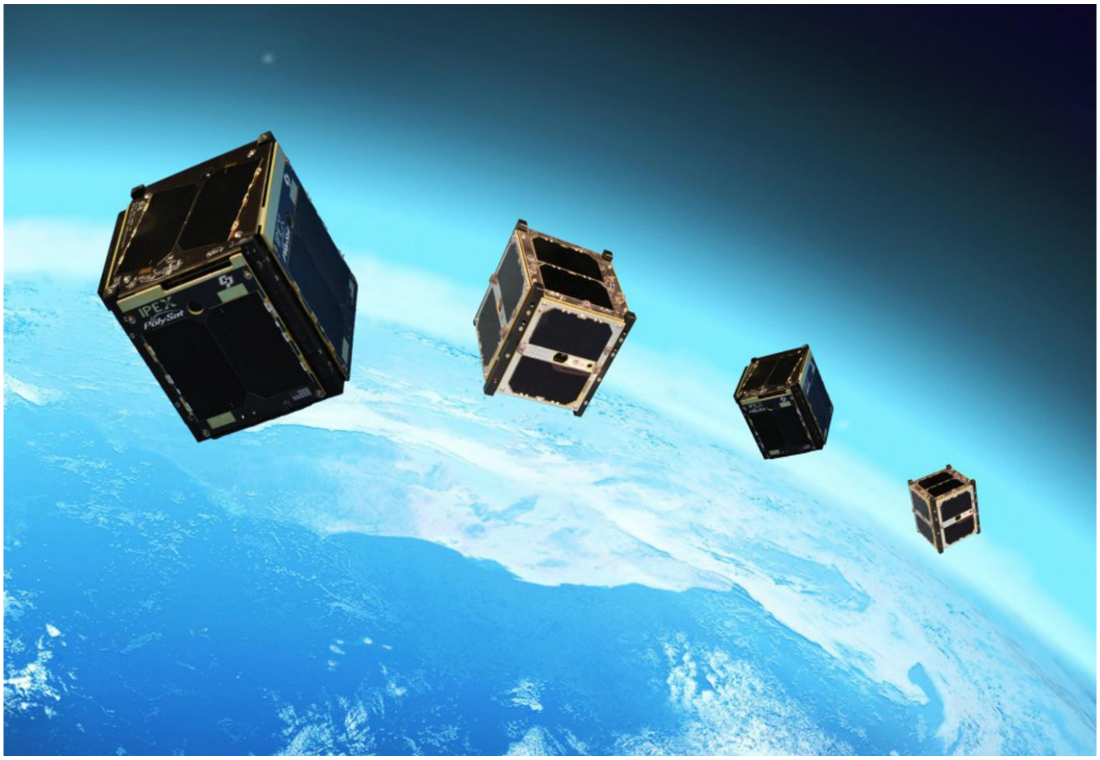
Overview: Satellite Constellations



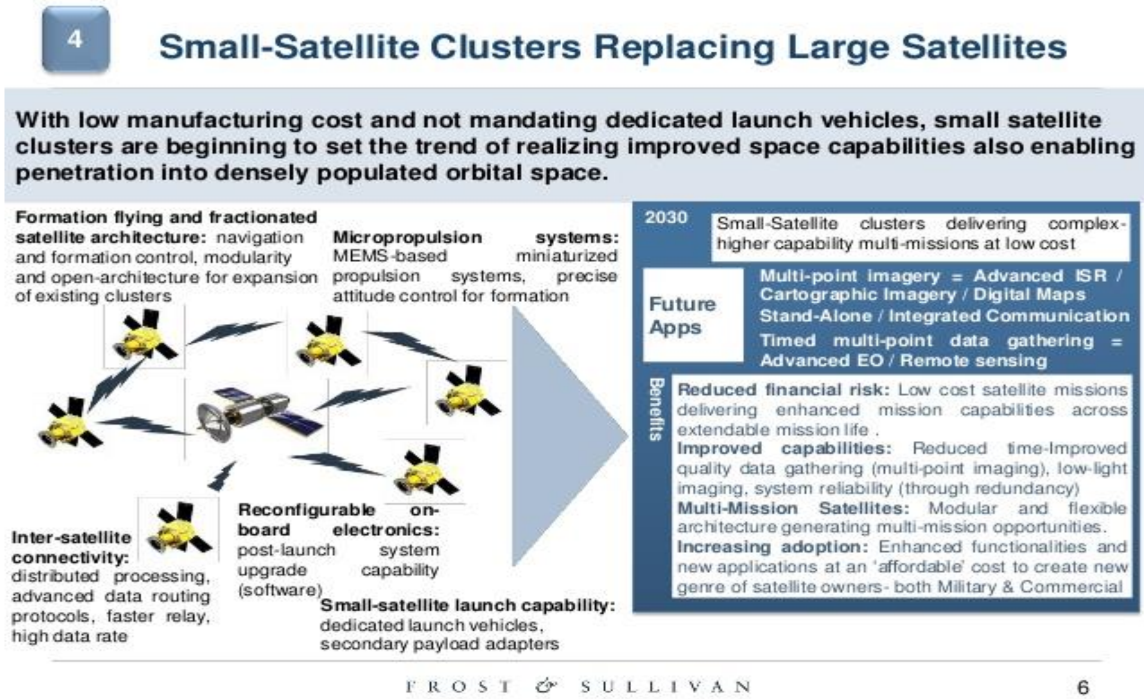
Sky and Space Global (UK) Ltd. A constellation of Nano-Satellites (approximately 200), placed in carefully selected orbits giving equatorial coverage of the Earth, creating a global communication network for voice, data and instant messaging.

From the Editor-in-Chief

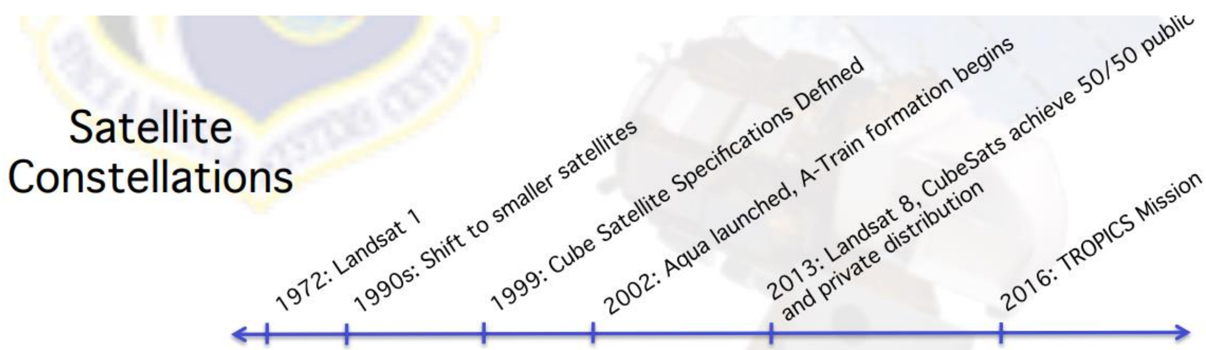
Journal of Space Operations & Communicator, a quarterly online publication (www.opsjournal.org), serves as a forum for those involved in the space operations field to communicate with one another in order to share ideas that could improve the way operations are carried out in space. The Journal is a cross-disciplinary scholarly publication designed to advance space communication as a profession and as an academic discipline. The Journal is distributed electronically without charge to users on a global basis. JSOC contains peer-reviewed articles, comments and case notes written by leading scientists, professors, and practitioners in their respective fields of aerospace expertise. The editorial board seeks articles that demonstrate exemplary academic research of emerging trends in space technology and space operations fields.

The current issue is dedicated to Satellite Constellations, a phenomenon of space operations and applications ever-evolving. The talk of 2019 has been a new kind of space race. SpaceX has already launched the first satellites of its Starlink constellation, with a proposed final number of 42,000. Earlier this year, Blue Origin announced its intention to create its own constellation for satellite internet (with more than 3,000 satellites), and OneWeb has already launched the first satellites in its endeavor (about 2,500). Established companies and startups alike are launching large networks of small satellites (generally considered anything under 500 kilograms—in comparison, the Hubble Space Telescope is more than 11,000 kilograms). Cheaper, easier to manufacture, and less expensive to send to space, small satellite constellations collectively cover a much bigger portion of the Earth than standard satellites. Spatial and temporal sampling properties of the science measurements made by constellations are improved by spreading the satellites out around their orbit plane. Global measurements of vertically resolved atmospheric wind profiles offer the potential for improved weather forecasts and superior predictions of atmospheric wind patterns.

Sincerely,
Ronald H. Freeman, PhD (Editor-in-Chief)



Planned constellations of hundreds communication satellites enable the use of optical telecommunication's capability to transmit increasingly higher data rates with compact, low-mass terminals, while avoiding interference problems and radio frequency band saturation. Two thematic drivers motivate the science community towards constellations of small satellites: (1) the revelation that many next generation system science questions are uniquely addressed with sufficient numbers of simultaneous space based measurements and (2) the realization that in an environment of constrained costs –innovations require more be done with less. National Aeronautics and Space Administration's (NASA's) motto 'faster, better, cheaper' prompts the search for alternative designs and methods needed for future missions. In the late 1980s a new satellite paradigm, modern small satellites, opened up a new class of space applications. Micro- and nano-satellites enabled exploring and testing new ideas for space missions without spending huge amounts of money. The actual launch cost per kilogram payload was as high as or even higher than ordinary satellites. The first micro-satellites (mass 10–100 kg) were launched during the period 1957–1969. In the period 1980–1999 a total of 238 mini-satellites (mass 100–500 kg) and 249 micro-satellites were launched from countries all over the globe [1].

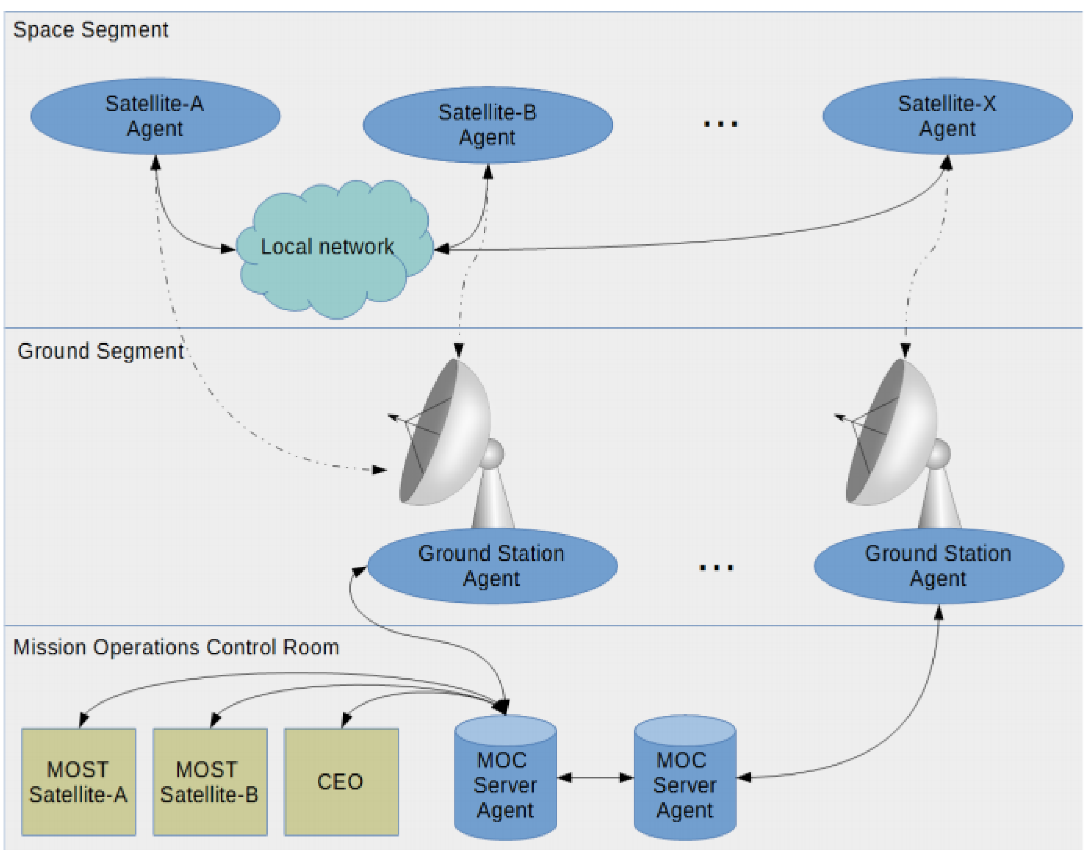


Landsat 1, launched on July 23, 1972, carried a Return-Beam Vidicon camera and MultiSpectral Scanner to image the earth from a 900 km altitude with green, red and two IR spectral bands at 80m resolution. Landsat 1 in a near-polar sun synchronous orbit obtained visible and near IR photographic images of the earth up to January 6, 1978, when the degradation of the orbit caused it to see almost constant sunlight which led to overheating [2].

In the early 1990's there were optimistic projections for mobile satellite services in general and global satellite telephony in particular within the telecommunications market. The idea of having telephones that could operate wirelessly almost anywhere on Earth, without ever being "out of range", was revolutionary at that time. This led to the conception, design and launch of a number of communications satellite constellations such as Iridium (66 satellites) and Globalstar (48 satellites). Each of these constellations broke new ground in terms of technologies such as handheld satellite terminals and inter-satellite links, as well as bulk manufacturing, launch and simultaneous operations of large numbers of spacecraft. System design was conducted during 1991-1997 and Federal Communications Commission (FCC) licensing of these systems occurred in 1995 for an unprecedented, long-term characterization of the state of Earth's troposphere and middle atmosphere via cm and mm wavelength satellite-to-satellite occultation measurements [3].

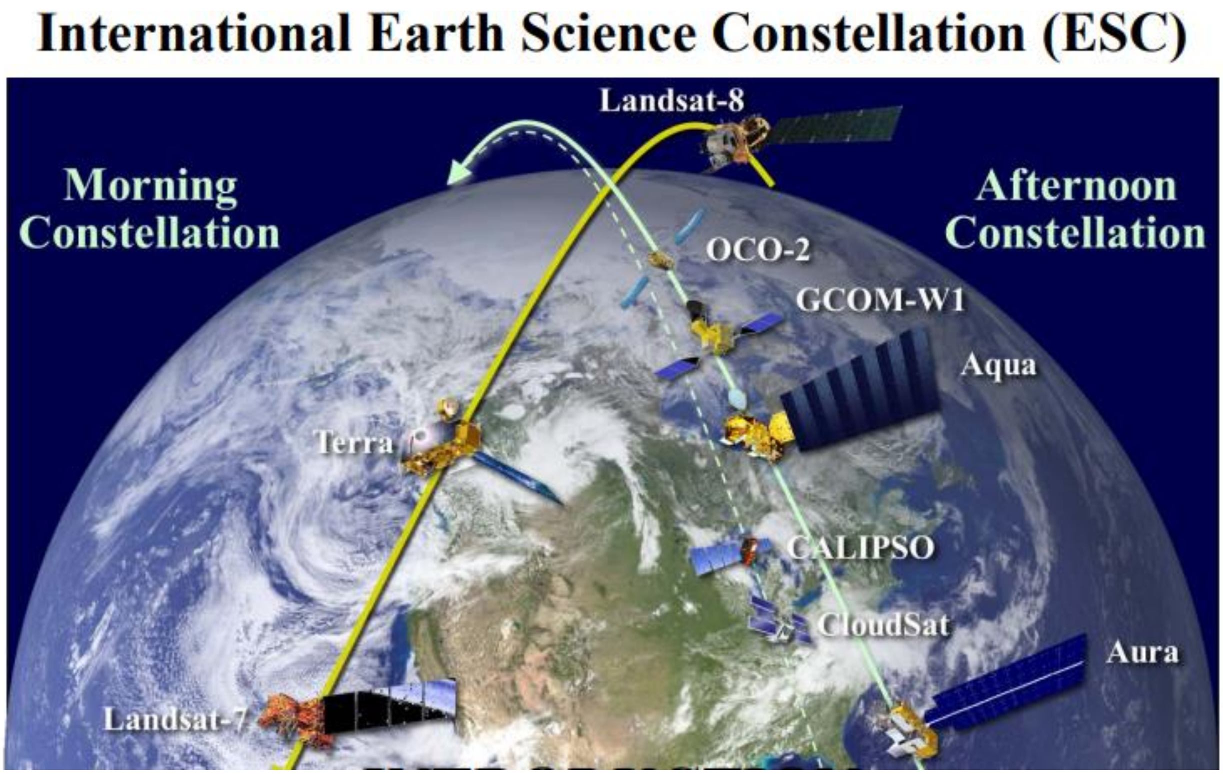
The Global Positioning System (GPS), originally NAVSTAR GPS, was a satellite-based radionavigation system owned by the United States government. The GPS project started the first prototype spacecraft launched in 1978. and the full constellation of 24 satellites operational in 1993, was distributed equally among six orbital planes [4]. In the current global positioning system (GPS), the reliability of information transmissions is enhanced with the aid of inter-satellite links (ISLs) or crosslinks between satellites. Instead of only using conventional radio frequency (RF) crosslinks, laser crosslinks provide an option to significantly increase the data throughput. The connectivity and robustness of ISL are needed for analysis. An optical crosslink assignment criterion, considered practical to incorporate optical communication factors such as optical line- of-sight (LOS) range, link distance, and angular velocity, etc., requires further improved capability with a topology control algorithm formulated to optimize GPS crosslink networks at both physical and network layers [4].

Planned constellations of hundreds communication satellites enabled the use of optical telecommunication to transmit increasingly higher data rates while avoiding interference problems and radio frequency band saturation. Two thematic drivers motivate the science community towards constellations of small satellites: (1) the revelation that many next generation system science questions are uniquely addressed with sufficient numbers of simultaneous space based measurements and (2) the realization that in an environment of constrained costs –innovations require more be done with less [5].



There is an ongoing effort to reduce the cost of small satellites and to increase their capabilities [6]. Unlike a single satellite, a satellite constellation is a group of artificial satellites providing global or near-global coverage. Constellations are gaining popularity in government and commercial space-based missions for Earth Observation (EO) due to their risk tolerance and ability to improve observation sampling in space and time [7]. Studies show that key science data obtained in space independently converge towards similar results, i.e. that approximately 60+ satellites are needed for transformative, as opposed to incremental capability in system science. The current challenge is how to effectively transition products from design to mass production for space based instruments and vehicles [8]. The metrology of a satellite formation is a system-level issue relying on the measurement technology, number and selection of metrology links, location and tolerances of the components used to materialize the optical paths, and a variety of issues related to redundancy, recovery from contingencies, failure modes and sensor degradation. Constellations have proven to be an effective and efficient way to acquire earth science data by flying sensors on all satellites taking measurements of the same air, water, or land mass at essentially the same time. The sensors form a single "virtual satellite". The key to making a constellation effective and efficient is keeping the operations as independent as possible in order to minimize the operational burden and costs. The successful Earth Science Constellation (ESC) continues to welcome new missions to continue its 18+ year record of coincidental earth science observations [9].

NASA's Earth Science Enterprise (ESE) aimed to develop a scientific understanding of the Earth system and its response to natural and human-induced changes for improved prediction of climate, weather, and natural hazards [10]. Satellite constellations became the distributed architecture for which spacecraft mission was shared and allocated among multiple small spacecraft. And, cost and performance were optimized across multiple instruments and platforms vs. one at a time [11].



Economic Metrics of SmallSat Constellations

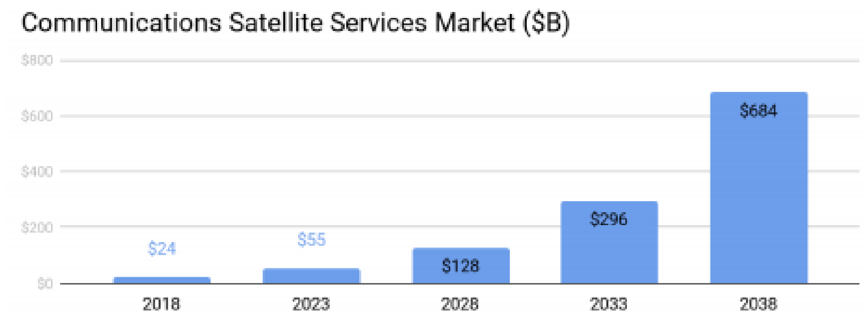
Based on the surface area and mass of the satellite, orbital decay can be found for a range of altitudes. Although all orbits are placed below the Van Allen belts, radiation damage and other hardware failures are likely to become limiting factors in lifetime before orbital decay, and a maximum lifetime of ten years for each system is assumed. With the design space reduced to a handful of unique systems, a detailed analysis is required to further evaluate the cost vs performance trade. The analysis consists of three major technical capability estimations: a downlink budget, a power budget, and system coverage. The driving performance metric for these systems is the $/megabytes vs.

altitude function, which captures the total cost of the system, the lifetime of the system, and the total system capacity. To get the best price per capacity, optimizing this metric across system designs, makes it competitive from both a business and performance perspective. Different coverages produce different $/Megabyte curves as the cost and system capacity ratio fluctuates. In each case, the optimum coverage value (where $/Megabyte is minimized) represents that design for system comparisons. For example, the absolute minimum of $/Megabyte occurs on the Global curve at 487 km altitude, the lowest $/Megabyte for the MidRange constellation occurs at 505 km with Global coverage, and the optimal (in terms of lowest $/Megabyte) altitude for the NextGen constellation with Global coverage occurs at 444 km. And, the Tech Heavy constellation is optimized at 411 km with Equatorial coverage. The comparison of $/Megabyte versus altitude for the selected coverage option in each design is summarized in the following Table.

Decission/Name	NanoSat	MidRange	NextGen	Tech Heavy
Mass [kg]	12.7	38.3	125	480
Frequency	X Band	X Band	Ku/Ka Band	Ku/Ka Band
Antenna Type	Parabolic	Electronically Steered	Electronically Steered	Electronically Steered
Crosslink Type	None	None	RF	Optical
Relay Type	Bent Pipe	Bent Pipe	Bent Pipe	Regenerative
Architecture	None	None	Ring	Ring
Coverage	Global	Global	Global	Equatorial
Altitude [km]	487	505	444	411
Est. Constellation Size	264	253	312	203
System Capacity [Gbps]	102.5	370.5	1832.5	3203
Development Cost	$33M	$33M	$48M	$64M
AI Software Cost	$5M	$5M	$5M	$5M
Total Satellite Cost	$38M	$1,453M	$8,112M	$12,434M
Total Launch Cost	$270M	$682M	$744M	$1,302M
Regulatory Fees	$10M	$10M	$20M	$20M
Total Constellation Cost	$356M	$2,183M	$8,929M	$13,825M
NPV	-$328M	$501M	$1,401M	-$1,748M

Once the individual systems are vetted for optimal performance, the overall highest-performing system must be determined. Selection is aligned with mission requirements and objectives. Although NanoSat had the overall smallest $/Megabyte, it could not compete with reference cases Starlink and Viasat in terms of capacity or throughput. At altitude 444 km, NextGen exceeds ViaSat capacity and latency, and with the highest NPV (net present value), can provide subscribers 10 Mbps of throughput during peak operation [12].

Missions of satellite constellations require the multiple spacecraft to share not only mission objectives and the cooperative efforts of all in their respective network but to pre-define the tradespace of such variables as science output, cost and risk goals. The tradespace will be based on variability in heritage versus state-of-the-art designs, and include options with different Technology Readiness Level (TRL). Predictions by Morgan Stanley show the market for satellite communications is expected to grow exponentially from $24B in 2018 to $128B by 2028. Driving growth in this market are upgrades to 5G networks, where satellite communications can play an important role in backhauling, tower feed, mobility, and hybrid multiplay, as well as consumer broadband [13].

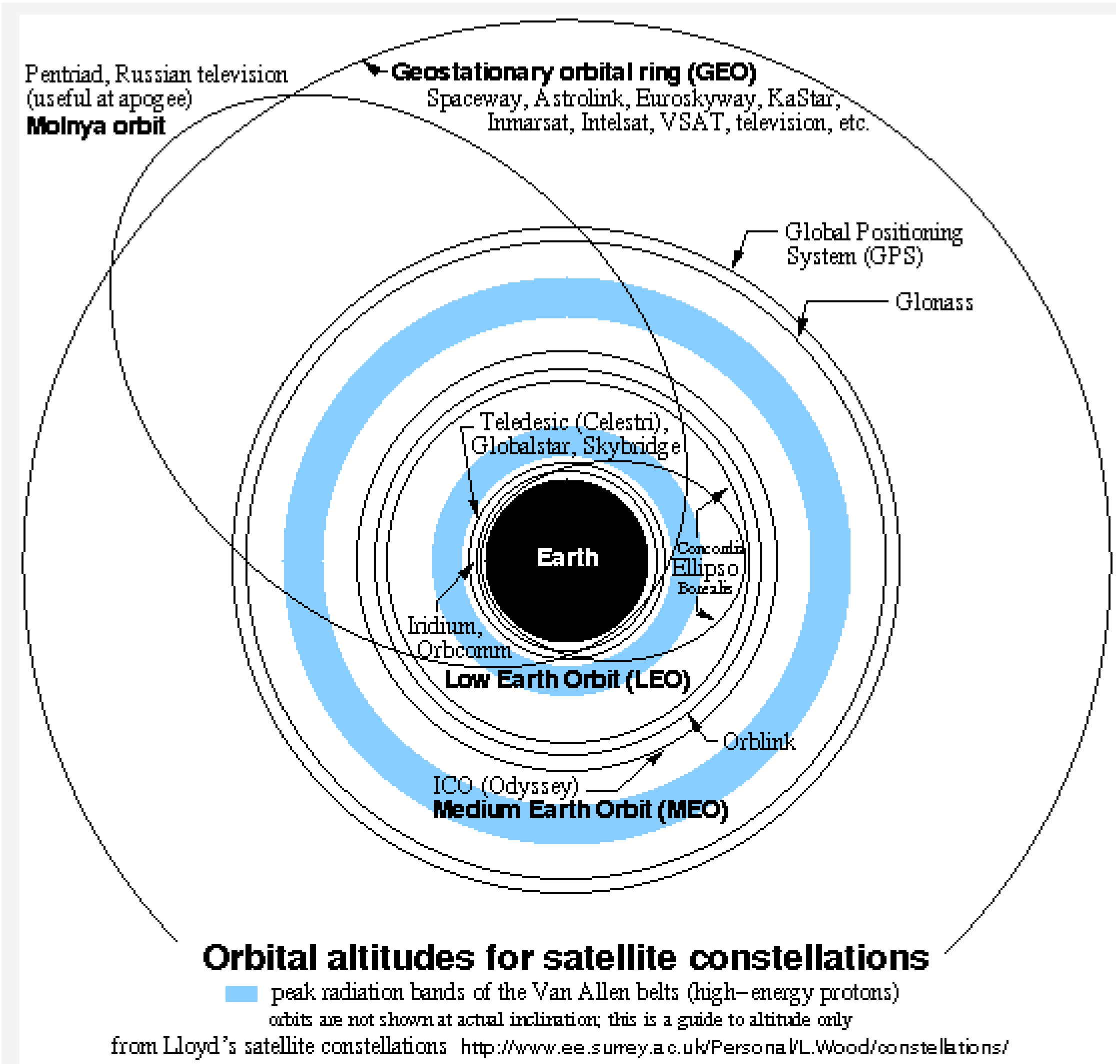


Predicted growth in the satellite services market over the next 20 years.

CubeSat Constellation Missions

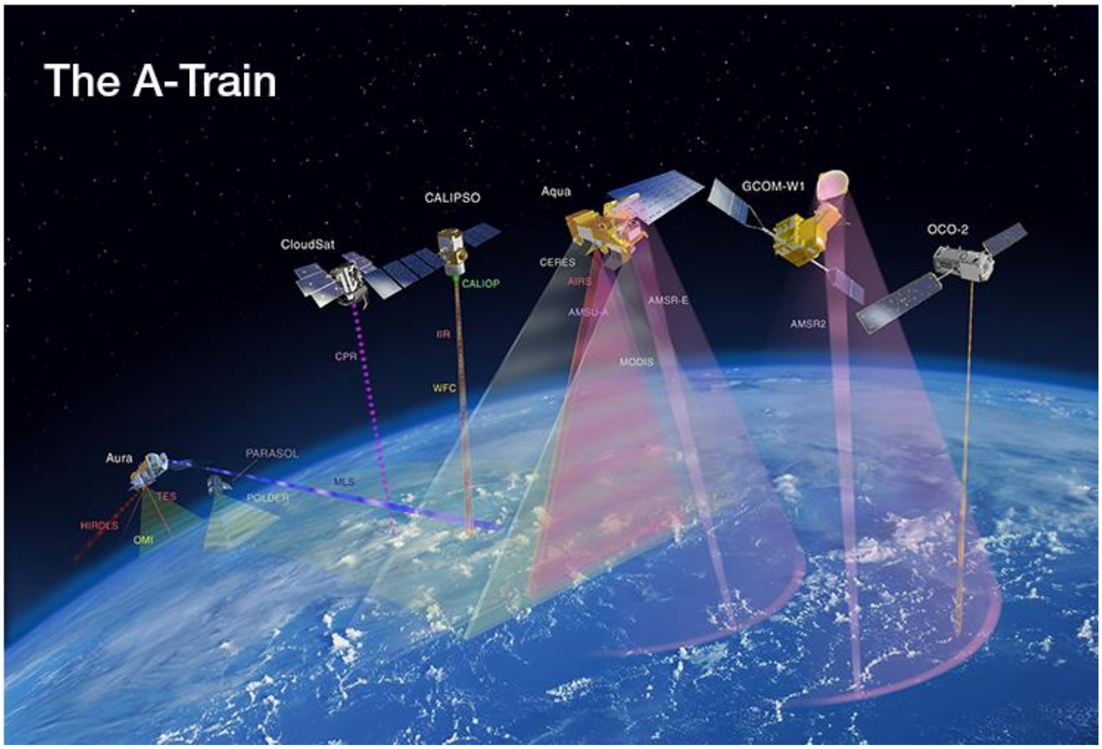
The Iridium system was designed to be accessed by small handheld phones, the size of a cell phone. Omnidirectional antennas were small enough to be mounted on the phone but with low battery power, the phone's radio waves could not reach a satellite in geostationary orbit, the normal orbit of communications satellites. In order for a handheld phone to communicate with them, the Iridium satellites had to be deployed closer to the Earth LEO. With an orbital period of about 100 minutes, a satellite was only in view of a phone for about 7 minutes, so the call was automatically "handed off" to another satellite when passing beyond the local horizon. This required a large number of satellites, carefully spaced out in polar orbits to ensure that at least one satellite was continually in view from every point on the Earth's surface [10f]. At least 66 satellites were required in 6 polar orbits containing 11 satellites each, for seamless coverage **[7a]**. Each satellite supported up to 1100 concurrent phone calls at 2400 bit/s and weighed about 680 kg (1,500 lb). The total capital investment ($5.7 billion for Iridium and $3.3 billion for Globalstar) was secured. Soon after commercial service started in November 1998 (Iridium) and March 2000 (Globalstar), it became apparent that the earlier market predictions had been overly optimistic. Only a small fraction of system capacity was used and revenues were insufficient to generate a profit or to service debt payments. Iridium filed for bankruptcy protection in August 1999, Globalstar followed in February 2002. Both constellations continued to operate in 2003 with moderate success in a post-bankruptcy mode [14].

CubeSat constellations additionally exploit Signals-of-Opportunity (SoOp) reflectometry for reutilizing existing microwave satellite transmissions, in bands allocated for space-to-Earth communications and navigation, for the purpose of Earth remote sensing. SoOp uses a bistatic radar geometry employing forward scatter, which views Earth differently from traditional monostatic (backscatter) radars and radiometers. A powerful example of the science returns achievable using SoOp is currently being demonstrated on orbit by the NASA's Cyclone Global Navigation Satellite System (CYGNSS) mission, which measures ocean surface wind speed using reflected Global Positioning System (GPS) signals.

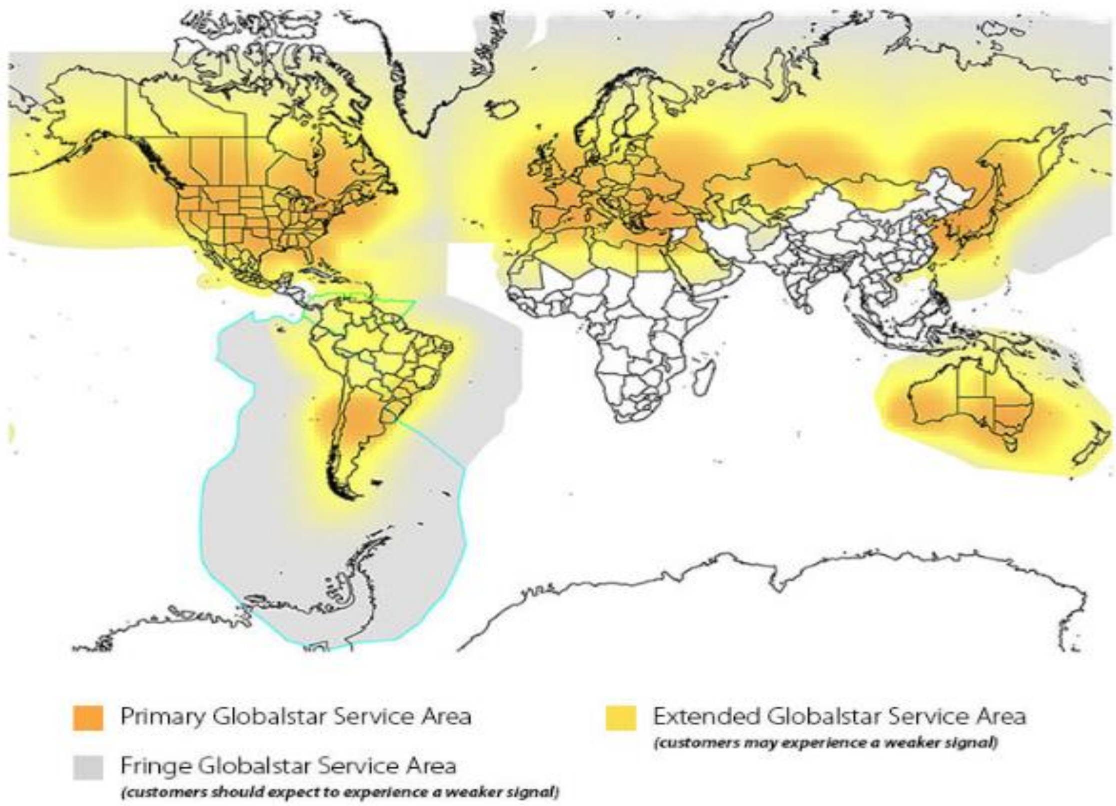


The primary purpose of an Earth observing spacecraft constellation is to obtain global measurements with improved spatial and temporal resolution. Validating and improving numerical climate and weather models depend on measurements from space-borne spacecraft. Cloud- and precipitation- profiling instruments onboard smallsats deployed in LEO provide limited temporal resolution for observing evolution of short-time or –scale weather phenomena in order to improve numerical weather prediction models. Because of their small size, moderate mass, and low power requirements, cubesats constellation missions enable the capability to observe the dynamics and thermodynamics at sub-diurnal time scales in order to visualize developing convections [15]. Additionally, instrumental payloads of solar and earth radiometers have acquired technical maturity for cubesat constellation missions to insure global measurement coverage. Harris' HyperCube constellation of twelve 6U hyperspectral cubesats provide measurements of global tropospheric, vertically-resolved atmospheric wind profiles for improved weather forecasts and predictions of atmospheric wind patterns [16]. And, a medium-class mission of 12 cubesats, the Active Temperature, Ozone and Moisture Microwave Spectrometer (ATOMMS) provides an unprecedented, long-term characterization of the state of Earth's troposphere and middle atmosphere via cm- and mm- wavelength satellite-to-satellite occultation measurements. ATOMMS observations yield a quantum step in performance relative to passive observations in terms of vertical resolution, precision and accuracy of moisture, ozone, temperature and pressure measurements in both clear and cloudy conditions. To hold costs down and achieve high reliability, the strategy of redundancy implements: multiple spacecraft, multiple channel instruments and multiple launches. Preliminary satellite cost estimates from vendors indicate non-recurring spacecraft design engineering (NRE) costs ranging from $12 to $40M and spacecraft replication costs will fall between $6.5 and $12M. Based on the satellite failure rates of Iridium and Globalstar, approximately 16 satellites will be needed to keep 12 satellites functioning over 10 years with 4 functioning initially as on-orbit spares [17], [18].

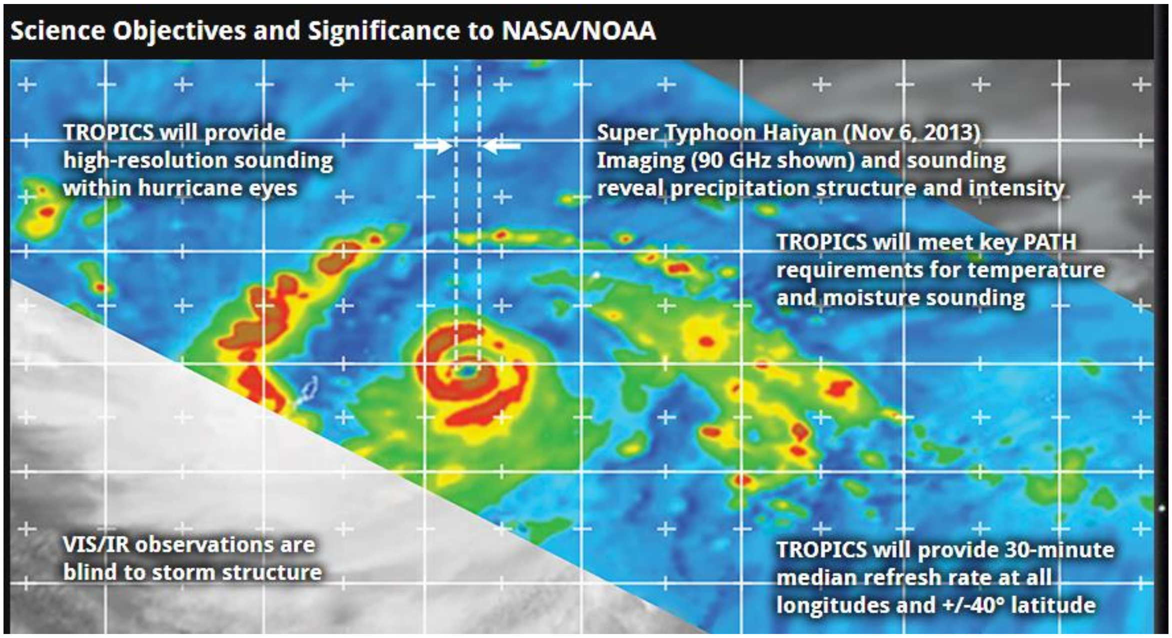
The existence of the Earth Observing System and the more-focused Earth System Science Pathfinder (ESSP) missions made possible the configuration of various platforms and instruments, the A-Train achieved. A-Train is a constellation of five satellites flying in a tight formation to accurately collocate and cointerpret data from synoptic-to-climate scales. Collocated subsets of MODIS (Moderate Resolution Imaging Spectroradiometer)/Aqua Atmospheres Level 2 result in such science measures as aerosols, atmospheric water vapor, clouds, profiles, cloud mask, and other certain geolocation and radiance metrics. The A-Train addresses broad aspects of radiation budget, aerosols, clouds, atmospheric water in all phases, trace gases, stratospheric ozone, and interaction among them [19].



There is a large undiscovered potential in multitemporal airborne laser scanning (ALS) for topographic mapping. Direct comparisons between height and intensity data from different dates reveal even small changes related to the development of a suburban area. In the future, there will be a need to effectively utilize multisource remotely sensed mapping data by exploiting the potential of satellite images, ground-based data to complement multispectral ALS. A method for continuous change monitoring from a time series of Sentinel-2 satellite images was developed and tested [20]. Landsat 8 (originally, Landsat Data Continuity Mission), an American Earth observation satellite launched on February 11, 2013, ensures the continued acquisition and availability of Landsat data, with its two-sensor payload: the Operational Land Imager (OLI) and the Thermal InfraRed Sensor (TIRS). These two instruments collect image data for nine shortwave bands and two long wave thermal bands. Providing moderate-resolution imagery, from 15 meters to 100 meters of Earth's land surface and polar regions, Landsat 8 operates in the visible, near-infrared, short wave infrared, and thermal infrared spectrums. Landsat 8 captures more than 700 scenes a day. The combined use of both Landsat 8/OLI and Sentinel-2A/B/MSI data provide high-frequency observations at moderate and higher spatial resolutions for terrestrial studies. Synthetic aperture radar (SAR) observations add to improve the frequency of data in areas with high cloud cover [21].

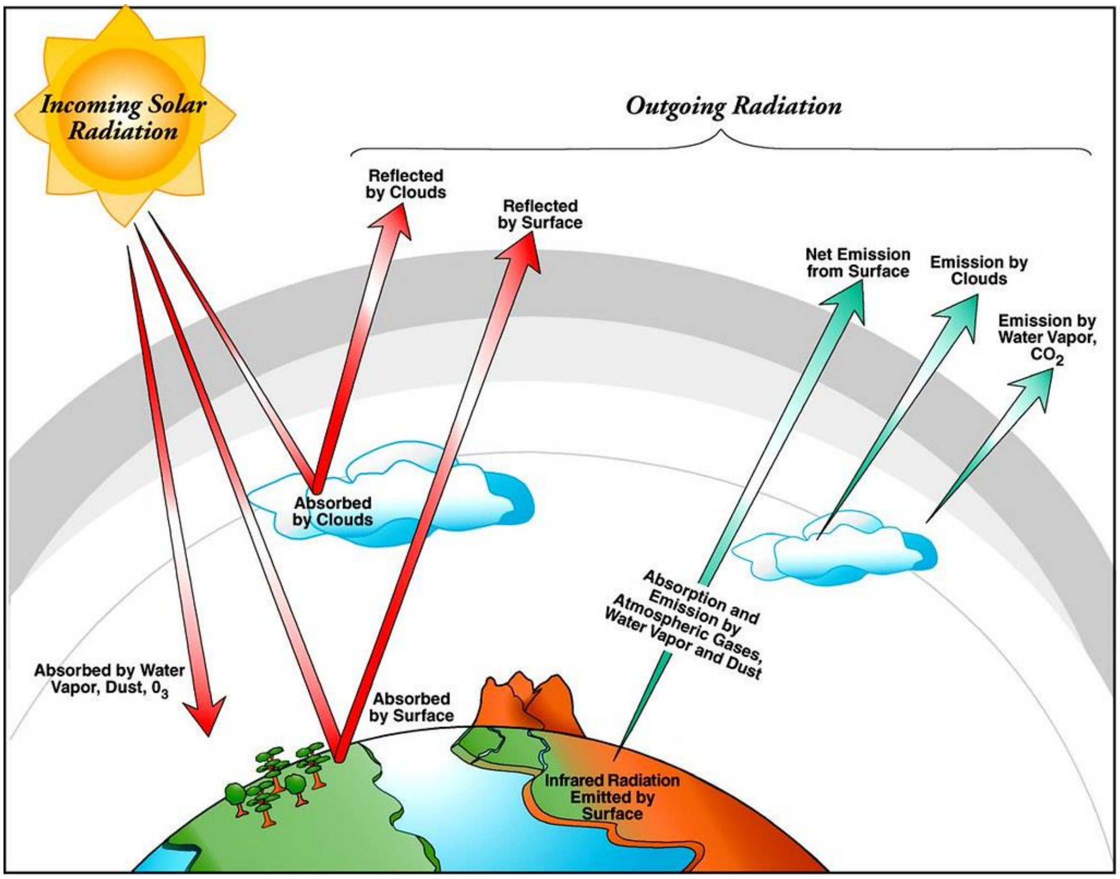


The Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) mission is projected to launch later in 2020, and its 1U 12 channel passive microwave radiometer is based on the current CubeSat mission MicroMAS-2A. In order to effectively use small satellites such as MicroMAS-2A and TROPICS as a weather monitoring platform, calibration must ensure consistency with state of the art measurements, such as the Advanced Technology Microwave Sounder (ATMS), which has a noise equivalent delta temperature (NEDT) at 300 K of 0.5 - 3.0 K [10g]. The overarching goal for TROPICS is to provide nearly all-weather observations of 3-D temperature and humidity, as well as cloud ice and precipitation horizontal structure, at high temporal resolution to conduct high-value science investigations of hurricanes and other tropical cyclones. TROPICS will provide rapid refresh microwave measurements (median refresh rate better than 60 minutes for the baseline mission) that can be used to observe the thermodynamics of the troposphere and precipitation structure for storm systems at the mesoscale over the entire storm lifecycle. TROPICS will comprise a constellation of at least six CubeSats in three low-Earth orbital planes. Each CubeSat will host a high performance radiometer to provide temperature profiles using seven channels near the 118.75 GHz oxygen absorption line, water vapor profiles using three channels near the 183 GHz water vapor absorption line, imagery in a single channel near 90 GHz for precipitation measurements (when combined with higher resolution water vapor channels), and a single channel at 205 GHz that is more sensitive to precipitation-sized ice particles and low-level moisture. This observing system offers an unprecedented combination of horizontal and temporal resolution in the microwave spectrum to measure environmental and inner-core conditions for TCs on a nearly global scale and is a major leap forward in the temporal resolution of several key parameters needed for assimilation into advanced data assimilation systems capable of utilizing rapid-update radiance or retrieval data [22]



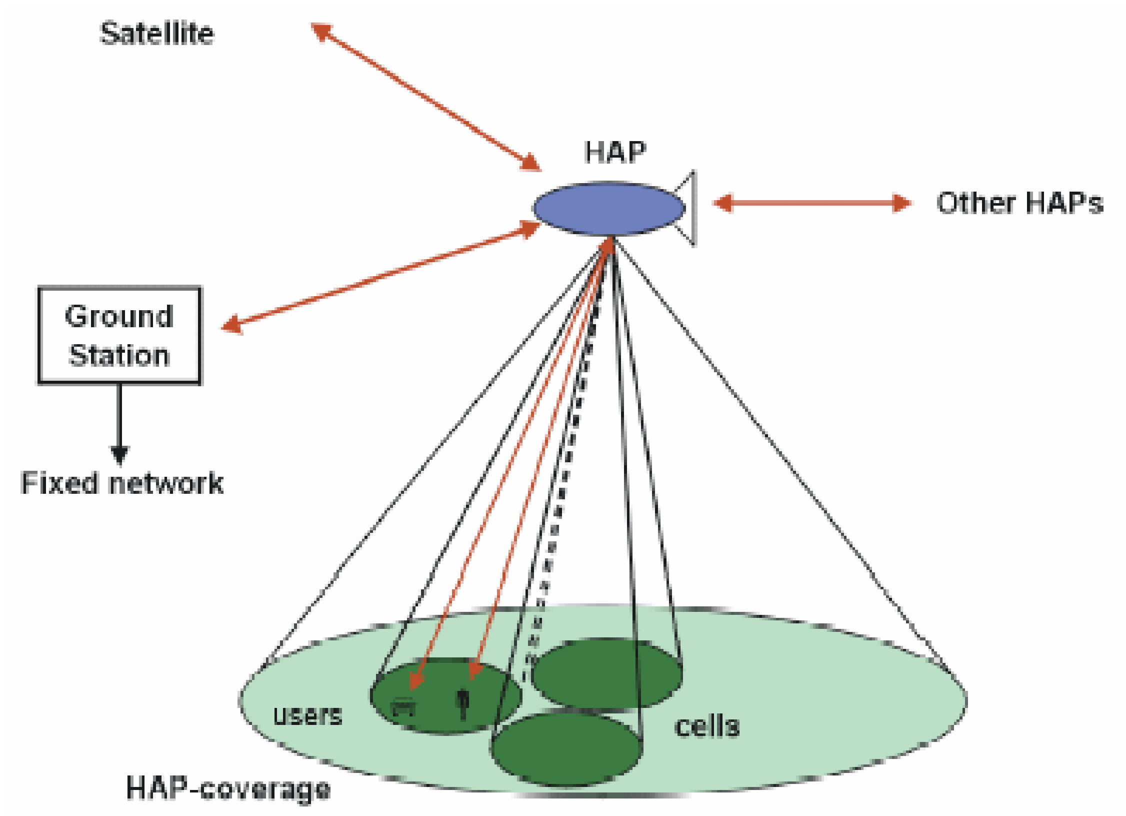
Nano-satellite Constellations

About 150 nano-satellites have been launched so far. The use of nano-satellites is no longer limited to educational institutions. Development of nano-satellite constellations expands observations of the Sun (total solar irradiance and solar spectral irradiance measurements) and the Earth (outgoing long-wave radiation, short-wave radiation measurements and stratospheric ozone measurements) [23]. Measurements of the true Earth Radiation Imbalance are a crucial quantity for predicting the future course of global warming. Despite the fact that the greenhouse-gas radiative forcing continues to rise, all estimates (ocean heat content and top of atmosphere) show that over the past decade the Earth radiation imbalance ranges between 0.5 to 1 Watts/ m^2. Up to now, the Earth radiation imbalance has not been measured directly. The only way to measure the imbalance with sufficient accuracy is to measure both the incoming solar radiations (total solar irradiance) and the outgoing terrestrial radiations (top of atmosphere outgoing longwave radiations and shortwave radiations) onboard the same satellite, and ideally, with the same instrument. The incoming solar radiations and the outgoing terrestrial radiations are of nearly equal magnitude of the order of 340.5 W/m^2. Total solar irradiance (TSI) reconstructions according to Vieira et al (2011) rely on solar activity indices such as sunspot number, geomagnetic indices such as aa index, cosmogenic isotopes such as C^{14} or Be^{10}, or solar models such as flux transport models [24]. The TSI is a crucial input for all climate models.The objective is to measure these quantities over time by using differential Sun-Earth measurements, to have redundant instruments to track aging in space in order to measure during a decade, and to measure global diurnal cycle with a dozen satellites. Solar irradiance and Earth Radiation Budget (SERB) nano-satellite aims to measure on the same platform the different components of the Earth radiation budget and the total solar irradiance. Instrumental payloads (solar radiometer and Earth radiometers) can acquire the technical maturity for the future large constellation missions that insure global measurement cover [25]. Future nano-satellite constellations will extend TSI variability measurement, improve the knowledge of the absolute value of the TSI, establish a radiation balance of the Earth with an accuracy better than 5% and aid in understanding the relation between solar ultraviolet variability and stratospheric ozone [26].



Remote Sensing Satellites

Revisiting time and global coverage are two major requirements for most remote sensing satellites in the Sun Synchronous Orbit (SSO). However for low latitude countries, SSO remote sensing and store-and- front communication services require more satellites to cover the communication service gap [27]. In China, HJ Satellite Constellation provides large-area, all-weather, all-time dynamic monitoring for environments and disasters. The microsatellite constellation includes 3 remote-sensing satellites, A and B optical satellites and C, a SAR satellite. The HJ Satellite Constellation provides. The sensors' data quality and in-flight performance are systematically monitored and measured by an integrated Data Quality Analysis and Assessment System for the constellation's ground system [28]. During the decades the data amount has steadily increased due to improved sensor technologies with increased temporal resolution, and pixel count. As a result, EO satellite missions have become constrained by downlink data rates of microwave communication systems (mcs) due to spectrum restrictions, manageable antenna sizes, and available transmit power. Optical downlinks from EO satellites with data rates of several Gbps mitigate mcs' limiting effects but cloud blockage prevents the necessary link availability through the atmosphere. However, a stratospheric High Altitude Platform (HAP) relays the optical communication beam over the last 20km through the atmosphere to the ground station where short-range, high data-rate microwave systems are feasible [29].



Challenges for Satellite Constellations

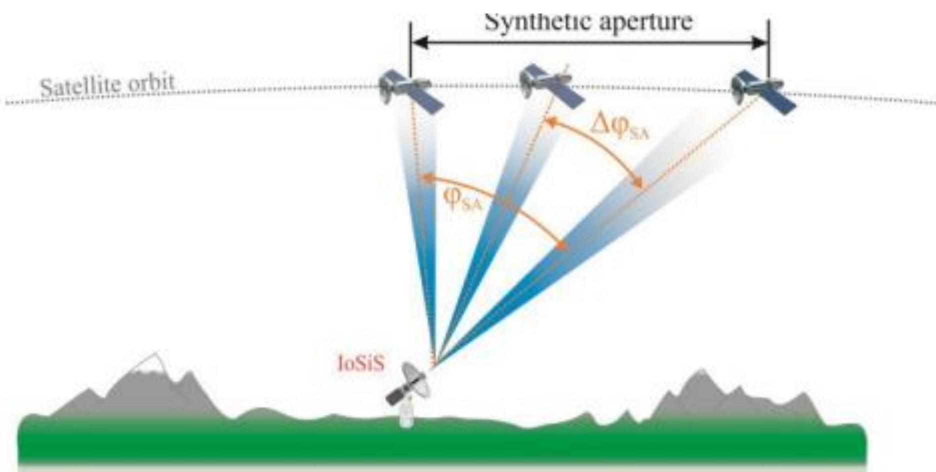
Significant reductions of uncertainty in weather and climate prediction require global observations of greater information content than currently provided. Wavelengths chosen for minimal interaction with atmosphere, limit GPS observations. GPS occultations cannot profile temperature, pressure and humidity nor clouds and turbulence [30]. Dynamic changes in satellite network topology challenge reliable transmission over satellite networks resulting in large delays and high error rates. Network coding-aware algorithm is an option for improved transmission [31]. Satellite networks play an indispensable role in providing global Internet access and electronic connectivity. One of the key mechanisms of implementing the quality of service (QoS) is traffic management. Traffic management becomes a crucial factor in the case of satellite network because of the limited availability of their resources. Currently, Internet Protocol (IP) only has minimal traffic management capabilities and provides best effort services. IP-based routing for military LEO/ MEO satellite ad hoc networks is challenging due to network topology, as well. Dynamic Autonomous Routing Technology (DART) provides a traffic priority-aware routing scheme for the ad hoc networks. DART ensures end-to-end data delivery with QoS assurances by incorporating several resource management and innovating routing mechanisms that integrate a resource reservation mechanism in order to reserve network bandwidth resources [32].

Atmospheric circulation is better discerned with information on the distribution and transport of upper tropospheric humidity. However, efforts to develop a dataset not diurnally biased (or, one that is based on geostationary data) are hindered by a lack of inter-calibration of the historical geostationary satellite water vapor channels. Determining high resolution infrared radiation sounder (HIRS) intersatellite bias between HIRS instruments on different satellites will result in a record from which geostationary satellite water vapor channels can be intercalibrated in order to produce a uniform analysis of upper troposheric water vapor [33].

Collision Risk for Satellite Constellations

Multiple companies have recently proposed or begun work on large constellations of hundreds to thousands of satellites in low-Earth orbits for the purpose of providing worldwide internet access. The sudden infusion of so many satellites in an already highly-populated orbital regime presents an operational risk to all LEO objects. To enable risk analyses and ensure safe operations, a robust system will be needed to efficiently observe these constellations, and use the resulting data to accurately and precisely track all objects. One strategy is for the scheduler to use an information theoretic reward function to prioritize high-value tasks and a ranked assignment algorithm to optimally allocate these tasks to a sensor network. By labeling a multi-Bernoulli filter to process the generated data, the multi-target state of the entire constellation may be estimated. The effectiveness of this system strategy was demonstrated using a simulated large constellation of 4,425 satellites and a network of six ground-based radar sensors [34].

Changes in satellite velocity predisposed toward collision are not predictable before the actual event. Moreover, several collisions can occur at the same time. Both scenarios suggest continuous LEO monitoring on order to determine and implement collision avoidance strategies. Scenarios may be pre-scripted based on simulations of multiple platforms carrying EO/ IR sensors for collision detection or simulations encompassing the full complexity of LEO trajectory changes wherein collisions with operating satellites may arise. The advent of large satellite constellations has focused on the need for 'traffic regulation' in the LEO environment [35]. The likelihood of a collision-induced breakup of a satellite is significant, yet the probability of a collisional cascade within the constellation remains small [36]. The Microwaves and Radar Institute of German Aerospace Center (DLR) is currently developing an experimental radar system called IoSiS (Imaging of Satellites in Space), for the purpose of gathering high-resolution radar images of objects in a low earth orbit. IoSiS is based on an existing steering antenna structure and our multipurpose high-performance radar system GigaRad for experimental investigations. GigaRad is a multi-channel system operating at X band and using a bandwidth of up to 4.4 GHz in the IoSiS configuration, providing fully separated transmit (TX) and receive (RX) channels, and separated antennas. High-resolution radar images are obtained by using Inverse Synthetic Aperture Radar (ISAR) techniques. The guided tracking of known objects during orbit pass allows here wide azimuth observation angles. Thus high azimuth resolution comparable to the range resolution can be achieved.



IoSiS satellite imaging geometry with a steerable antenna following the satellite on its orbit path in order to acquire range profiles over a large synthetic aperture path for ISAR processing.

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