3 Key Trends in Remote-Sensing Satellite Systems and Services

Introduction

Remote sensing is an extremely valuable tool that is vital to many industries, from mining to fishing and farming to mapping and surveying operations. Indeed the uses of Earth observation satellites spread across a wide spectra of other industries. The ways to use remote sensing just keeps expanding. Each year new applications are being developed in fields as diverse as real estate development, retail sales, urban planning, law enforcement, disaster relief and recovery, archaeology, energy exploration, and transportation. There is even an online listing of the top 100 uses that can now be made of remote-sensing satellites [1].

There are basically two types of tools used in Earth observation – passive and active. The most common type of space-based remote-sensing uses reflected sunlight and energy, or what is called passive sensing. The other approach uses active sensing systems. Active systems require both transmitted energy to be sent down and also requires a capability to receive the reflected signals that come back up to the satellite. The passive systems use optical sensors and photography, infrared sensors, charge-coupled devices and even radiometers for higher spectra. Active systems that require the transmission of energy, which is then reflected back to the satellite, include RADAR and LIDAR. All of these space-based remote-sensing satellite systems have been fine-tuned and improved to provide increased accuracy of observation. Over the course of a half century, remarkable progress has been made to improve the accuracy of remote sensing and the analytical capabilities that can be used to interpret this data.

Weather or meteorological satellites are a special form of remote-sensing or Earth-observation satellites. Since these satellites, which monitor Earth's weather and now also monitor climate change and solar weather, are so vital to modern civilization and are exclusively operated as governmental facilities, these satellites will be addressed later in a separate chapter.

Remote-sensing satellites have not only provided vital assistance to many commercial industries, but they have aided government in providing vital

J. N. Pelton, *Space 2.0*, Astronautical Engineering,
https://doi.org/10.1007/978-3-030-15281-9_3

services. These services range from law and regulatory enforcement, prosecuting crimes against humanity, environmental and pollution monitoring, to providing assistance in areas such as agriculture, forestry, mining, water management and fishing regulation. Of all these governmental functions perhaps the most important of all has been in the area of providing assistance with regard to disaster prediction, response and mitigation.

There are four primary ways of increasing the precision of Earth observation – or remote observation of other planets for that matter. These include: spatial (i.e., more pixels per area of measurement), spectral (i.e., the width or precision of the frequency spectrum bands where the observations are made), temporal (i.e., how frequently the observations are updated), and radiometric (precision of the data recorded in terms of available categories to collect data).

Radiometric precision started with just a 6-bit data recorder (equivalent to 64 bits of data). This then moved up to an 8-bit data recorder (equivalent to 256 bits), and today information is typically collected with a 10-bit data recorder (equivalent to 1,024 bits). Over time, all of these scales of precision have increased dramatically. There are civilian systems today that record pixels of data spatially equivalent to 0.35 meters and defense-based systems that are even more precise. Hyper-spectral systems can collect spectral data with great precision by recording data over as many as 100 different discrete spectrum bands, if not more. New constellations with hundreds of small satellites can update data with amazing frequency down to hours within a day. The most modern data recorders use 10-bit systems or even higher.

There are a number of obvious reasons that have given impetus to growth in the field of remote-sensing satellites; these have served to move it forward over the past 50 years. These reasons are combining to create not only more precise observations but innovation in how the various systems are applied to solving problems or assisting both government and industry to perform their various tasks. Although remote-sensing economic activities are much smaller than satellite communications in market size, significant growth is forecast for the future. One market study has concluded that the Global Remote Sensing Services Market accounted for $8.68 billion in 2017 but is projected to rise sharply in the next decade to reach $38 billion by 2026. This would represent a cumulative aggregated growth rate of nearly 18%. This study included not only satellite-based growth but also that of aeronautical sensing, drones and high-altitude platform systems [2].

The growth factors include: (a) the development of small satellite technology and the lower costs of manufacture, testing and launch of all types of remote-sensing satellites; (b) new digital processing and analysis techniques and especially the development of new hyper-spectral sensing capabilities; (c) spinoffs from defense-related surveillance; (d) new commercial business interests around the world; and (e) strong political motivation to have national remote-sensing satellite capabilities in space among a growing number of countries.

Reinventing the World of Remote Sensing

The world of remote sensing, just like the world of satellite communications, is being turned upside down. Disruptive technologies and new commercial applications for remote-sensing services are seemingly everywhere. This is true with regard to the small satellite innovations, new thinking with regard to launch services, new commercial applications, and in the context of the new entrepreneurial spirit born of the Space 2.0 revolution.

The Small Satellite Revolution in Remote Sensing

Many of the changes that are now occurring in the world of space applications have come from the world of cubesats. This has already been described as the coming together of the world of Silicon Valley with the world of aerospace. This Space 2.0 mentality is driven by the zeal for entrepreneurial innovation meshing in new and disruptive ways of doing things in the space industry around the world.

It turns out that many of the key components needed for smaller and more efficient remote-sensing satellites – namely digital processors, digital imaging devices, charged-coupled devices, radiometers, and digital sensors – are all possible to miniaturize. The young innovators who came out of Silicon Valley and who, in particular, founded Skybox and Planet Labs, asked why not invent a new way of doing things? They brashly thought that they could design and build small satellites that were more cost effective than the conventional remote-sensing satellites that had been growing in size and performance since the first systems such as Corona and Landsat were designed and built a half century ago. It turns out that they were right.

These new entrants thought their "good enough" technology, designed with miniaturized components and in some cases using off-the-shelf technology, could be used to build successful small satellites. Their small sats actually could provide commercial competition to the big and expensive remote-sensing satellites. Their innovative plan was to build satellites that could be ten to even a hundred times less costly than the much bigger remote-sensing systems that had evolved over a forty-year period.

Communications satellites need high gain and thus large antennas and more power, but remote-sensing satellites, with their "shrunk" electronic sensors and imaging device were a logical fit for creating a small sat fleet for remote imaging. Further, their data from imaging did not have to be continuously linked to Earth stations. Also, their constellations circling in low Earth orbits allowed their sensors to have higher spatial resolution. These were some of the technological reasons why small satellites for remote sensing, especially passive systems, have some advantages over telecommunications satellites.

Actually Skybox and Planet Labs were not the only innovators to led the way. The first champions of small satellites were the scientists, educators and engineers at the Surrey Space Centre at the University of Surrey just outside of London, England. The University of Surrey small satellites were known as UOS satellites. The spinout group, known as Surrey Satellite Technology Ltd (SSTL), was created in 1979. It started with designing very small satellites similar to the OSCAR satellites for store-and-forward messaging that were first used by amateur radio operators. SSTL, which is now majority owned by Airbus, then moved on to remote-sensing satellites. Their Disaster Monitoring Constellation (DMC) satellites (in 2002) and their UoS-12 remote-sensing satellite (2006-2008) led to a series of contracts or technical cooperation agreements to design, build or support the building of remote-sensing satellites [3]. Technical support from the Surrey Space Centre and SSTL in the design and manufacture of small sats allowed countries such as Nigeria (NigeriaSat-2) [4], Korea (Arirang-1 in 1999) [5], China, and other countries to deploy relatively small and cost-effective small remote-sensing satellite in the 1999-2010 timeframe.

Progress in the small sat field for remote sensing has recently moved ahead very swiftly. In one of the latest examples a new commercial system was developed for precise imaging. This Chinese Jilin satellite system consists of a three-satellite constellation. In this case, SSTL provided the spacecraft bus design for the three-satellite constellation while China designed the imaging payload. These three satellites were launched from India by ISRO in 2015. Although these were small sats with only 450 kilograms in mass, each nevertheless have an amazingly high spatial resolution of 1 meter [6].

The Chinese Jilin-1 satellite, which was based on an SSTL spacecraft design but contains a Chinese imaging payload, is the first commercial Chinese remote sensing satellite system now fully operational [7]. The first three satellites in the satellite constellation, now operated by the Chang Guang Satellite Technology Company, will be joined by a fourth higher performance remote-sensing satellite designed and built entirely within China. The remarkably high spatial resolution of images taken from this constellation at 1-meter resolution shows amazing detail. (See Fig. 3.1 that shows a precise image

Fig. 3.1 Image of the Ferarri Exhibit in UAE from China's Jilin-1 commercial imaging satellite. (Illustration courtesy of NASA Spaceflight, Global Commons)

taken from the Jilin-1 satellite over the Ferrari Exhibit in Dubai, United Arab Emirates.)

In addition to the Jilin commerical satellite, there is an even more ambitious Chinese commercial project now underway. Satellites for both video and hyperspectral remote-sensing purposes are currently being deployed via Long March 11 solid rocket launchers. On board the most recent April 2018 launch were one high-resolution video coverage satellite and four hyperspectral Earth-observation satellites. These satellites were for the Zhuhai Orbita commercial constellation and were designated as OHS-01, 02, 03 and 04 (hyperspectral) and OVS-2 (video).

This system is being deployed by Zhuhai Orbita Aerospace Science and Technology Co. Ltd. This Chinese remote-sensing company is based in the city of Shenzhen. The OVS-1A and OVS-1B satellites were launched in June 2017, and on April 26, 2018, five more satellites were launched. One of these was the improved OVS-2 video satellite that has a spatial resolution of 90 centimeters. In addition four commercial hyperspectral satellites were also launched with a resolution of 10 meters. Eventually, a full constellation of 34 satellites orbiting at 500 km altitude is planned to be launched by the Zhuhai Orbita company. This combined constellation of high-resolution video satellites and lower resolution but hyperspectral scanning satellites is designed to provide geographic, environmental and geologic monitoring as well as coverage related to marine and urban planning use. Small sat efficiency and economies has seemingly served to accelerate commercial remote-sensing satellite launches around the world in the last few years (http://spacenews.com/china-launches-five-commercial-remote-sensing-satellites-via-long-march-11/).

The advent of small satellites and original thinking that comes from the world of NewSpace keeps spawning completely new ideas. One of the latest space innovations is the Hawkeye 360 project. This new remote-sensing constellation plans to deploy 30 small sats that consist of ten groups of three satellites that will be monitoring radio frequency usage on a global basis. This satellite constellation will collect data on the usage of mobile cellphones and satellite usage that will provide worldwide updates every 30 to 45 minutes. Such monitoring can track usage and movements of ships and boats, illegal fishing, location of jamming systems and hundreds of other new applications. The U. S.-based startup is a subsidiary of Allied Minds, which is a 'venture creation' firm and is also teamed with Lockheed Martin [8].

For many decades the lead in remote-sensing satellites remained with the United States and other countries of the OECD and particularly with NASA, NOAA, and ESA, but the small satellite revolution has served to change the world of remote sensing. Many other countries are designing, manufacturing, and deploying or arranging for the launch of their own remote-sensing satellites. Some new satellite systems, such as Theia, will be offering remote sensing, communications services and data analytics services to create what might be considered a whole new category of satellite services [9]. The deployment of so many of these new satellite constellations, particularly in Sun-synchronous polar and LEO orbits, contributes to concern about the continuing increase in orbital space debris.

The number of remote-sensing satellites continues to increase. In the latest SIA State of the Industry Report, remote-sensing satellites represent some 15% of all operational satellites. A decade ago that number was well below 10%. With the growth of commercial constellations comprised of small satellites, the number of commercial communications satellites and remote-sensing satellites will only continue to grow. The Indian Polar Satellite launch vehicle that placed 88 3-unit cube satellites for the Planet Corporation, along with other cubesats for other customers and some larger satellites all into low Earth orbit with a single launch, perhaps portends a future with an dramatic increase of small sats in Earth orbit [10]. (See Fig. 3.2.)

One of the more interesting international developments has been the recent agreement reached at a meeting in Haikou, China, in July 2017 by the five BRICS countries – Brazil, Russia, India, China and South Africa. These countries will develop a Brics Remote Sensing Satellite Constellation under the first substantive BRICS cooperation agreement related to space research (http://www.engineeringnews.co.za/article/brics-bloc-agree-remote-sensing-space-constellation-project-2017-07-04/rep_id:4136). (See Fig. 3.3.)

The Brazilian CBERS-4 satellite, which is pictured in Fig. 3.2, is under construction as a joint project between Brazil and the Chinese National Space Administration (CNSA) and is to be deployed into the virtual constellation. The CEO of the South Africa National Space Agency, Dr. Val Munsami, made the following statement at the end of the sessions held in China about the new BRICS initiative in space cooperation: "We remain committed to ensuring the integration of African space-based knowledge and technology in improving the lives of fellow Africans and welcome such esteemed partners in achieving this important objective" [11].

In Phase 1 of the project, the constellation would be a virtual network with the five countries creating a remote-sensing data sharing system. This would involve a network for sharing data from the countries' existing Earth observation (EO) satellites. Phase 2, as now planned, would involve the creation of a new EO satellite constellation. Of the five countries only South Africa does not have a full-scale remote-sensing satellite. It does have plans to deploy, either in 2019 or 2020, such a full-sized spacecraft known as EOSat-1 and which is currently under development.

Currently there are many dozens of remote-sensing satellite networks in operation on behalf of governments and private companies. The idea of consortia and international partnerships can aid not only international cooperation but also curtail the needless proliferation of satellite remote-sensing satellites in Earth orbit and the increasing problem of orbit space debris plus the higher risk of orbital collisions.

Developments in Digital Processing and Analysis of Remote Sensing Satellite Data

There are several counter trends in the remote-sensing satellite industry when it comes to the analysis and distribution of remote-sensing data. There are quite

Fig. 3.2 The Indian Polar Satellite launch vehicle that sent up a record number of 104 cube satellites in Feb. 2017. (Illustration courtesy of the Indian Space Research Organization.)

different needs with regard to the processing of remote-sensing satellite data when it comes to the requirements of various users in government, of different types and sizes of industry, and individual consumers. We are seeing increases in the number of satellites deployed. We are seeing even small sats with improved spatial resolution. Finally we are seeing various types of hyper-spectral satellites that are monitoring as many as a hundred small segments or bands of spectra. This can result in more timely updates of data. It can require higher

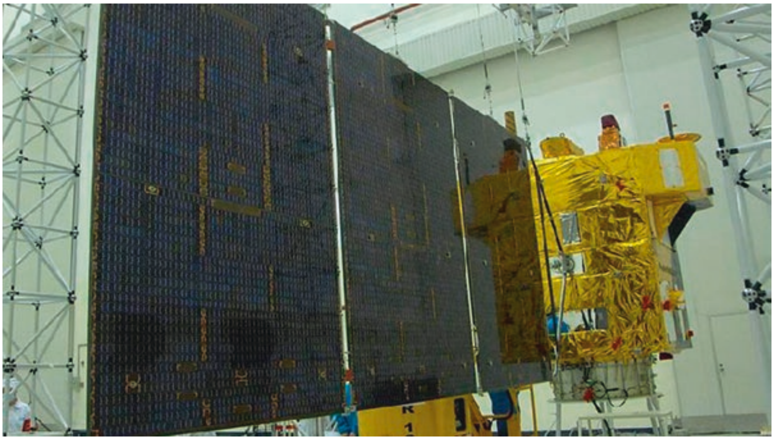

Fig. 3.3 The joint Brazilian/Chinese CBERS-4 satellite will form part of the planned BRICS virtual EO constellation in Phase 1. (Illustration courtesy of INPE of Brazil.)

performance data recorders, and faster downloads of data plus the need to cope more efficiently with the streams of encoded data. Overall these innovations has created a Niagara of data streaming from space that is difficult to process efficiently.

The huge spikes in data create a giant challenge to timely and thorough data analysis. Two key possibilities are on-board processing as well as AI algoritms that allow the 'automated' analysis of data based on expert systems and even more advanced AI 'reasoned' analysis. The NASA remote-sensing project named "Mission to Planet Earth" that began in the 1990s had to be reduced in scope just because the processing and analysis involved so many petabytes of data that it was impossible to cope with the downloading and analysis requirement. This is just one of the many instances where the hardware design for a new scientific mission and the supporting software can find themselves out of synch [12].

This push toward automated analysis and pre-processing has set off a controversial debate as to how much "ground-truthing" of remote-sensing data and expert analysis is needed to attain scientifically accurate results versus quickly providing analysis in near real-time to end users. There are fears that such end users, not well versed in data analysis, may be led into false conclusions from quickly downloaded pre-processed data that might tend to produce spurious results and wrong conclusions about such things as soil conditions, tree blight, oceanic pollution, and so on.

As the amount of data being produced by remote-sensing satellites rises from terabytes to petabytes to exabytes and beyond it will be increasingly likely that AI algorithms and other forms of pre-processing will be needed with the giant streams of data traffic. Thus in this area, as in many other aspects of a super-automated future, for great care to be given to human-machine interfaces (HMI). Such precautions can hopefully prevent major errors from being made.

One of the key software concerns is the now critical need to make sure that cyber-security systems are carefully put in place. Recent studies have shown how accessing aircraft systems could provid a means to cause an airplane crash. It is, of course, equally true that such a hacking of spacecraft avionics could be used to weaponize a spacecraft and to cause it to de-orbit or possibly crash into another space system [13].

Spinoffs from Defense-Related Surveillance

The first remote-sensing or Earth-observation satellite systems were designed and deployed for military and defense-related surveillance purposes. The very secret U. S. Corona spy satellite program was operational for many years before it was ultimately declassified. What were once highly classified spy satellite capabilities, however, are now routinely provided on commercial remote-sensing satellites such as Ikonos. Even the Chinese commercial remote-sensing capabilities provided on small satellites, such as the Jilian satellites at 1-meter resolution, were once considered to be spy satellite capabilities. The United States has reserved the right for 'shutter control' on commercial satellite systems with high spatial resolution that would serve to blank out areas where military hostilities might be taking place. This type of shutter control, however, tends to become a moot point if there are many different countries operating governmental or commercial satellite systems with equivalent spatial resolution.

It is also true that some countries seek to hide sensitive military installations or facilities by making them deliberately fuzzy on remote-sensing satellite images. This, however, becomes somewhat self-defeating in that hostile forces only have to look to the fuzzy regions on remote-sensing images to identify where these facililties are located.

Article 4 of the U. N. Outer Space Treaty of 1967 states in part: "States Parties to the Treaty undertake not to place in orbit around the Earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction, install such weapons on celestial bodies, or station such weapons in outer space in any other manner.

> The moon and other celestial bodies shall be used by all States Parties to the Treaty exclusively for peaceful purposes. The establishment of military bases, installations and fortifications, the testing of any type of weapons and the conduct of military manoeuvres on celestial bodies shall be forbidden…..

This treaty does not define what is a space weapon *per se*. It also does not explicitly prohibit the placing of satellites into Earth orbit that might be used to support military communications, operations, targeting, surveillance or reconnaisance. Today, the GPS and other GNSS networks can be used for the targeting of bombs, while other remote-sensing and Earth-observation satellites can be used for surveillance and reconaissance, and there are many satellites whose function is to support military communications and tactical operations. There are many remote-sensing satellites – both commercial and governmental – with spatial resolutions in the range of 0.35 m to 1.00 m that could be used for either offensive

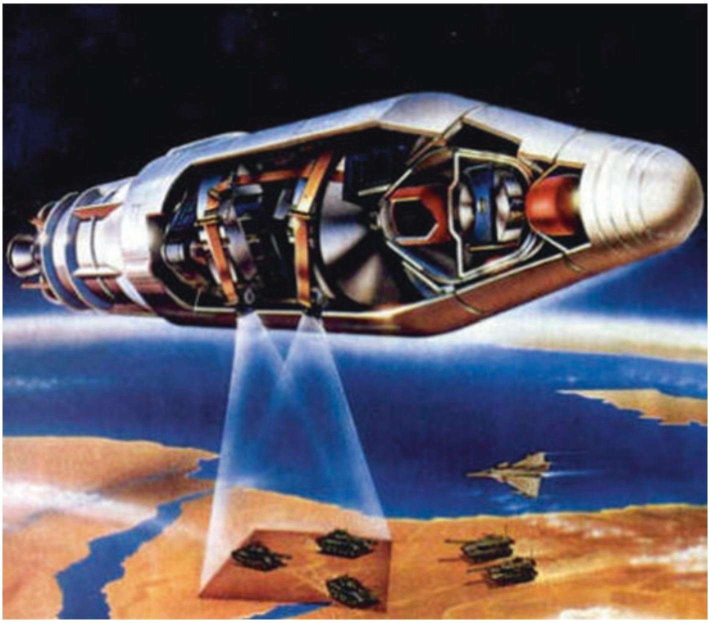

Fig. 3.4 The Corona program for defense spying led the way for civilian remote sensing in the years that followed. (Graphic courtesy of Yahoo History Chronicles.)

or defensive action by armed forces, and most are not subject to shutter control in the case of war. When the 50th anniversary of the U. N. Outer Space Treaty was celebrated in 2017, no international law expert foresaw the opportunity or even any prospect that new treaties to define space weapons or to ban their use could be agreed in today's political climate. The recent proposals that have come from the U. S. White House in mid March 2018 to create a U. S. Space Force has clouded the waters even further. Some believe that such proposals further jeopardize the ability of the nations of the world to respect the concept of space being a weapons-free zone [14].

Today, the eyes in the sky only continue to become more clear-sighted. If any nation seeks to hide strategic facilities or equipment, they tend to move it underground and thus out of sight of surveillance or remote-sensing satellites.

New Commercial Business Interests Around the World

The latest breakthroughs are now even allowing the deployment of small satellites that are capable of hyperspectral sensing in many dozens to over one hundred different bands and quite reduced-sized satellites able to provide video color imaging at spatial resolutions under 1 meter per pixel. These developments are changing the economics, business plans and applications of the world of remote sensing. The costs of these operations, that have come down by a factor of ten to even a hundred times, means that these services can be provided to a much broader range of users.

Farmers are increasingly seeing that the marginal cost of obtaining hyperspectral information for their farmlands makes a good investment to see how they can change their use of fertilizers and watering systems to increase productivity by 10% to even 25%. Entirely new applications are emerging. The rapid coverage provided by large-scale constellations such as Planet can allow retailing organizations, gambling casinos, and others to now track the parking in not only their own parking lots but also those of their competitors.

The challenge of the operators of today's remote-sensing satellite systems is not how to improve the imaging technology of their space systems but to find new commercial users for their increasingly detailed and useful data that comes down at a faster and faster rate. The key is in the analysis, distribution and sales of their space-based observations.

An entirely different concern is that as remote-sensing satellite services become more and more commercialized by entrepreneurial companies, the key role that remote satellites can play with regard to detecting disasters and providing assistance to disaster relief might become more limited. The International Charter on Space and Major Disasters was signed in the year 2000 and now has16 member agencies. These space agencies are committed to contributing free satellite, data processing and data distribution assets when this charter is formally invoked. It aims to provide a unified system of space data acquisition and delivery to those affected by natural or manmade disasters through authorized users.

The International Charter on Space and Major Disasters is a worldwide collaboration among space agencies, through which satellite-derived information and analysis products are made available to support disaster response efforts. The charter has been operational since November 2000, and currently the following global space agencies participate: ESA, CNES, CSA, NOAA, CONAE, ISRO, JAXA, USGS, UKSA & DMCii, CNSA, DLR, KARI, INPE, EUMETSAT, and ROSCOSMOS. This charter process involves only national and regional space agencies and official governmental agencies involved with remote-sensing data [15].

In the future it might certainly make sense to see if there were a process whereby a number of the commercial remote-sensing concerns that may in many instances have more rapid temporal updates of affected disaster areas might be included within the charter to provide vital data and analysis on an emergency basis to aid recovery efforts in a more timely way.

The Proliferation of Remote-Sensing Satellite Systems

The spread of remote-sensing satellite systems operated by national governments and a rapidly growing number of commercial satellite systems is one of the major stories in the rapid growth and expansion of the satellite world and the burgeoning Space 2.0 story.

For many years there were only a few spacefaring nations, i.e., less than ten, and this meant that there were a limited number of remote-sensing satellite networks, even with the inclusion of meteorological satellites. The world of small sats, which that has seen the rapid growth of RS satellites with hundreds of 3-unit cube satellite networks in operation and many other small satellites now operating as commercial operations, has dramatically altered the "spacescape" in the past decade. Today there are some that are questioning the need for quite so many satellite networks both for remote sensing and for space navigation and timing. Such networks are still expensive to design, build, operate, and even to de-orbit. There is particular concern about the deployment of so many satellites in low Earth orbit, and particularly in low Earth orbit Sun-synchronous polar orbit in terms of proliferating space junk and the rising threat of increasing orbital space debris.

The motivation behind the deployment of these networks continues to be various in number and not the same from country to country or from company to company. Many countries feel they need such types of space systems from the perspective of national defense, and particularly feel they need their own space resources rather than be dependent on other countries' resources. This is a motivation that is probably even stronger with regard to space-based precise navigation and timing satellites. Some countries or commercial companies feel they have special sensors or technical capabilities that are not available on other systems. Yet others believe that, with the latest small sat technology and automated testing capabilities and new, more cost-effective launch systems that can deploy new space systems at a cost that is perhaps as much as a hundred times less than was the case before, they can afford to do this themselves where once this was not the case. The motivation may be particularly strong for countries or commercial entities that see such satellite deployments as "flying their flag" in space and thus be able to display a special sense of accomplishment. (Fig. 3.5 shows the proliferation of remote-sensing satellites in recent years, and this chart is far from complete, with hundreds of new remote-sensing satellites launched in just the last two years.)

The greatest concern is with regard to the increasing deployment of both communications satellites and remote-sensing satellite constellations. This rapid increase of satellites in low Earth orbit exacerbates the problem of orbital space debris. With the current lack of clearcut and international agreements for space traffic management these problems will likely only become worse. Efforts to coordinate remote-sensing activities among nations and share data more freely are positive steps that can be taken.

In this regard one of the key developments is the global coordinative processes that are now in place through the International Committee on Global Navigation Satellilte Systems (GNSS) that is known as the ICG. The stated purposes of the ICG are to: "encourage coordination among providers of global navigation satellite systems (GNSS), regional systems….to ensure greater compatibility, interoperability, and transparency, and to promote the introduction and utilization of these services and ….encouraging coordination and serving as a focal point for information exchange." [17] The ICG came into existence through the good offices of the U. N. Office of Outer Space Affairs and has been in existence since 2005. If there are more processes for information exchange and more transparency and interoperability, this can perhaps help to minimize additional redundancy among remote-sensing satellite launches [18].

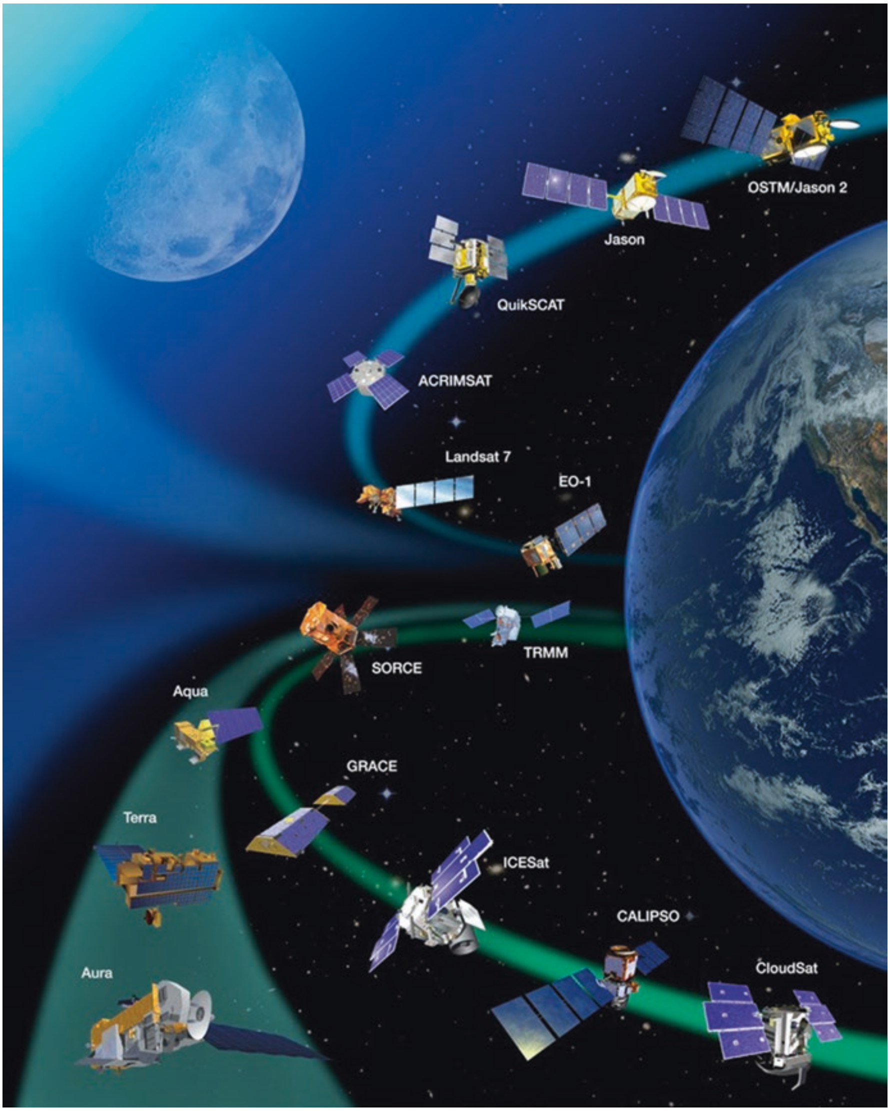

Fig. 3.5 The proliferation of governmental and commercial rs satellites globally. (Illustration courtesy of SERC, Carleton.edu.) [16]

Conclusions

The current rapid reinvention of the space industry and the growing success of Space 2.0 enterprises are particularly evident in the area of remote-sensing satellites. The strong influence that Silicon Valley has had on the space industry is particularly strong in the remote-sensing sector. The Skybox and Planet Labs initiatives were born of Silicon Valley ventures. Google purchased Skybox, renamed it Terra Bella and then facilitated the merging of the assets of the Skybox satellite system with Planet Labs to become the new Planet system. Hawkeye 360 is in the process of developing an entirely new form of satellite monitoring via small sats to track global use of mobile radio frequencies.

There are enormous amounts of data flowing from an unprecedented number of remote-sensing satellites in orbit, and the applications keep growing. The appendix to this chapter provides a guide to some of the databases that are now available free of charge that can be easily accessed by the Internet.

In addition to important new and growing industrial applications, governments are using RS satellite data for regulatory oversight, law enforcement, support to first responders, fire and environmental concerns and more effective response to disasters – both manmade and natural catastrophes. The challenge is to cope with the mounting problem of orbital space debris and in this context to develop a meaningful system for space traffic management that can minimize the risk and perhaps facilitate active debris removal.

See Appendix A at the end of this book for an addendum to this chapter.

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