2017
2017-008BN	42008	Dove 3p-42 (0 Flock 3P-42 101E)	USA	Planet Labs, Inc.	14/02/2017
2017-008BM	42007	Dove 3p-43 (0 Flock 3P-43 1041)	USA	Planet Labs, Inc.	14/02/2017
2017-008CP	42033	Dove 3p-44 (0 Flock 3P-44 1019)	USA	Planet Labs, Inc.	14/02/2017
2017-008BK	42005	Dove 3p-45 (0 Flock 3P-45 101A)	USA	Planet Labs, Inc.	14/02/2017
2017-008CM	42031	Dove 3p-46 (0 Flock 3P-46 1011)	USA	Planet Labs, Inc.	14/02/2017
2017-008CN	42032	Dove 3p-47 (0 Flock 3P-47 1027)	USA	Planet Labs, Inc.	14/02/2017
2017-008BL	42006	Dove 3p-48 (0 Flock 3P-48 1042)	USA	Planet Labs, Inc.	14/02/2017
2017-008BF	42001	Dove 3p-49 (0 Flock 3P-49 1038)	USA	Planet Labs, Inc.	14/02/2017
2017-008Z	41971	Dove 3p-5 (0 Flock 3P-5 0F18)	USA	Planet Labs, Inc.	14/02/2017
2017-008CK	42029	Dove 3p-50 (0 Flock 3P-50 1034)	USA	Planet Labs, Inc.	14/02/2017
2017-008E	41952	Dove 3p-51 (0 Flock 3P-51 1006)	USA	Planet Labs, Inc.	14/02/2017
2017-008CL	42030	Dove 3p-52 (0 Flock 3P-52 1044)	USA	Planet Labs, Inc.	14/02/2017
2017-008BT	42013	Dove 3p-53 (0 Flock 3P-53 1007)	USA	Planet Labs, Inc.	14/02/2017
2017-008BU	42014	Dove 3p-54 (0 Flock 3P-54 1005)	USA	Planet Labs, Inc.	14/02/2017
2017-008CX	42041	Dove 3p-55 (0 Flock 3P-55 1008)	USA	Planet Labs, Inc.	14/02/2017
2017-008CY	42042	Dove 3p-56 (0 Flock 3P-46 100F)	USA	Planet Labs, Inc.	14/02/2017
2017-008AG	41978	Dove 3p-57 (0 Flock 3P-57 1014)	USA	Planet Labs, Inc.	14/02/2017
2017-008AF	41977	Dove 3p-58 (0 Flock 3P-58 1009)	USA	Planet Labs, Inc.	14/02/2017
2017-008CC	42022	Dove 3p-59 (0 Flock 3P-59 1045)	USA	Planet Labs, Inc.	14/02/2017
2017-008X	41969	Dove 3p-6 (0 Flock 3P-6 0F35)	USA	Planet Labs, Inc.	14/02/2017
2017-008AE	41976	Dove 3p-60 (0 Flock 3P-60 101B)	USA	Planet Labs, Inc.	14/02/2017
2017-008BP	42009	Dove 3p-61 (0 Flock 3P-61 1012)	USA	Planet Labs, Inc.	14/02/2017
2017-008CS	42036	Dove 3p-62 (0 Flock 3P-62 1046)	USA	Planet Labs, Inc.	14/02/2017
2017-008CR	42035	Dove 3p-63 (0 Flock 3P-63 1015)	USA	Planet Labs, Inc.	14/02/2017
2017-008CQ	42034	Dove 3p-64 (0 Flock 3P-64 100A)	USA	Planet Labs, Inc.	14/02/2017
2017-008CJ	42028	Dove 3p-65 (0 Flock 3P-65 1040)	USA	Planet Labs, Inc.	14/02/2017
2017-008BG	42002	Dove 3p-67 (0 Flock 3P-67 1017)	USA	Planet Labs, Inc.	14/02/2017
2017008BH	42003	Dove 3p-68 (0 Flock 3P-68 1004)	USA	Planet Labs, Inc.	14/02/2017
2017-008CA	42020	Dove 3p-69 (0 Flock 3P-69 0F43)	USA	Planet Labs, Inc.	14/02/2017
2017-008Y	41970	Dove 3p-7 (0 Flock 3P-7 100B)	USA	Planet Labs, Inc.	14/02/2017
2017-008AJ	41980	Dove 3p-70 (0 Flock 3P-70 0F15)	USA	Planet Labs, Inc.	14/02/2017
2017-008CE	42024	Dove 3p-71 (0 Flock 3P-71 0F11)	USA	Planet Labs, Inc.	14/02/2017
2017-008DH	42051	Dove 3p-72 (0 Flock 3P-72 0F11)	USA	Planet Labs, Inc.	14/02/2017

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2017-008AK	41981	Dove 3p-73 (0 Flock 3P-73 0F1B)	USA	Planet Labs, Inc.	14/02/2017
2017-008DE	42048	Dove 3p-74 (0 Flock 3P-74 0F22)	USA	Planet Labs, Inc.	14/02/2017
2017-008BZ	42019	Dove 3p-76 (0 Flock 3P-76 0F17)	USA	Planet Labs, Inc.	14/02/2017
2017-008CF	42025	Dove 3p-77 (0 Flock 3P-77 0F28)	USA	Planet Labs, Inc.	14/02/2017
2017-008DD	42047	Dove 3p-78 (0 Flock 3P-78 0F51)	USA	Planet Labs, Inc.	14/02/2017
2017-008AN	41984	Dove 3p-79 (0 Flock 3P-79 0F52)	USA	Planet Labs, Inc.	14/02/2017
2017-008D	41951	Dove 3p-8 (0 Flock 3P-8 100C)	USA	Planet Labs, Inc.	14/02/2017
2017-008CG	42026	Dove 3p-80 (0 Flock 3P-80 0F4E)	USA	Planet Labs, Inc.	14/02/2017
2017-008CZ	42043	Dove 3p-81 (0 Flock 3P-81 0F25)	USA	Planet Labs, Inc.	14/02/2017
2017-008DC	42046	Dove 3p-82 (0 Flock 3P-82 0F41)	USA	Planet Labs, Inc.	14/02/2017
2017-008DG	42050	Dove 3p-83 (0 Flock 3P-83 0F3F)	USA	Planet Labs, Inc.	14/02/2017
2017-008CB	42021	Dove 3p-84 (0 Flock 3P-84 0F42)	USA	Planet Labs, Inc.	14/02/2017
2017-008AM	41983	Dove 3p-85 (0 Flock 3P-85 0F1D)	USA	Planet Labs, Inc.	14/02/2017
2017-008AP	41985	Dove 3p-86 (0 Flock 3P-86 0F34)	USA	Planet Labs, Inc.	14/02/2017
2017-008DA	42044	Dove 3p-87 (0 Flock 3P-87 0F31)	USA	Planet Labs, Inc.	14/02/2017
2017-008AL	41982	Dove 3p-88 (0 Flock 3P-88 0F38)	USA	Planet Labs, Inc.	14/02/2017
2017-008AB	41973	Dove 3p-9 (0 Flock 3P-9 1021)	USA	Planet Labs, Inc.	14/02/2017
2017-008CH	42027	Dove3p-66 (0 Flock 3P-66 1013)	USA	Planet Labs, Inc.	14/02/2017
2017-008AH	41979	Dove3p-75 (0 Flock 3P-75 0F12)	USA	Planet Labs, Inc.	14/02/2017
1997-008A	24737	DSP 18 (USA 130) (Defense Support Program)	USA	Air Force	23/02/1997
2000-024A	26356	DSP 20 (USA 149) (Defense Support Program)	USA	Air Force	18/05/2000
2001-033A	26880	DSP 21 (USA 159) (Defense Support Program)	USA	Air Force	06/08/2001
2004-004A	28158	DSP 22 (USA 176) (Defense Support Program)	USA	Air Force	14/02/2004
2009-041B	35682	DubaiSat-1	United Arab Emirates	Emirates Institution for Advanced Science & Technology (EIAST)	29/07/2009
2013-066D	39419	DubaiSat-2	United Arab Emirates	Emirates Institution for Advanced Science & Technology (EIAST)	21/11/2013
2015-066A	41032	EKS-1 (Integrated Space System, Cosmos 2510, Tundra 11L)	Russia	Ministry of Defense	17/11/2015
2017-027A	42719	EKS-2 (Integrated Space System, Cosmos 2518, Tundra 12L)	Russia	Ministry of Defense	25/05/2017
2011-001A	37344	Electro-L1 (GOMS 2 [Geostationary Operational Meteorological Satellite 2]	Russia	Roshydromet - Planeta	20/01/2011
2015-074A	41105	Electro-L2	Russia	Roshydromet - Planeta	11/12/2015
2011-076D	38010	ELISA-E12 (ELectronic Intelligence by SAtellite)	France	DGA (Arms Procurement Agency)/Centre National d'Etudes Spatiales (CNES)	17/12/2011
2011-076B	38008	ELISA-E24 (ELectronic Intelligence by SAtellite)	France	DGA (Arms Procurement Agency)/Centre National d'Etudes Spatiales (CNES)	17/12/2011
2011-076A	38007	ELISA-W11 (ELectronic Intelligence by SAtellite)	France	DGA (Arms Procurement Agency)/Centre National d'Etudes Spatiales (CNES)	17/12/2011

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2011-076C	38009	ELISA-W23 (ELectronic Intelligence by SAtellite)	France	DGA (Arms Procurement Agency)/Centre National d'Etudes Spatiales (CNES)	17/12/2011
1999-068A	25994	EOS-AM Terra	USA/ Canada/ Japan	Earth Sciences Enterprise (NASA)	18/12/1999
2004-026A	28376	EOS-CHEM Aura	USA	Goddard Space Flight Center/ EOS Data and Operations System	15/07/2004
2002-022A	27424	EOS-PM Aqua (Advanced Microwave Scanning Radiometer for EOS, EOS PM-1)	USA/Japan/ Brazil	National Aeronautics and Space Administration (NASA) - Earth Science Enterprise/ Japan Meteorological Agency/ Brazilian Space Agency	04/05/2002
2006-014A	29079	EROS B1 (Earth Resources Observation Satellite)	Israel	ImageSat International, NV/ Ministry of Defense	25/04/2006
2006-053A	29640	Fengyun 2D (FY-2D)	China	China Meteorological Administration	08/12/2006
2008-066A	33463	Fengyun 2E (FY-2E)	China	China Meteorological Administration	23/12/2008
2012-002A	38049	Fengyun 2F (FY-2F)	China	China Meteorological Administration	12/01/2012
2014-090A	40367	Fengyun 2G (FY 2G)	China	China Meteorological Administration	31/12/2014
2008-026A	32958	Fengyun 3A (FY-3A)	China	China Meteorological Administration	27/05/2008
2010-059A	37214	Fengyun 3B (FY-3B)	China	China Meteorological Administration	04/11/2010
2013-052A	39260	Fengyun 3C (FY-3C)	China	China Meteorological Administration	23/09/2013
2010-046A	37162	FIA Radar 1 (Future Imagery Architecture (FIA) Radar 1, NROL-41, USA 215, Topaz)	USA	National Reconnaissance Office (NRO)	21/09/2010
2012-014A	38109	FIA Radar 2 (Future Imagery Architecture (FIA) Radar 2, NROL-25, USA 234, Topaz)	USA	National Reconnaissance Office (NRO)	03/04/2012
2013-072A	39462	FIA Radar 3 (Future Imagery Architecture (FIA) Radar 3, NROL-39 , USA 247, Topaz)	USA	National Reconnaissance Office (NRO)	06/12/2013
2016-010A	41334	FIA Radar 4 (Future Imagery Architecture (FIA) Radar 4, NROL-45, USA 267, Topax)	USA	National Reconnaissance Office (NRO)	10/02/2016
2017-049A	42920	FormoSat-5	Taiwan	National Space Organization	25/08/2017
1997-047A	24920	FORTÉ (Fast On-orbit Recording of Transient Events)	USA	Los Alamos National Laboratory	29/08/1997
2013-018A	39150	Gaofen 1	China	Shanghai Academy of Spaceflight Technology (SAST)	26/04/2013
2014-049A	40118	Gaofen 2	China	Shanghai Academy of Spaceflight Technology (SAST)	19/08/2014
2016-049A	41727	Gaofen 3	China	State Oceanic Administration (SOA)	09/08/2016
2015-083A	41194	Gaofen 4	China	China Aerospace Science and Technology Corporation (CASC)	28/12/2015
2015-030A	40701	Gaofen 8	China	Shanghai Academy of Spaceflight Technology (SAST)	26/06/2015
2015-047A	40894	Gaofen 9	China	China Aerospace Science and Technology Corporation (CASC)	14/09/2015

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2008-042A	33331	GeoEye-1 (Orbview 5)	USA	DigitalGlobal Corporation	06/09/2008
2012-025A	38337	Global Change Observation Mission - 1 Water (GCOM-1, Shikuzu)	USA/Japan	Japan Aerospace Exploration Agency (JAXA)	17/05/2012
2006-018A	29155	GOES 13 (Geostationary Operational Environmental Satellite, GOES-N)	USA	NOAA (National Oceanographic and Atmospheric Administration)	24/05/2006
2009-033A	35491	GOES 14 (Geostationary Operational Environmental Satellite, GOES-O)	USA	NOAA (National Oceanographic and Atmospheric Administration)	27/06/2009
2010-008A	36411	GOES 15 (Geostationary Operational Ennvironmental Satellite, GOES-P)	USA	NOAA (National Oceanographic and Atmospheric Administration)	04/03/2010
2016-071A	41866	GOES 16 (Geostationary Operational Environmental Satellite GOES-R)	USA	NOAA (National Oceanographic and Atmospheric Administration)	19/11/2016
2016-073A	41875	Göktürk 1	Turkey	Turkish Ministry of National Defense	05/12/2016
2012-073A	39030	Göktürk 2	Turkey	Turkish Ministry of National Defense	18/12/2012
2014-009C	39574	GPM Core Observatory (Global Precipitation Measurement)	USA/Japan	National Aeronautics and Space Administration (NASA)/ JAXA	27/02/2014
2002-012A	27391	Grace 1 (Gravity Recovery and Climate Experiment, "Tom and Jerry")	Germany/ USA	GeoForschungsZentrum (GFZ)/Center for Space Research, University of Texas	17/03/2002
2002-012B	27392	Grace 2 (Gravity Recovery and Climate Experiment, "Tom and Jerry")	Germany/ USA	GeoForschungsZentrum (GFZ)/Center for Space Research, University of Texas	17/03/2002
2009-002A	33492	Greenhouse Gases Observing Satellite (Ibuki, GoSAT)	Japan	Japan Aerospace Exploration Agency (JAXA)	23/01/2009
2011-043A	37781	Haiyang 2A (HY 2A)	China	State Oceanic Administration (SOA)	15/08/2011
2004-049A	28492	Helios 2A	France/Italy/ Belgium/ Spain/ Greece	Centre National d'Etudes Spatiales (CNES)/Délégation Générale de l'Armement (DGA)	18/12/2004
2009-073A	36124	Helios 2B	France/Italy/ Belgium/ Spain/ Greece	Centre National d'Etudes Spatiales (CNES)/Délégation Générale de l'Armement (DGA)	18/12/2009
2014-060A	40267	Himawari 8	Japan	Japan Meteorological Agency/ Meteorological Satellite Center (MSC)	07/10/2014
2016-064A	41836	Himawari 9	Japan	Japan Meteorological Agency/ Meteorological Satellite Center (MSC)	02/11/2016
2008-041A	33320	HJ-1A (Huan Jing 1A)	China	National Remote Sensing Center (NRSCC)	05/09/2008
2008-041B	33321	HJ-1B (Huan Jing 1B)	China	National Remote Sensing Center (NRSCC)	05/09/2008
2012-064A	38997	HJ-1C (Huan Jing 1C)	China	National Committee for Disaster Reduction and State Environmental Protection	18/11/2012
2014-070B	40299	Hodoyoshi-1	Japan	University of Tokyo and NESTRA	06/11/2014
2017-015A	42078	IGS-10A (Information Gathering Satellite 10A, IGS Radar 5)	Japan	Cabinet Satellite Intelligence Center (CSIC)	16/03/2017

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2009-066A	36104	IGS-5A (Information Gathering Satellite 5A, IGS Optical 3)	Japan	Cabinet Satellite Intelligence Center (CSIC)	28/11/2009
2011-050A	37813	IGS-6A (Information Gathering Satellite 6A, IGS Optical 4)	Japan	Cabinet Satellite Intelligence Center (CSIC)	23/09/2011
2011-075A	37954	IGS-7A (Information Gathering Satellite 7A, IGS Radar 3)	Japan	Cabinet Satellite Intelligence Center (CSIC)	12/12/2011
2013-002A	39061	IGS-8A (Information Gathering Satellite 8A, IGS Radar 4)	Japan	Cabinet Satellite Intelligence Center (CSIC)	27/01/2013
2013-002B	39062	IGS-8B (Information Gathering Satellite 8B, IGS Optical 5 Demonstrator)	Japan	Cabinet Satellite Intelligence Center (CSIC)	27/01/2013
2015-004A	40381	IGS-9A (Information Gathering Satellite 9A, IGS Radar Spare)	Japan	Cabinet Satellite Intelligence Center (CSIC)	31/01/2015
2015-015A	40538	IGS-9B (Information Gathering Satellite 9B, IGS Optical 5)	Japan	Cabinet Satellite Intelligence Center (CSIC)	26/03/2015
2006-027A	29249	Improved Trumpet 4 (NROL-22, National Reconnaissance Office Launch-22, SBIRS HEO-1, Twins 1, USA 184)	USA	National Reconnaissance Office (NRO)	28/06/2006
2008-010A	32706	Improved Trumpet 5 (NROL-28, National Reconnaissance Office Launch-28, SBIRS HEO-2, Twins 2, USA 200)	USA	National Reconnaissance Office (NRO)	13/03/2008
2014-081A	40344	Improved Trumpet 6 (NROL-35, National Reconnaissance Office Launch-35, SBIRS HEO-3, USA 259)	USA	National Reconnaissance Office (NRO)	13/12/2014
2017-008B	41949	INS-1A (ISRO Nano Satellite)	India	Indian Space Research Organization (ISRO)	15/02/2017
2017-008G	41954	INS-1B (ISRO Nano Satellite)	India	Indian Space Research Organization (ISRO)	15/02/2017
2003-013A	27714	INSAT 3A (Indian National Satellite)	India	Indian Space Research Organization (ISRO)	09/04/2003
2013-038B	39216	INSAT 3D (Indian National Satellite)	India	Indian Space Research Organization (ISRO)	25/07/2013
2016-054A	41752	INSAT 3DR (Indian National Satellite)	India	Indian Space Research Organization (ISRO)	08/09/2016
2003-046A	28051	IRS-P6 (Resourcesat-1)	India	Indian Space Research Organization (ISRO)	17/10/2003
2008-032A	33105	Jason 2	USA/France	National Aeronautics and Space Administration (NASA)/ Centre National d'Etudes Spatiales (CNES)/NOAA/ EUMETSAT	20/06/2008
2016-002A	41240	Jason 3	USA/France	National Aeronautics and Space Administration (NASA)/ Centre National d'Etudes Spatiales (CNES)/NOAA/ EUMETSAT	17/01/2016
2017-002B	41914	Jilin 1-3 (Lingqiao 3)	China	Changchun Institute of Optics	09/01/2017
2015-057A	40958	Jilin 1-A (Lingqiao Satellite, LQSat)	China	Changchun Institute of Optics	07/10/2015
2015-057B	40959	Jilin-1 (Lingqiao-A, Lingqiao Video A)	China	Changchun Institute of Optics	07/10/2015
2015-057C	40960	Jilin-1 (Lingqiao-B, Lingqiao Video B)	China	Changchun Institute of Optics	07/10/2015
2015-057D	40961	Jilin-1-1 (Optical A, Lingqiao 1)	China	Changchun Institute of Optics	07/10/2015
2011-058B	37839	Jugnu	India	Indian Institute of Technology Kanpur	12/10/2011
2002-043A	27525	Kalpana-1 (Metsat-1)	India	Indian Space Research Organization (ISRO)	12/09/2002

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2012-039A	38707	Kanopus-B (Kanopus Vulcan 1)	Russia	Scientific Production Corporation (joint stock creation of Russian Space Agency)	22/07/2012
2017-042A	42825	Kanopus-V-IK-2	Russia	Roscosmos State Corporation	14/07/2017
2014-024A	39731	KazEOSat-1 (Kazcosmos Earth Observation Satellite)	Kazakhstan	Kazcosmos	30/04/2014
2014-033A	40010	KazEOSat-2 (kazcosmos Earth Observation Satellite)	Kazakhstan	Kazcosmos	19/06/2014
2015-077B	41167	Kent Ridge 1	Singapore	National University of Singapore	16/12/2015
2005-042A	28888	Keyhole 5 (Advanced KH-11, KH-12-5, Improved Crystal, EIS-3, USA 186)	USA	National Reconnaissance Office (NRO)	19/10/2005
2011-002A	37348	Keyhole 6 (NRO L49, Advanced KH-11, KH-12-6, Improved Crystal, USA 224)	USA	National Reconnaissance Office (NRO)	20/01/2011
2013-043A	39232	Keyhole 7 (NRO L65, Advanced KH-11, Improved Crystal, USA 245)	USA	National Reconnaissance Office (NRO)	28/08/2013
2012-025B	38338	Kompsat-3 (Arirang 3, Korean Multipurpose Satellite-3)	South Korea	Korea Aerospace Research Institute (KARI)	17/05/2012
2015-014A	40536	Kompsat-3A (Arirang 3A, Korean Multipurpose Satellite-3A)	South Korea	Korea Aerospace Research Institute (KARI)	25/03/2015
2013-042A	39227	Kompsat-5 (Arirang 5, Korean Multipurpose Satellite-4)	South Korea	Korea Aerospace Research Institute (KARI)	22/08/2013
2013-032A	39194	Kondor (Cosmos 2487)	Russia	Ministry of Defense	27/06/2013
1997-064A	25017	Lacrosse/Onyx 3 (Lacrosse-3, USA 133)	USA	National Reconnaissance Office (NRO)	24/10/1997
2000-047A	26473	Lacrosse/Onyx 4 (Lacrosse-4, USA 152)	USA	National Reconnaissance Office (NRO)	17/08/2000
2005-016A	28646	Lacrosse/Onyx 5 (Lacrosse-5, NROL 16, USA 182)	USA	National Reconnaissance Office (NRO)	30/04/2005
1999-020A	25682	Landsat 7	USA	National Aeronautics and Space Administration (NASA)/ US Geological Survey	15/04/1999
2013-008A	39084	Landsat 8	USA	National Aeronautics and Space Administration (NASA)/ US Geological Survey	11/02/2013
2015-052B	40931	LAPAN A2	Indonesia	Indonesian National Aeronautics and Space Agency (Lembaga Penerbangan dan Antariksa Nasional - LAPAN)	24/09/2015
2016-040E	41603	LAPAN A3	Indonesia	Indonesian National Aeronautics and Space Agency (Lembaga Penerbangan dan Antariksa Nasional - LAPAN)	22/06/2016
2015-052G	40936	Lemur-2 Chris (Lemur-2 F4)	USA	Spire Global Inc.	28/09/2015
2015-052F	40935	Lemur-2 Jeroen (Lemur-2 F3)	USA	Spire Global Inc.	28/09/2015
2015-052D	40933	Lemur-2 Joel (Lemur-2 F1)	USA	Spire Global Inc.	28/09/2015
2015-052E	40934	Lemur-2 Peter (Lemur-2 F2)	USA	Spire Global Inc.	28/09/2015
2017-042P	42838	Lemur-2-AndiS (Lemur 2F47)	USA	Spire Global Inc.	14/07/2017
2017-019C	42753	Lemur-2-Angela (Lemur 2F31)	USA	Spire Global Inc.	18/04/2017
2016-062E	41873	Lemur-2-Anubhavthakur (Lemur 2-F16)	USA	Spire Global Inc.	17/10/2016

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2017-042BJ	42881	Lemur-2-ArtFischer (Lemur 2F43)	USA	Spire Global Inc.	14/07/2017
1998-067LD	42068	Lemur-2-Austintacious (Lemur2-F20)	USA	Spire Global Inc.	09/12/2016
2017-042T	42842	Lemur-2-Dembitz (Lemur 2F49)	USA	Spire Global Inc.	14/07/2017
2017-042R	42840	Lemur-2-Furiaus (Lemur 2F45)	USA	Spire Global Inc.	14/07/2017
2017-042N	42837	Lemur-2-Greenberg (Lemur 2F42)	USA	Spire Global Inc.	14/07/2017
2017-019B	42752	Lemur-2-JennyBarna (Lemur 2F30)	USA	Spire Global Inc.	18/04/2017
2017-008BB	41997	Lemur-2-Jobanputra (Lemur 2-F22)	USA	Spire Global Inc.	15/02/2017
2017-036K	24774	Lemur-2-KungFoo (Lemur 2F37)	USA	Spire Global Inc.	23/06/2017
2017-036R	42780	Lemur-2-Lisasaurus (Lemur 2F40)	USA	Spire Global Inc.	23/06/2017
2017-036J	24773	Lemur-2-LucyBryce (Lemur 2F36)	USA	Spire Global Inc.	23/06/2017
2017-036Q	42779	Lemur-2-Lynsey-Symo (Lemur 2F41)	USA	Spire Global Inc.	23/06/2017
2017-036T	42782	Lemur-2-McPeake (Lemur 2F38)	USA	Spire Global Inc.	23/06/2017
2017-008AW	41992	Lemur-2-Mia-Grace (Lemur 2F27)	USA	Spire Global Inc.	15/02/2017
2017-042Q	42839	Lemur-2-Monson (Lemur 2F44)	USA	Spire Global Inc.	14/07/2017
2017-008BA	41996	Lemur-2-NoguesCorreig (Lemur 2F28)	USA	Spire Global Inc.	15/02/2017
2017-042S	42841	Lemur-2-PeterG (Lemur 2F48)	USA	Spire Global Inc.	14/07/2017
2017-008AZ	41995	Lemur-2-Rdeaton (Lemur 2-F25)	USA	Spire Global Inc.	15/02/2017
1998-067LA	42059	Lemur-2-Redfern-Goes (Lemur 2-F21)	USA	Spire Global Inc.	09/12/2016
2017-019E	42755	Lemur-2-RobMoore) (Lemur 2F33)	USA	Spire Global Inc.	18/04/2017
2017-036S	42781	Lemur-2-Sam-Amelia (Lemur 2F39)	USA	Spire Global Inc.	23/06/2017
2017-008AV	41991	Lemur-2-Satchmo (Lemur 2-F24)	USA	Spire Global Inc.	15/02/2017
2017-036G	24771	Lemur-2-ShainaJohl (Lemur 2F34)	USA	Spire Global Inc.	23/06/2017
2017-008AX	41993	Lemur-2-Smita-Sharad (Lemur 2-F26)	USA	Spire Global Inc.	15/02/2017
2016-062D	41872	Lemur-2-Sokolsky (Lemur 2-F14)	USA	Spire Global Inc.	17/10/2016
2017-008AY	41994	Lemur-2-Spire-Minions (Lemur 2F23)	USA	Spire Global Inc.	15/02/2017
2017-019D	42754	Lemur-2-SpiroVision) (Lemur 2F32)	USA	Spire Global Inc.	18/04/2017
2017-008BC	41998	Lemur-2-Tachikoma (Lemur 2F29)	USA	Spire Global Inc.	15/02/2017
1998-067LC	42067	Lemur-2-Trutna (Lemur 2-F18)	USA	Spire Global Inc.	09/12/2016
1998-067LE	42069	Lemur-2-TrutnaHD (Lemur 2-F19)	USA	Spire Global Inc.	09/12/2016
2016-062F	41874	Lemur-2-Wingo (Lemur 2-F17)	USA	Spire Global Inc.	17/10/2016
2016-062C	41871	Lemur-2-Xiaoqing (Lemur-2 F15)	USA	Spire Global Inc.	17/10/2016
2017-036H	24772	Lemur-2-XueniTerence (Lemur 2F35)	USA	Spire Global Inc.	23/06/2017
2017-042W	42845	Lemur-2-Zachary (Lemur 2F46)	USA	Spire Global Inc.	14/07/2017
2009-063A	36095	Lotos-S1 (Cosmos 2455)	Russia	Ministry of Defense	20/11/2009
2014-086A	40358	Lotos-S2 (Cosmos 2502)	Russia	Ministry of Defense	23/12/2014
2015-057A	40958	LQSat (Lingqiao Satellite, Jilian 1A)	China	Changchun Institute of Optics	07/10/2015
2016-040G	41605	M3MSat (Maritime Monitoring and Messaging Microsatellite)	Canada	Defence Research and Development Canada (DRDC)/ Canadian Space Agency	22/06/2016

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2011-058A	37838	Megha-Tropiques	India/ France	Indian Space Research Organization (ISRO)/Centre National d'Etudes Spatiales (CNES)	12/10/2011
1994-054A	23223	Mercury 1 (Advanced Vortex 1, USA 105)	USA	National Reconnaissance Office (NRO)/USAF	27/08/1994
1996-026A	23855	Mercury 2 (Advanced Vortex 2, USA 118)	USA	National Reconnaissance Office (NRO)/USAF	24/04/1996
2014-020A	39652	Mercury 3 (NROL 67, USA 250)	USA	National Reconnaissance Office (NRO)/USAF	10/04/2014
2014-037A	40069	Meteor-M N-2	Russia	Russian Federal Service For Hydrometeorology and Environmental Monitoring (ROSHYDROMET)	08/07/2014
2012-035B	38552	Meteosat 10 (MSGalaxy-3,MSG 3)	Multinational	EUMETSAT (European Organization for the Exploitation of Meteorological Satellites)	05/07/2012
2015-034A	40732	Meteosat 11 (MSG 4)	Multinational	EUMETSAT (European Organization for the Exploitation of Meteorological Satellites)	15/07/2015
2002-040B	27509	Meteosat 8 (MSGalaxy-1, MSG-1)	Multinational	EUMETSAT (European Organization for the Exploitation of Meteorological Satellites)	21/08/2002
2005-049B	28912	Meteosat 9 (MSGalaxy-2, MSG 2)	Multinational	EUMETSAT (European Organization for the Exploitation of Meteorological Satellites)	21/12/2005
2006-044A	29499	MetOp-A (Meteorological Operational satellite)	Multinational	ESA/EUMETSAT (European Organization for the Exploitation of Meterological Satellites)	19/10/2006
2012-049A	38771	MetOp-B (Meteorological Operational satellite)	Multinational	ESA/EUMETSAT (European Organization for the Exploitation of Meterological Satellites)	17/09/2012
2017-042J	42833	MKA-1	Russia	Roscosmos State Corporation	14/07/2017
2017-042K	42834	MKA-2	Russia	Roscosmos State Corporation	14/07/2017
2006-004A	28937	MTSAT-2 (Multi-Functional Transport Satellite)	Japan	Japan Meteorological Agency/ Meteorological Satellite Center (MSC)	18/02/2006
2011-044B	37789	NigeriaSat-2	Nigeria	National Space Research and Development Agency (NASRDA)	17/08/2011
1998-030A	25338	NOAA-15 (NOAA-K)	USA	National Oceanographic and Atmospheric Administration (NOAA) (part of international program)	13/05/1998
2005-018A	28654	NOAA-18 (NOAA-N, COSPAS-SARSAT)	USA	National Oceanographic and Atmospheric Administration (NOAA) (part of international program)	20/05/2005
2009-005A	33591	NOAA-19 (NOAA-N Prime, COSPAS-SARSAT)	USA	National Oceanographic and Atmospheric Administration (NOAA) (part of international program)	06/02/2009

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2017-042D	42828	NorSat-2	Norway	Norwegian Space Center	14/07/2017
2011-061A	37849	NPP (National Polar-orbiting Operational Environmental Satellite System [NPOESS])	USA	National Oceanographic and Atmospheric Administration (NOAA)/NASA	28/10/2011
2016-033B	41557	ÑuSat-1 (Fresco)	Argentina	Satellogic	29/05/2016
2016-033C	41558	ÑuSat-2 (Batata)	Argentina	Satellogic	29/05/2016
2017-034C	42760	ÑuSat-3 (Milanesat)	Argentina	Satellogic	15/06/2017
2014-035A	40059	OCO 2 (Orbiting Carbon Observatory)	USA	National Aeronautics and Space Administration (NASA)	02/07/2014
2001-007A	26702	Odin	Sweden	Swedish National Space Board	20/02/2001
2014-019A	39650	Ofeq 10	Israel	Ministry of Defense	09/04/2014
2016-056A	41759	Ofeq 11	Israel	Ministry of Defense	13/09/2016
2002-025A	27434	Ofeq 5	Israel	Ministry of Defense	28/05/2002
2007-025A	31601	Ofeq 7	Israel	Ministry of Defense	10/06/2007
2010-031A	36608	Ofeq 9	Israel	Ministry of Defense	22/06/2010
2017-044A	42900	Optsat-3000	Italy	Italian Defense Ministry	01/08/2017
2009-047A	35815	PAN-1 (Nemesis, Palladium at Night, P360, USA 207)	USA	Unknown US intelligence agency	08/09/2009
2013-028A	39177	Persona-2 (Cosmos 2486)	Russia	Ministry of Defense	07/06/2013
2015-029A	40699	Persona-3 (Cosmos 2506)	Russia	Ministry of Defense	23/06/2015
2016-058A	41770	PeruSat-1	Peru	Peruvian SpaceAgency	16/09/2016
2011-076F	38012	Pléiades HR1A	France/Italy	Ministry of Defense/Centre National d'Etudes Spatiales (CNES) - cooperation with Austria, Belgium, Spain, Sweden	17/12/2011
2012-068A	39019	Pléiades HR1B	France	Ministry of Defense/Centre National d'Etudes Spatiales (CNES) - cooperation with Austria, Belgium, Spain, Sweden	02/12/2012
2013-021A	39159	Proba V (Project for On-Board Autonomy)	ESA	European Space Agency (ESA)	07/05/2013
2014-070D	40301	Qsat-EOS (KYUshu SATellite - Earth Observation System)	Japan	Kyushu University	06/11/2014
2007-061A	32382	Radarsat-2	Canada	Radarsat International	14/12/2007
2008-040C	33314	RapidEye-1 (RapidEye-C)	Germany	RapidEye AG	29/08/2008
2008-040A	33312	RapidEye-2 (RapidEye A)	Germany	RapidEye AG	29/08/2008
2008-040D	33315	RapidEye-3 (RapidEye D)	Germany	RapidEye AG	29/08/2008
2008-040E	33316	RapidEye-4 (RapidEye E)	Germany	RapidEye AG	29/08/2008
2008-040B	33313	RapidEye-5 (RapidEye B)	Germany	RapidEye AG	29/08/2008
2011-044D	37791	RASAT	Turkey	Space Technologies Research Institute	17/08/2011
2014-037B	40070	Relek (ICA-FC1)	Russia	Skobeltsyn Institute of Nuclear Physics	08/07/2014
2011-015A	37387	Resourcesat 2 (exactView-2)	India/ Canada	Indian Space Research Organization (ISRO)/ exactEarth	20/04/2011

COSPAR Number	NORAD Number	Name of Satellite\Alternate Names	Country	Operator/Owner	Date of Launch
2016-074A	41877	Resourcesat-2A	India	Indian Space Research Organization (ISRO)	07/12/2016
2013-030A	39186	Resurs-P1	Russia	Russian Federal Space Agency (Roskosmos)	25/06/2013
2016-016A	41386	Resurs-P3	Russia	Russian Federal Space Agency (Roskosmos)	13/03/2016
2012-017A	38248	RISat-1 (Radar Imaging Satellite 1)	India	Ministry of Defense	25/04/2012
2009-019A	34807	RISat-2 (Radar Imaging Satellite 2)	India	Ministry of Defense	20/04/2009
2014-029D	39769	Rising-2	Japan	Tohoku University/Hokkaido University	24/05/2014
2013-009A	39086	SARAL (Satellite with ARGOS and ALTIKA)	India/ France	Indian Space Research Organization (ISRO)/Centre National d'Etudes Spatiales (CNES)	25/02/2013
2006-060A	29658	SAR-Lupe 1	Germany	Armed Forces	19/12/2006
2007-030A	31797	SAR-Lupe 2	Germany	Armed Forces	02/07/2007
2007-053A	32283	SAR-Lupe 3	Germany	Armed Forces	01/11/2007
2008-014A	32750	SAR-Lupe 4	Germany	Armed Forces	27/03/2008
2008-036A	33244	SAR-Lupe 5	Germany	Armed Forces	22/07/2008
2004-025F	28371	Saudisat-2	Saudi Arabia	Riyadh Space Research Institute	29/06/2004
2007-012B	31118	Saudisat-3	Saudi Arabia	Riyadh Space Research Institute	17/04/2007
2011-019A	37481	SBIRS GEO 1 (Space Based Infrared System Geosynchronous 1, USA 230)	USA	US Air Force	07/05/2011
2013-011A	39120	SBIRS GEO 2 (Space Based Infrared System Geosynchronous 2, USA 241)	USA	US Air Force	19/03/2013
2017-004A	41937	SBIRS GEO 3 (Space Based Infrared System Geosynchronous 3, USA 273)	USA	US Air Force	20/01/2017
2005-004B	28541	SB-WASS 3-3 (Space Based Wide Area Surveillance System) (NOSS 3-3, USA 181, NRO L23, Intruder)	USA	National Reconnaissance Office (NRO)/US Navy	03/02/2005
2005-004A	28537	SB-WASS 3-3 (Space Based Wide Area Surveillance System) (NOSS 3-3, USA 181, NRO L23, Intruder)	USA	National Reconnaissance Office (NRO)/US Navy	03/02/2005
2007-027A	31701	SB-WASS 3-4 (Space Based Wide Area Surveillance System) NOSS 3-4, USA 194, NRO L30, Intruder)	USA	National Reconnaissance Office (NRO)/US Navy	15/06/2007
2007-027B	31708	SB-WASS 3-4 (Space Based Wide Area Surveillance System) NOSS 3-4, USA 194, NRO L30, Intruder)	USA	National Reconnaissance Office (NRO)/US Navy	15/06/2007
2011-014B	37391	SB-WASS 3-5 (Space Based Wide Area Surveillance System) NOSS 3-5, USA 229, NRO L34, Intruder)	USA	National Reconnaissance Office (NRO)/US Navy	15/04/2011
2011-014A	37386	SB-WASS 3-5 (Space Based Wide Area Surveillance System) NOSS 3-5, USA 229, NRO L34, Intruder)	USA	National Reconnaissance Office (NRO)/US Navy	15/04/2011
2012-048A	38758	SB-WASS 3-6 (Space Based Wide Area Surveillance System) NOSS 3-6, USA 238, NRO L36, Intruder)	USA	National Reconnaissance Office (NRO)/US Navy	13/09/2012
2012-048P	38773	SB-WASS 3-6 (Space Based Wide Area Surveillance System) NOSS 3-6, USA 238, NRO L36, Intruder)	USA	National Reconnaissance Office (NRO)/US Navy	13/09/2012

COSPAR Number	NORAD Number	Name of Satellite\Alternate Names	Country	Operator/Owner	Date of Launch
2015-058A	40964	SB-WASS 3-7 (Space Based Wide Area Surveillance System) NOSS 3-7, USA 264, NRO L55, Intruder)	USA	National Reconnaissance Office (NRO)/US Navy	08/10/2015
2015-058R	40981	SB-WASS 3-7 (Space Based Wide Area Surveillance System) NOSS 3-7, USA 264, NRO L55, Intruder)	USA	National Reconnaissance Office (NRO)/US Navy	08/10/2015
2017-011A	42058	SB-WASS 3-8 (Space Based Wide Area Surveillance System) NOSS 3-8, USA 274, NRO L79, Intruder)	USA	National Reconnaissance Office (NRO)/US Navy	01/03/2017
2017-011B	42065	SB-WASS 3-8 (Space Based Wide Area Surveillance System) NOSS 3-8, USA 274, NRO L79, Intruder)	USA	National Reconnaissance Office (NRO)/US Navy	01/03/2017
2016-059H	41790	ScatSat-1	India	Indian Space Research Organization (ISRO)	26/09/2016
1993-009B	22491	SCD-1 (Satélite de Coleta de Dados)	Brazil	Instituto Nacional de Pesquisas Espaciais (INPE)	09/02/1993
1998-060A	25504	SCD-2 (Satélite de Coleta de Dados)	Brazil	Instituto Nacional de Pesquisas Espaciais (INPE)	23/10/1998
2014-016A	39634	Sentinel 1A	ESA	EUMETSAT (European Organization for the Exploitation of Meteorological Satellites)	03/04/2014
2016-025A	41456	Sentinel 1B	ESA	EUMETSAT (European Organization for the Exploitation of Meteorological Satellites)	25/04/2016
2015-028A	40697	Sentinel 2A	ESA	EUMETSAT (European Organization for the Exploitation of Meteorological Satellites)	23/06/2015
2017-013A	42063	Sentinel 2B	ESA	EUMETSAT (European Organization for the Exploitation of Meteorological Satellites)	06/03/2017
2016-011A	41335	Sentinel 3A	ESA	EUMETSAT (European Organization for the Exploitation of Meteorological Satellites)	16/02/2016
2010-051A	37179	Shijian 6G (SJ6-04A)	China	Chinese Academy of Space Technology (CAST)	06/10/2010
2010-051B	37180	Shijian 6H (SJ6_04B)	China	Chinese Academy of Space Technology (CAST)	06/10/2010
2004-012A	28220	Shiyan 1 (SY 1, Tansuo 1, Experimental Satellite 1)	China	Chinese Academy of Space Technology (CAST)	18/04/2004
2008-056A	33433	Shiyan 3 (SY3, Experimental Satellite 3)	China	Chinese Academy of Space Technology (CAST)	05/11/2008
2011-068B	37931	Shiyan 4 (SY4, Experimental Satellite 4)	China	Chinese Academy of Space Technology (CAST)	20/11/2011
2013-068A	39455	Shiyan 5 (SY5, Experimental Satellite 5)	China	Chinese Academy of Space Technology (CAST)	25/11/2013
2013-066C	39418	SkySat-1	USA	Planet	21/11/2013
2014-037D	40072	SkySat-2	USA	Planet	08/07/2014
2016-040C	41601	SkySat-3 (SkySat Gen 2-1)	USA	Planet	22/06/2016
2016-058D	41773	Skysat-4	USA	Planet	16/09/2016
2016-058E	41774	Skysat-5	USA	Planet	16/09/2016

COSPAR Number	NORAD Number	Name of Satellite\Alternate Names	Country	Operator/Owner	Date of Launch
2016-058B	41771	Skysat-6	USA	Planet	16/09/2016
2016-058C	41772	Skysat-7	USA	Planet	16/09/2016
2015-003A	40376	SMAP (Soil Moisture Active Passive Satellite)	USA	National Aeronautics and Space Administration (NASA)	31/01/2015
2009-059A	36036	SMOS (Soil Moisture and Ocean Salinity satellite)	ESA	Centre National d'Etudes Spatiales (CNES)/European Space Agency	02/11/2009
2016-081C	41900	Spark-1	China	Shanghai Engineering Center for Microsatellites	21/12/2016
2016-081D	41901	Spark-2	China	Shanghai Engineering Center for Microsatellites	21/12/2016
2012-047A	38755	Spot 6 (Système Probatoire d'Observation de la Terre)	France/ Belgium/ Sweden	Spot Image	09/09/2012
2014-034A	40053	Spot 7 (Système Probatoire d'Observation de la Terre)	France/ Belgium/ Sweden	Spot Image	30/06/2014
2011-076E	38011	SSOT (Sistema Satelital para la Observación de la Tierra)	Chile	Chilean Air Force	17/12/2011
2016-083A	41907	Superview 1-01 (GaoJing 1-01)	China	Siwei Star Co. Ltd.	28/12/2016
2016-083B	41908	Superview 1-02 (GaoJing 1-02)	China	Siwei Star Co. Ltd.	28/12/2016
2013-067B	39452	SWARM-A	ESA	European Space Agency (ESA)	22/11/2013
2013-067A	39451	SWARM-B	ESA	European Space Agency (ESA)	22/11/2013
2013-067C	39453	SWARM-C	ESA	European Space Agency (ESA)	22/11/2013
2010-030A	36605	TanDEM-X (TerraSAR-X add-on for Digital Elevation Measurement)	Germany	German Aerospace Center (DLR)/Astrium	21/06/2010
2016-081A	41898	TanSat (Tan Weixing, Carbon Satellite)	China	China Meteorological Administration	21/12/2016
2008-002A	32476	TecSAR (Ofeq 8, Polaris)	Israel	Defense Ministry	21/01/2008
2015-077D	41169	TeLEOS 1	Singapore	AgilSpace	16/12/2015
2007-026A	31698	TerraSAR-X 1 (Terra Synthetic Aperture Radar X-Band)	Germany	German Aerospace Center (DLR)/Infoterra	15/06/2007
2008-049A	33396	THEOS (Thailand Earth Observation System)	Thailand	Geo-Informatics and Space Technology Development Agency (GISTDA)	01/10/2008
2010-040A	36985	Tianhui 1-01	China	China Aerospace Science and Technology Corporation (CASC)	24/08/2010
2012-020A	38256	Tianhui 1-02	China	China Aerospace Science and Technology Corporation (CASC)	06/05/2012
2015-061A	40988	Tianhui 1-03	China	China Aerospace Science and Technology Corporation (CASC)	26/10/2015
2014-033AK	40043	TIGRISat	Iraq	La Sapienza University of Rome	19/06/2014
1997-068A	25034	Trumpet 3 (NROL-4, National Reconnaissance Office Launch-4, USA 136)	USA	National Reconnaissance Office (NRO)/USAF	08/11/1997
2007-029A	31792	Tselina-2 (Cosmos 2428)	Russia	Ministry of Defense	29/06/2007

COSPAR Number	NORAD Number	Name of Satellite\Alternate Names	Country	Operator/Owner	Date of Launch
2014-070E	40302	TSUBAME	Japan	Tokyo Institute of Technology, Tokyo University of Science and JAXA	06/11/2014
2009-041C	35683	UK-DMC-2 (BNSCSat-2, British National Science Center Satellite 2)	United Kingdom	UK/DMC International Imaging (DMCII)	29/07/2009
2014-029B	39767	UNIFORM 1 (UNiversity International FORmation Mission 1)	Japan	Wakayama University (UNIFORM consortium)	24/05/2014
2012-046A	38752	Van Allen Probe A (RBSP-A, Radiation Belt Storm Probes)	USA	National Aeronautics and Space Administration (NASA)/ Johns Hopkins University Applied Physics Laboratory	30/08/2012
2012-046B	38753	Van Allen Probe B (RBSP-B, Radiation Belt Storm Probes)	USA	National Aeronautics and Space Administration (NASA)/ Johns Hopkins University Applied Physics Laboratory	30/08/2012
2017-044B	42901	Venµs	France/ Israel	Centre National d'Etudes Spatiales (CNES)/Israel Space Agency	01/08/2017
2013-021B	39160	VNREDSat 1A (Vietnam Natural Resources Environment and Disaster monitoring small Satellite)	Vietnam	Space Technology Institute-Vietnam Academy of Science and Technology (STI-VAST)	07/05/2013
2012-052A	38782	VRSS-1 (Venezuelan Remote Sensing Satellite, Francisco Miranda)	Venezuela	Bolivarian Agency for Space Activities	28/09/2012
2013-066H	39423	WNISat-1 (Weather News Inc. Satellite 1)	Japan	Weathernews, Inc.	21/11/2013
2017-042L	42835	WNISat-1R (Weather News Inc. Satellite 1R)	Japan	Weathernews, Inc.	14/07/2017
2007-041A	32060	Worldview 1	USA	DigitalGlobe Corporation	18/09/2007
2009-055A	35946	Worldview 2	USA	DigitalGlobe Corporation	08/10/2009
2014-048A	40115	Worldview 3	USA	DigitalGlobe Corporation	13/08/2014
2016-067A	41848	Worldview 4	USA	DigitalGlobe Corporation	11/11/2016
2011-015C	37389	X-Sat	Singapore	Centre for Research in Satellite Technology (CREST)	20/04/2011
2010-038A	36834	Yaogan 10 (Remote Sensing Satellite 10)	China	People's Liberation Army (C41)	09/08/2010
2010-047A	37165	Yaogan 11 (Remote Sensing Satellite 11)	China	People's Liberation Army (C41)	22/09/2010
2011-066B	37875	Yaogan 12 (Remote Sensing Satellite 12)	China	People's Liberation Army (C41)	09/11/2011
2011-072A	37941	Yaogan 13 (Remote Sensing Satellite 13)	China	People's Liberation Army (C41)	29/11/2011
2012-021A	38257	Yaogan 14 (Remote Sensing Satellite 14)	China	People's Liberation Army (C41)	10/05/2012
2012-029A	38354	Yaogan 15 (Remote Sensing Satellite 15)	China	People's Liberation Army (C41)	29/05/2012
2012-066A	39011	Yaogan 16A (Remote Sensing Satellite 16A, Yaogan Weixing 16)	China	People's Liberation Army (C41)	25/11/2012
2012-066B	39012	Yaogan 16B (Remote Sensing Satellite 16B)	China	People's Liberation Army (C41)	25/11/2012
2012-066C	39013	Yaogan 16C (Remote Sensing Satlelite 16C)	China	People's Liberation Army (C41)	25/11/2012
2013-046A	39239	Yaogan 17A (Remote Sensing Satellite 17A, Yaogan Weixing 17)	China	People's Liberation Army (C41)	01/09/2013
2013-046B	39240	Yaogan 17B (Remote Sensing Satellite 17B)	China	People's Liberation Army (C41)	01/09/2013
2013-046C	39241	Yaogan 17C (Remote Sensing Satellite 17C)	China	People's Liberation Army (C41)	01/09/2013
2013-059A	39363	Yaogan 18 (Remote Sensing Satellite 18)	China	People's Liberation Army (C41)	29/10/2013
2013-065A	39410	Yaogan 19 (Remote Sensing Satellite 19)	China	People's Liberation Army (C41)	20/11/2013
2014-047A	40109	Yaogan 20A (Remote Sensing Satellite 20A)	China	People's Liberation Army (C41)	09/08/2014
2014-047B	40110	Yaogan 20B (Remote Sensing Satellite 20B)	China	People's Liberation Army (C41)	09/08/2014

COSPAR Number	NORAD Number	Name of Satellite\Alternate Names	Country	Operator/Owner	Date of Launch
2014-047C	40111	Yaogan 20C (Remote Sensing Satellite 20C)	China	People's Liberation Army (C41)	09/08/2014
2014-053A	40143	Yaogan 21 (Remote Sensing Satellite 21)	China	People's Liberation Army (C41)	08/09/2014
2014-063A	40275	Yaogan 22 (Remote Sensing Satellite 22)	China	People's Liberation Army (C41)	20/10/2014
2014-071A	40305	Yaogan 23 (Remote Sensing Satellite 23)	China	People's Liberation Army (C41)	14/11/2014
2014-072A	40310	Yaogan 24 (Remote Sensing Satellite 24)	China	People's Liberation Army (C41)	20/11/2014
2014-080A	40338	Yaogan 25A (Remote Sensing Satellite 25A)	China	People's Liberation Army (C41)	10/12/2014
2014-080B	40339	Yaogan 25B (Remote Sensing Satellite 25B)	China	People's Liberation Army (C41)	10/12/2014
2014-0808C	40340	Yaogan 25C (Remote Sensing Satellite 25C)	China	People's Liberation Army (C41)	10/12/2014
2014-088A	40362	Yaogan 26 (Remote Sensing Satellite 26)	China	People's Liberation Army (C41)	27/12/2014
2015-040A	40878	Yaogan 27 (Remote Sensing Satellite 27)	China	People's Liberation Army (C41)	27/08/2015
2015-064A	41026	Yaogan 28 (Remote Sensing Satellite 28)	China	People's Liberation Army (C41)	08/11/2015
2015-069A	41038	Yaogan 29 (Remote Sensing Satellite 29)	China	People's Liberation Army (C41)	26/11/2015
2016-029A	41473	Yaogan 30 (Remote Sensing Satellite 30)	China	People's Liberation Army (C41)	15/05/2016
2008-061A	33446	Yaogan 4 (Remote Sensing Satellite 4)	China	People's Liberation Army (C41)	01/12/2008
2009-021A	34839	Yaogan 6 (Remote Sensing Satellite 6, Jian Bing 7-A)	China	People's Liberation Army (C41)	22/04/2009
2009-069A	36110	Yaogan 7 (Remote Sensing Satellite 7)	China	People's Liberation Army (C41)	09/12/2009
2009-072A	36121	Yaogan 8 (Remote Sensing Satellite 8)	China	People's Liberation Army (C41)	15/12/2009
2010-009A	36413	Yaogan 9A (Remote Sensing Satellite 9A)	China	People's Liberation Army (C41)	05/03/2010
2010-009B	36414	Yaogan 9B (Remote Sensing Satellite 9B)	China	People's Liberation Army (C41)	05/03/2010
2010-009C	36415	Yaogan 9C (Remote Sensing Satellite 9C)	China	People's Liberation Army (C41)	05/03/2010
2016-068A	41857	Yunhai-1	China	Shanghai Academy of Spaceflight Technology (SAST)	11/11/2016
2004-044A	28470	Zhangguo Ziyuan 2C (ZY-2C, JB-3C)	China	Chinese Academy of Space Technology	04/11/2004
2017-034D	52761	Zhuhai-1-01 (OVS-1A)	China	Zhuhai Orbita Control Engineering Co. Ltd.	15/06/2017
2017-034B	52759	Zhuhai-1-02 (OVS-1B)	China	Zhuhai Orbita Control Engineering Co. Ltd.	15/06/2017
2011-079A	38038	Ziyuan 1-02C	China	China Centre for Resources Satellite Data and Application (CRESDA)	22/12/2011
2012-001A	38046	Ziyuan 3 (ZY-3)	China	China Centre for Resources Satellite Data and Application (CRESDA)	09/01/2012
2016-033A	41556	Ziyuan 3-2	China	China Centre for Resources Satellite Data and Application (CRESDA)	29/05/2016
2016-081B	41899	Chao Fenbianlu Duo Guangpu Chengxiang Weixing (Ultra-resolution multispectral imaging satellite)	China	Shanghai Engineering Center for Microsatellites	21/12/2016
2010-032A	36744	COMS-1 (Communication, Ocean and Meteorological Satellite; Cheollian)	South Korea	Korea Aerospace Research Institute (KARI)	26/06/2010
2014-053B	40144	Tiantuo-2	China	National University of Defense Technology	08/09/2014
2014-087A	40360	Resurs-P2	Russia	Russian Federal Space Agency (Roskosmos)	26/12/2014
2017-042G	42831	FLP (Flying Laptop)	Germany	University of Stuttgart	14/07/2017

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2001-049C	26959	Bird 2 (Bispectral InfraRed Detector 2)	Germany	Institute of Space Sensor Technology and Planetary Exploration	22/10/2001
2015-058E	40968	BisonSat (Nwist Qwiqway)	USA	Salish Kootenai College	08/10/2015
2006-031A	29268	Kompsat-2 (Arirang 2, Korean planned Multipurpose Satellite-2)	South Korea	Korea Aerospace Research Institute (KARI)	28/07/2006
2007-001A	29709	LAPAN-Tubsat (LAPAN A1)	Indonesia	Indonesian National Aeronautics and Space Agency (Lembaga Penerbangan dan Antariksa Nasional - LAPAN)	10/01/2007
2011-044C	37790	Nigeriasat-X	Nigeria	National Space Research and Development Agency (NASRDA)	17/08/2011
2017-012A	42061	Tiankun-1	China	Chinese Academy of Launch Vehicle Technology (CASIC)	02/03/2017
2017-042B	42826	NorSat-1	Norway	Norwegian Space Center	14/07/2017

APPENDIX C: LIST OF GNSS SATELLITES AS OF 31 AUGUST 2017

(Source: Union of Concerned Scientists)

COSPAR Number	NORAD Number	Name of Satellite\Alternate Names	Country	Operator/Owner	Date of Launch
2012-018A	38250	Beidou 2-12 (Compass M3)	China	Chinese Defense Ministry	28/04/2012
2012-018B	38251	Beidou 2-13 (Compass M4)	China	Chinese Defense Ministry	28/04/2012
2012-050A	38774	Beidou 2-14 (Compass M5)	China	Chinese Defense Ministry	18/09/2012
2012-050B	38775	Beidou 2-15 (Compass M6)	China	Chinese Defense Ministry	18/09/2012
2012-059A	38953	Beidou 2-16 (Compass G-6)	China	Chinese Defense Ministry	25/10/2012
2016-021A	41434	Beidou 2-17 (IGSO-6)	China	Chinese Defense Ministry	30/03/2016
2016-037A	41586	Beidou 2-18 (Compass G-7)	China	Chinese Defense Ministry	12/06/2016
2015-019A	40549	Beidou 3I-1S	China	Chinese Defense Ministry	30/03/2015
2015-053A	40938	Beidou 3I-2S	China	Chinese Defense Ministry	29/09/2015
2015-037A	40748	Beidou 3M-1S	China	Chinese Defense Ministry	25/07/2015
2015-037B	40749	Beidou 3M-2S	China	Chinese Defense Ministry	25/07/2015
2016-006A	41315	Beidou 3M-3S	China	Chinese Defense Ministry	01/02/2016
2010-001A	36287	Beidou G1 (Compass G-1)	China	Chinese Defense Ministry	16/01/2010
2010-024A	36590	Beidou G3 (Compass G-3)	China	Chinese Defense Ministry	02/06/2010
2010-057A	37210	Beidou G4 (Compass G-4)	China	Chinese Defense Ministry	31/10/2010
2012-008A	38091	Beidou G5 (Compass G-11)	China	Chinese Defense Ministry	24/02/2012
2010-036A	36828	Beidou IGSO-1 (Compass G-5)	China	Chinese Defense Ministry	31/07/2010
2010-068A	37256	Beidou IGSO-2 (Compass G-7)	China	Chinese Defense Ministry	17/12/2010
2011-013A	37384	Beidou IGSO-3 (Compass G-8)	China	Chinese Defense Ministry	09/04/2011
2011-038A	37763	Beidou IGSO-4 (Compass G-9)	China	Chinese Defense Ministry	26/07/2011
2011-073A	37948	Beidou IGSO-5 (Compass G-10)	China	Chinese Defense Ministry	01/12/2011
2007-011A	31115	Beidou M1 (Compass M1)	China	Chinese Defense Ministry	14/04/2007
2014-050A	40128	Galileo FOC FM1 (0201, Galileo 5, PRN E18)	ESA	European Space Agency	22/08/2014
2016-030A	41549	Galileo FOC FM10 (0210, Galileo 13, PRN E01)	ESA	European Space Agency	24/05/2016
2016-030B	41550	Galileo FOC FM11 (0211, Galileo 14, PRN E02)	ESA	European Space Agency	24/05/2016
2016-069B	41860	Galileo FOC FM12 (0212, Galileo 16)	ESA	European Space Agency	17/11/2016
2016-069C	41861	Galileo FOC FM13 (0213, Galileo 17)	ESA	European Space Agency	17/11/2016
2016-069D	41862	Galileo FOC FM14 (0214, Galileo 18)	ESA	European Space Agency	17/11/2016
2014-050B	40129	Galileo FOC FM2 (0202, Galileo 6, PRN E14)	ESA	European Space Agency	22/08/2014
2015-017A	40544	Galileo FOC FM3 (0203, Galileo 7, PRN E26)	ESA	European Space Agency	27/03/2015
2015-017B	40545	Galileo FOC FM4 (0204, Galileo 8, PRN E22)	ESA	European Space Agency	27/03/2015
2015-045A	40889	Galileo FOC FM5 (0205, Galileo 9, PRN E24)	ESA	European Space Agency	11/09/2015
2015-045B	40890	Galileo FOC FM6 (0206, Galileo 10, PRN E30)	ESA	European Space Agency	11/09/2015
2016-069A	41859	Galileo FOC FM7 (0207, Galileo 15)	ESA	European Space Agency	17/11/2016
2015-079B	41175	Galileo FOC FM8 (0208, Galileo 11, PRN E08)	ESA	European Space Agency	17/12/2015
2015-079A	41174	Galileo FOC FM9 (0209, Galileo 12, E09)	ESA	European Space Agency	17/12/2015
2011-060B	37847	Galileo IOV-1 FM2 (0102, PRN E12)	ESA	European Space Agency	21/10/2011
2011-060A	37846	Galileo IOV-1 PFM (0101, PRN E11)	ESA	European Space Agency	21/10/2011
2012-055A	38857	Galileo IOV-2 FM3 (0103, PRN E19)	ESA	European Space Agency	12/10/2012

COSPAR Number	NORAD Number	Name of Satellite\Alternate Names	Country	Operator/Owner	Date of Launch
2012-055B	38858	Galileo IOV-2 FM4 (0104, PRN E20)	ESA	European Space Agency	12/10/2012
2011-009A	37372	Glonass 701 (Glonass-K, Cosmos 2471)	Russia	Ministry of Defense	26/02/2011
2014-075A	40315	Glonass 702 (Glonass K, Cosmos 2501)	Russia	Ministry of Defense	01/12/2014
2005-050A	28915	Glonass 714 (Cosmos 2419)	Russia	Ministry of Defense	25/12/2005
2006-062C	29672	Glonass 715 (Glonass 35-1, Cosmos 2424)	Russia	Ministry of Defense	25/12/2006
2006-062A	29670	Glonass 716 (Glonass 35-2, Cosmos 2425)	Russia	Ministry of Defense	25/12/2006
2006-062B	29671	Glonass 717 (Glonass 35-3, Cosmos 2426)	Russia	Ministry of Defense	25/12/2006
2007-052B	32276	Glonass 719 (Glonass 36-2, Cosmos 2432)	Russia	Ministry of Defense	26/10/2007
2007-052A	32275	Glonass 720 (Glonass 36-3, Cosmos 2433)	Russia	Ministry of Defense	26/10/2007
2007-065A	32393	Glonass 721 (Glonass 37-1, Cosmos 2435)	Russia	Ministry of Defense	25/12/2007
2007-065C	32395	Glonass 723 (Glonass 37-3, Cosmos 2436)	Russia	Ministry of Defense	25/12/2007
2009-070A	36111	Glonass 730 (Glonass 41-1, Cosmos 2456)	Russia	Ministry of Defense	14/12/2009
2010-007A	36400	Glonass 731 (Glonass 42-1, Cosmos 2459)	Russia	Ministry of Defense	01/03/2010
2010-007C	36402	Glonass 732 (Glonass 42-3, Cosmos 2460)	Russia	Ministry of Defense	01/03/2010
2009-070B	36112	Glonass 733 (Glonass 41-2, Cosmos 2457)	Russia	Ministry of Defense	14/12/2009
2009-070C	36113	Glonass 734 (Glonass 41-3, Cosmos 2458)	Russia	Ministry of Defense	14/12/2009
2010-007B	36401	Glonass 735 (Glonass 42-2, Cosmos 2461)	Russia	Ministry of Defense	01/03/2010
2010-041C	37139	Glonass 736 (Glonass 43-1, Cosmos 2464)	Russia	Ministry of Defense	02/09/2010
2010-041B	37138	Glonass 737 (Glonass 43-2, Cosmos 2465)	Russia	Ministry of Defense	02/09/2010
2011-055A	37829	Glonass 742 (Glonass-M, Cosmos 2474)	Russia	Ministry of Defense	02/10/2011
2011-064A	37867	Glonass 743 (Glonass 44-2, Cosmos 2476)	Russia	Ministry of Defense	04/11/2011
2011-064B	37868	Glonass 744 (Glonass 44-3, Cosmos 2477)	Russia	Ministry of Defense	04/11/2011
2011-064C	37869	Glonass 745 (Glonass 44-1, Cosmos 2475)	Russia	Ministry of Defense	04/11/2011
2013-019A	39155	Glonass 747 (Glonass-M, Cosmos 2485)	Russia	Ministry of Defense	26/04/2013
2016-008A	41330	Glonass 751 (Glonass-M, Cosmos 2514)	Russia	Ministry of Defense	07/02/2016
2016-032A	41554	Glonass 753 (Glonass-M, Cosmos 2516)	Russia	Ministry of Defense	29/05/2016
2014-012A	39620	Glonass 754 (Glonass-M, Cosmos 2491, RS-46)	Russia	Ministry of Defense	23/03/2014
2014-032A	40001	Glonass 755 (Glonass-M, Cosmos 2500)	Russia	Ministry of Defense	14/06/2014
2010-022A	36585	Navstar GPS IIF-1 (Navstar SVN 62, PRN 25, USA 213)	USA	DoD/US Air Force	28/05/2010
2015-033A	40730	Navstar GPS IIF-10 (Navstar SVN 72, PRN 8, USA 262)	USA	DoD/US Air Force	15/07/2015
2015-062A	41019	Navstar GPS IIF-11 (Navstar SVN 73, PRN 10, USA 265)	USA	DoD/US Air Force	31/10/2015
2016-007A	41328	Navstar GPS IIF-12 (Navstar SVN 70, PRN 32, USA 266)	USA	DoD/US Air Force	05/02/2016
2011-036A	37753	Navstar GPS IIF-2 (Navstar SVN 63, PRN 01, USA 232)	USA	DoD/US Air Force	16/07/2011
2012-053A	38833	Navstar GPS IIF-3 (Navstar SVN 65, PRN 24, USA 239)	USA	DoD/US Air Force	04/10/2012
2013-023A	39166	Navstar GPS IIF-4 (Navstar SVN 66, PRN 27, USA 242)	USA	DoD/US Air Force	15/05/2013
2014-008A	39533	Navstar GPS IIF-5 (Navstar SVN 64, PRN 30, USA 248)	USA	DoD/US Air Force	21/02/2014

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2014-026A	39741	Navstar GPS IIF-6 (Navstar SVN 67, PRN 06, USA 251)	USA	DoD/US Air Force	17/05/2014
2014-045A	40105	Navstar GPS IIF-7 (Navstar SVN 68, PRN 09, USA 256)	USA	DoD/US Air Force	02/08/2014
2014-068A	40294	Navstar GPS IIF-8 (Navstar SVN 69, PRN 03, USA 258)	USA	DoD/US Air Force	29/10/2014
2015-013A	40534	Navstar GPS IIF-9 (Navstar SVN 71, PRN 26, USA 260)	USA	DoD/US Air Force	25/03/2015
2003-058A	28129	Navstar GPS IIR-10 (Navstar SVN 47, PRN 22, USA 175)	USA	DoD/US Air Force	21/12/2003
2004-009A	28190	Navstar GPS IIR-11 (Navstar SVN 59, PRN 19, USA 177)	USA	DoD/US Air Force	20/03/2004
2004-023A	28361	Navstar GPS IIR-12 (Navstar SVN 60, PRN 23, USA 178)	USA	DoD/US Air Force	23/06/2004
2004-045A	28474	Navstar GPS IIR-13 (Navstar SVN 61, PRN 02, USA 180)	USA	DoD/US Air Force	06/11/2004
1997-035A	24876	Navstar GPS IIR-2 (Navstar SVN 43, PRN 13, USA 132)	USA	DoD/US Air Force	23/07/1997
1999-055A	25933	Navstar GPS IIR-3 (Navstar SVN 46, PRN 11, USA 145)	USA	DoD/US Air Force	07/10/1999
2000-025A	26360	Navstar GPS IIR-4 (Navstar SVN 51, PRN 20, USA 150)	USA	DoD/US Air Force	11/05/2000
2000-040A	26407	Navstar GPS IIR-5 (Navstar SVN 44, PRN 28, USA 151)	USA	DoD/US Air Force	16/07/2000
2000-071A	26605	Navstar GPS IIR-6 (Navstar SVN 41, PRN 14, USA 154)	USA	DoD/US Air Force	10/11/2000
2001-004A	26690	Navstar GPS IIR-7 (Navstar SVN 54, PRN 18, USA 156)	USA	DoD/US Air Force	30/01/2001
2003-005A	27663	Navstar GPS IIR-8 (Navstar SVN 56, PRN 16, USA 166)	USA	DoD/US Air Force	29/01/2003
2003-010A	27704	Navstar GPS IIR-9 (Navstar SVN 45, PRN 21, USA 168)	USA	DoD/US Air Force	31/03/2003
2005-038A	28874	Navstar GPS IIR-M-1 (Navstar SVN 53, PRN 17, USA 183)	USA	DoD/US Air Force	26/09/2005
2006-042A	29486	Navstar GPS IIR-M-2 (Navstar SVN 52, PRN 31, USA 190)	USA	DoD/US Air Force	25/09/2006
2006-052A	29601	Navstar GPS IIR-M-3 (Navstar SVN 58, PRN 12, USA 192)	USA	DoD/US Air Force	17/11/2006
2007-047A	32260	Navstar GPS IIR-M-4 (Navstar SVN 55, PRN 15, USA 196)	USA	DoD/US Air Force	17/10/2007
2007-062A	32384	Navstar GPS IIR-M-5 (Navstar SVN 57, PRN 29, USA 199)	USA	DoD/US Air Force	20/12/2007
2008-012A	32711	Navstar GPS IIR-M-6 (Navstar SVN 48, PRN 07, USA 201)	USA	DoD/US Air Force	15/03/2008
2009-043A	35752	Navstar GPS IIR-M-8 (Navstar SVN 50, PRN 05, USA 206)	USA	DoD/US Air Force	17/08/2009
2013-034A	39199	IRNSS-1A (Indian Regional Navigation Satellite System)	India	Indian Space Research Organization (ISRO)	01/07/2013
2014-017A	39635	IRNSS-1B (Indian Regional Navigation Satellite System)	India	Indian Space Research Organization (ISRO)	04/04/2014
2014-061A	40269	IRNSS-1C (Indian Regional Navigation Satellite System)	India	Indian Space Research Organization (ISRO)	15/10/2014
2015-018A	40547	IRNSS-1D (Indian Regional Navigation Satellite System)	India	Indian Space Research Organization (ISRO)	30/03/2015

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2016-003A	41241	IRNSS-1E (Indian Regional Navigation Satellite System)	India	Indian Space Research Organization (ISRO)	20/01/2016
2016-015A	41384	IRNSS-1F (Indian Regional Navigation Satellite System)	India	Indian Space Research Organization (ISRO)	10/03/2016
2016-027A	41469	IRNSS-1G (Indian Regional Navigation Satellite System)	India	Indian Space Research Organization (ISRO)	28/04/2016
2017-048A	42917	QAZ-3 (Quazi-Zenith Satellite System, Michibiki-3)	Japan	Japan Aerospace Exploration Agency (JAXA)	19/08/2017
2010-045A	37158	QZS-1 (Quazi-Zenith Satellite System, Michibiki-1)	Japan	Japan Aerospace Exploration Agency (JAXA)	11/09/2010
2017-028A	42738	QZS-2 (Quazi-Zenith Satellite System, Michibiki-2)	Japan	Japan Aerospace Exploration Agency (JAXA)	31/05/2017

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