Article

A new Orbiting Deployable System for Small Satellite Observations for Ecology and Earth Observation

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Abstract: In this paper, we present several study cases focused on marine, oceanographic, and atmospheric environments, which would greatly benefit from the use of a deployable system for small satellite observations. As opposed to the large standard ones, small satellites have become an effective and affordable alternative access to space, owing to their lower costs, innovative design and technology, and higher revisiting times, when launched in a constellation configuration. One of the biggest challenges is created by the small satellite instrumentation working in the visible (VIS), infrared (IR), and microwave (MW) spectral ranges, for which the resolution of the acquired data depends on the physical dimension of the telescope and the antenna collecting the signal. In this respect, a deployable payload, fitting the limited size and mass imposed by the small satellite architecture, once unfolded in space, can reach performances similar to those of larger satellites. In this study, we show how ecology and Earth observations can benefit from data acquired by small satellites, and how they can be further improved thanks to deployable payloads. We focus on DORA—Deployable Optics for Remote sensing Applications—in the VIS to TIR spectral range, and on a planned application in the MW spectral range, and we carry out a radiometric analysis to verify its performances for Earth observation studies.

Keywords: Earth Observation; remote sensing; deployable payload; optical instruments; radars; ocean; atmosphere; ecology

Table S1. The Table Lists all the medium to large space missions cited in the text, reporting all their relevant characteristics for the study cases in the spectral range from VIS to MW.

Satellite Acronym	Satellite Name	Satellite Class	Satellite Description & Main Goals	Satellite Weight [kg]	Satellite Size	Orbit Altitude [km]	Payload	Telescope or Antenna Aperture Diameter [mm]	f/Number Focal length	FoV / Beamwidth	Spatial Ground Resolution [m]	SNR	Swath width	Spectral Range [μm]* / Frequency	Spectral Resolution	Polarimetric capabilities	Revisiting Time	Constellation	Year*	Company (Country)	References
Aqua		Large	• multi-disciplinary study of the Earth's water cycle • study of the interrelated processes (atmosphere, oceans, and land surface) and their relationship to Earth system changes	2,934	*stowed configuraiton:* 2.68 m × 2.47 m × 6.49 m *deployed configuraiton:* 4.81 m × 16.70 m × 8.04 m	705 sun-synch	6 instruments, including *MODIS,* *AMSR-E*	*MODIS:* 17.78 cm *AMSR-E:* 1.95 m × 1.7 m × 2.4 m	–	*MODIS:* ±49.5° *AMSR-E:* 0.18°–2.2°	*MODIS:* 250 m (2 bands), 500 m (5 bands), 1000 m (29 bands) @ nadir	*MODIS:* 900 to 1300 for 1 km ocean color bands at 70° solar zenith angle *AMSR-E:* NEΔT>1.1 K	*MODIS:* 2330 km (cross track) by 10 km (along track) @ nadir *AMSR-E:* >1450 km	*MODIS:* 36 channels ranging from 0.4 μm to 14 μm *AMSR-E:* 12 channels at 6 discrete frequencies from 6.9 GHz to 89 GHz (6.925, 10.65, 18.7, 23.8, 36.5, and 89.0 GHz)	*MODIS:* ≥0.01 μm *AMSR-E:* bandwidth between 350 and 3000 MHz	yes: AMSR-E: H, V	16 days	A-train	2002	NASA (USA)	[43, 56, 307, 308]
Aura		Large	• global surveys of several atmospheric constituents, classified as anthropogenic sources (CFC types), radicals (e.g., ClO, NO, OH), reservoirs (e.g., HNO, HCl), and tracers (e.g., N_2O, CO_2, H_2O) • mapping of temperature, geopotential heights, and aerosol fields • study of the chemistry and dynamics of ≤80 km Earth's atmosphere • understanding the changing chemistry of Earth's atmosphere (ozone, air quality) due to the complex interactions of atmospheric constituents from both natural sources (biological activity and volcanoes), and man-made sources (biomass burning)	2,967	*stowed configuration:* 2.68 m × 2.34 m × 6.85 m *deployed configuration:* 4.71 m × 17.03 m × 6.85 m	705 SunSynch	UV to MW instrument package: *HIRDLS* (High-Resolution Dynamics Limb Sounder) *MLS* (Microwave Limb Sounder) *OMI* (Ozone Monitoring Instrument) / 3 acquisition modes, *TES* (Tropospheric Emission Spectrometer) / LIMB or NADIR acquisition modes	–	–	*HRIDLS:* 22.1º to 27.3º below horizontal *MLS:* Boresight 60–70º relative to nadir *OMI:* 114°	*MLS:* @ 640 GHz: 1.5 km vertical × 3 km cross-track × 300 km along-track at the limb tangent point *TES:* 0.5 km × 0.5 km @ nadir 2.3 km × 2.3 km @ limb	≥100 to 5800 depending on the data product	*HIRDLS:* 2000–3000 km OMI: 2600 km *TES:* 5.3 km × 8.5 km @ nadir 37 km × 23 km @ limb	*HIRDLS:* 21 channels ranging from 6.12–17.76 μm *MLS:* 5 bands at millimeter and submillimeter wavelengths *OMI:* UV-1: 270–314 nm UV-2: 306–380 nm VIS: 350–500 nm *TES:* 3.2–15.4 μm (650-3050 cm^{-1})	*OMI:* UV1: 0.42 nm FWHM UV2: 0.45 nm FWHM VIS: 0.63 nm FWHM *TES:* 0.03 cm^{-1}	no	16 days	A-train (Aqua in the lead and Aura at the tail, the nominal separation between Aqua and Aura is about 15 minutes)	2004 (>6 years)	NASA (USA)	[43, 56, 308, 309]
CSK	COSMO-SkyMed 1 Generation Constellation of Small Satellites for Mediterranean basin Observation	Medium/ Large	• frequent (<1 day) and all-weather global Earth's observation • the relevant data exploitation for both the military and the civil (institutional, commercial) needs, as well to plan recovery activities in case of environmental disasters	1,700	5.7 m × 1.4 m	620 sun-synch	*SAR-2000* (Synthetic Aperture Radar) / 5 acquisition modes: *SL*: SpotLight (Frame), *SM*: StripMap (HIMAGE), *WR*: ScanSAR WideRegion, *HR*: ScanSAR HugeRegion, *PP*: Ping Pong	5.7 m × 1.4 m	–	20–60°	SL: ≤1 m SM: 3 m (single) or 15 m (dual) WR: 30 m (single) HR: 100 m (dual) PP: 15 m	–	SL: 10×10 km SM: 40×40 km (single) or 30×30 km (dual) WR: 100×100 km (single) HR: 200×200 km (dual) PP: 30 × 30 km	X-band 9.6 GHz	maximum radar bandwidth of 400 MHz	yes: S, D	constellation: 9 hours (≤12 hours for the full constellation)	Cosmo-SkyMed is born as a constellation of 4 satellites	2007 (>5 years)	ASI, MoD, e-GEOS (Italy)	[43, 56, 57, 63, 310]
CSG	COSMO-SkyMed 2nd Generation	Medium/ Large	• continuity service for EO to the 1st generation (CSK) in several pplicative fields: risk management, cartography and planning, agriculture, forest, hydrology, geology, marine domain, archaeology etc. • 2 enhanced SAR Satellites (placed on the same orbit of the 1st Generation), and an improved Ground Segment • both military and civil user classes	2,400	5.7 m × 1.4 m	620 sun-synch	*CSG-SAR* (COSMO-SkyMed Second Generation Synthetic Aperture Radar) / 5 acquisition + 1 experimental modes: *SL*: SpotLight, *SM*: StripMap, *PP*: Ping Pong *QP*: QuadPol, *SS*: ScanSAR, *DI2S*: Discrete Stepped Strip	5.7 m × 1.4 m (~7.5 m^2)	–	*Standard:* 20–60° *DI2S (Non-Standard):* 20–45°	SL-2A: 0.35 m × 0.48/0.55 m SL-2B: 0.63 m × 0.63 m SM: 3 × 3 m PP: 12 × 5 m QP: 3× 3 m SS-1: 20 × 4 m SS-2: 40 × 6 m DI2S: 0.6 × 0.6 m	NESZ: -22 dB	SL-2A: 3 × 8 km SL-2B: 10 × 10 km SM: 40 × 40 km PP: 30 × 30 km QP: 40 × 15 km SS-1: 100 × 100 km SS-2: 200 × 200 km; 200 × 190 km DI2S: 10 × 4 km (2 images)	X-band 9.6 GHz	Programmable	yes: S, D, Q (HH, VV, HH+VV, HH+HV, VV+VH, HH/HV+VV/VH)	9.6 hours (≤85 hours for 2 satellite constellation currently in orbit)	CSG	2019 (7 nominal + 2 extended years)	ASI, MoD (Italy)	[43, 56, 63, 311]

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GeoEye-1	formerly OrbView-5	Large	• satellite imagery is used for a variety of purposes (e.g., defence, disaster response, air and marine transportation, oil and gas exploration, mining production and exploration, mapping of remote regions, location-based services, insurance and risk management, agricultural crop management)	1,955	*stowed configuration:* 4.35 m × 2.7 m	681 (770 after 2013) sun-synch	*GIS* (GeoEye Imaging System)	1.1 m	f/12 13.3 m	>1.28°	PAN: 0.41 @ nadir MS: 1.64 @ nadir	–	15.2 km	PAN: 450–900 nm Blue: 450–510 nm Green: 520–580 nm Red: 655–690 nm NIR: 780–920 nm	–	no	3 days	WorldView Legion Constellation	2008 (>7 years)	GeoEye Inc. (USA)	[43, 56]
GPM	Global Precipitation Measurements	Large	• unify and advance precipitation measurements • microwave sensors for delivering next-generation global precipitation data products	3,850	13 m × 6.5 m × 5 m	407 drift	*DPR* (Dual-frequency Precipitation Radar) / 7 operation modes *GMI* (GPM Microwave Imager)	*DPR–KaPR:* 1.44 m × 1.07 m × 0.7 m *DPR–KuPR:* 2.4 m × 2.4 m × 0.6 m *GMI:* 1.2 m diameter	–	~17.5°	*DPR–KaPR:* 5 km *DPR–KuPR:* 5 km	*DPR–KaPR:* 17 dBZ *DPR–KuPR:* 13 dBZ	*DPR–KaPR:* 120 km *DPR–KuPR:* 245 km *GMI:* 850 km	*DPR–KaPR:* 33.5 GHz *DPR–KuPR:* 13.6 GHz *GMI:* 13 channels in the 10-183 GHz range + 4 high frequency, millimeter-wave channels near 166 GHz and 183 GHz	*GMI*: 100–600 MHz bandwidth	*DPR*: no *GMI*: yes (H or V)	≤2.5 days	GPM constellation (14 satellites including TRMM)	2014 (3–5 years)	NASA / JAXA (USA, Japan)	[43, 56]
IKONOS-2		Medium	• Earth's observation via space-based telescope at very high resolution	817	1.83 m × 1.57 m (hexagonal shape)	681–709 sun-synch	*OSA* (Optical Sensor Assembly)	0.70 m	f/14.3 10 m	0.75º along-track 1.19º cross-track	PAN: 1 m (0.82 m @ nadir) MS: 4 m (3.2 m @ nadir)	>45	11–13 km (11.3 km @ nadir)	PAN: 526–929 nm Blue: 445–516 nm Green: 506–595 nm Red: 632–698 nm NIR: 757–853 nm	PAN: 400 nm MS: <100 nm	no	3 days @ 40° latitude	no	1999–2015	GeoEy (USA)	[43, 56]
Copernicus Sentinel 6 / JASON-CS (A and B)	Copernicus Sentinel-6A Michael Freilich + Sentinel-6B / JASON-Continuity of Service	Large	• built on the heritage from the Jason series of satellites, Copernicus Sentinel-3 and ESA's CryoSat mission • made up of two identical satellites flying in sequence • designed to provide operational measurements of sea surface height and wind speed to support operational oceanography and climate monitoring.	1,191	*stowed configuration:* 5.13 m × 2.58 m × 2.35 m *flight configuration:* 5.13 m × 4.33 m × 2.35 m	1336	*Poseidon-4* (Radar Altimeter) *AMR-C* (Advanced Microwave Radiometer for Climate) *DORIS* (Doppler Orbitography and Radiopositioning Integrated by Satellite), *LRA* (Laser Retroreflector Array), *GNSS-RO* (Global Navigation Satellite System - Radio Occultation)	*Poseidon-4:* 1.2 m	–	–	*Poseidon-4:* 300 m	*AMR-C:* NEΔT ~ 0.1 K	–	*Poseidon-4:* C-band and Ku-band *AMR-C:* 18.7 GHz, 23.8 GHz, and 34.0 GHz	*Poseidon-4:* 320 MHz bandwidth	*AMR-C*: yes (H or V)	9.92 days	JASON-3 tandem	S-6A: 2020 (7 years) S-6B: to be launched in 2025	EU / ESA / EUMETSAT / NASA / NOAA (Europe / USA)	[43, 56]
JPSS–1 (NOAA-20) to 4), as heritage of NPOESS		Large	• technological and scientific advances in environmental monitoring, to improve environmental, weather, climate, and oceanographic science • increasing timeliness and accuracy of severe weather event forecasts • advanced imaging capability to analyze fires, volcanoes, Gulf oil tracking and other adverse incidents	2,540	1.3 m × 1.3 m × 4.2 m	polar orbit, non-geo-synch	*ATMS* (Advanced Technology Microwave Sounder) *CrIS* (Cross-track Infrared Sounder) *CERES* (Clouds and the Earth's Radiant Energy System) *OMPS* (Ozone Mapping and Profiler Suite) *VIIRS* (Visible/Infrared Imager Radiometer Suite)	*VIIRS*: 18.4 cm	*VIIRS*: f/5.97	*OMPS*: 16.6º × 0.26º *VIIRS*: ±55.84°	*OMPS*: 50 km @ nadir	*OMPS*: 35 @ 252 nm 400 @ 310 nm	*OMPS*: 250 km	*OMPS*: 250–310 nm *VIIRS*: 22 spectral bands (4 focal planes: VNIR, SWIR, MWIR, TIR)	*OMPS*: 1 nm FWHM 2.4 samples/FWHM	*VIIRS*: dual	0.5 day in constellation mode	yes: JPSS–1 to 4 is a series, plus NPOESS	NOAA-20: 2017 (15 years)	NOAA	[43, 56, 312

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MetOp	Meteorological Operational Satellite Program of Europe	Large	• European undertaking providing weather data services to monitor the climate and improve weather forecasts • providing enhanced monitoring capabilities (complementary to Envisat) to fulfil the requirements to study the Earth's climate system as expressed in a number of international cooperative programs such as: GCOS, IGBP, and WCRP • ensuring continuity and availability for operational purposes of polar meteorological observations from the "morning" orbit to the global user community	4,085	*launch configuration:* 6.2 m × 3.4 m × 3.40 m *on-orbit configuration:* 17.6 m × 6.7 m × 5.4 m	817 near-circular sun-synch	13 instruments, including: *IASI* (Infrared Atmospheric Sounder Interferometer) *CIM-01* (Caméra Infrarouge Multimission / IASI Infrared Imager) *GOME-2* (Global Ozone Monitoring Experiment-2)	–	*CIM-01:* f/2.4	*IASI:* ±48.3º *CIM-01:* 60 mrad × 60 mrad	*IASI:* 12 km circular *CIM-01:* 64 × 64 pixels *GOME-2:* 40 km × 40 km (with 960 km swath and integration time of 0.1875 s) 40 km × 5 km (for polarization monitoring)	*IASI:* NEΔT <0.228 K at 280 K for all bands *CIM-01:* NEΔT < 0.5 K @ 280 K	*IASI:* 50 km × 50 km @ nadir *GOME-2:* ± 960 km, ±480 km, ±360 km, ±240 km, ±120 km	*IASI:* B1: 645–1210 cm^{-1} with 0.35 cm^{-1} (unapodized resolution) B2: 1210–2000 cm^{-1} with 0.5 cm^{-1} (apodized resolution) B3: 2100–2760 cm^{-1} with 1.5 cm^{-1} (apodized resolution) *CIM-01:* 10.3–12.5 μm *GOME-2:* 4 bands in the 240–790 nm range B1: 240–315 nm B2: 311–403 nm B3: 401–600 nm B4: 598–790 nm	*IASI:* 0.35–0.5 cm^{-1} *GOME-2:* B1: 0.22–0.28 nm FWHM B2: 0.24–0.30 nm FWHM B3: 0.40–0.50 nm FWHM B4: 0.40–0.50 nm FWHM	*IASI* and *GOME-2*: no	29 days	MetOp (3 satellites): each satellite should be launched every 5–6 years	MetOp-A: 2006 (>5 years) MetOp-B: 2012 (>5 years) MetOp–C: 2018 (>5years)	ESA / EPS (Europe)	[43, 56, 313]
Quick-Bird-2		Large	• providing high.resolution and commercial-focused imagery • obtaining images for change detection analysis in land usage, agriculture and forests.	1,100	3.04 m (height) × 1.6 m (diameter)	450 sun-synch	*BGIS2000* Instrument Parameters / 4 acquisition modes: *SN*: SnapShot mode, *SM*: StripMap *MM*: Mosaic Mode *ST*: Stereo Mode	60 cm	f/14.7 8.8 m	2.12°	PAN: 0.61–0.72 m MS: 2.4–2.6 m	–	@ 450 km altitude: SN: 16.5 km × 16.5 km SM: 16.5 km × 225 km MM: 32 km × 32 km ST: 16.5 km × 16.5 km	PAN + 4 MS: PAN: 450–900 nm Blue: 450–520 nm Green: 520–600 nm Red: 630–690 nm NIR: 760–900 nm	–	no	2.8 days at 1-metre GSD resolution 1.5 days at 1.5-metre GSD resolution These values are for targets at 20° latitude	no	2001–2015	Digital-Globe Inc. (formerly Earth-Watch), then acquired by Maxar Technologies Ltd. (USA)	[43, 56]
SeaSat		Large	• pioneering and demonstrating the techniques to study oceanography on a global scale from remote sensing data • proving the viability of imaging radar for studying our planet • ice and ocean monitoring (sea-surface winds, sea-surface temperatures, wave heights, internal waves, sea-ice features, ocean features, ocean topography, and the marine geoid), land use, geology, forestry, and mapping. • providing timely oceanographic data to scientists studying marine phenomena, and to users of the oceans as a resource (ocean shippers, fishermen, marine geologists, etc.)	2,290	21 m (length) × 1.5 m (diameter)	799 km × 775 km	Sensor module with 5 active and passive instruments: *SAR antenna* *SMRR* (Scanning Multichannel Microwave Radiometer) *ALT* (Radar Altimeters) *SASS* (Seasat-A Scatterometer System) *VIRR* (Visible and Infrared Radiometer)	*SAR:* 23 m^2 (10.74 m × 2.16 m)	–	6.2º (elevation) × 1º (azimuth)	25 m × 25 m	–	100 km	L-band: 1.275 GHz (23.5 cm)	bandwidth (linear FM) = 19.077 MHz	*SAR*: yes (HH)	17 days	no	1978–1978 (110-day lifetime due to a malfunctioning)	NASA/JPL (USA)	[43, 56]

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S-1A S-1B	Copernicus Sentinel 1A and B	Large	• representing the first new space component of the GMES (Global Monitoring for Environment and Security) satellite family, and the EU contribution to GEOSS (Global Earth Observation System of Systems) • ERS/ENVISAT SAR data continuity for Land and Ocean surveillance • independent operational capability for continuous radar mapping of the Earth: to provide enhanced revisit frequency, coverage, timeliness and reliability for operational services and applications requiring long time series, an operational interferometry capability through stringent requirements placed on attitude accuracy, attitude and orbit knowledge, and data-take timing accuracy	2,300	3.4m × 1.3 m × 1.3 m	693 tube of 50 m (RMS) wide in radius, around the nominal operational path SunSynch	*C-SAR* / 4 acquisition modes: *SM*: StripMap, *IW*: Interferometric Wide Swath Mode, *EW*: Extra Wide Swath Mode, *WV*: Wave mode	12.3 m × 0.821 m	–	–	SM: 5 × 5 m² IW: 5 × 20 m² EW: 25 × 100 m² WV: 5 × 20 m²	NESZ: σ^0=-25 d	SM: 80 km IW: 250 km EW: 400 km WV: 20 × 20 km² every 100 km	C-band: 5.405 GHz		yes: S, D (HH, HH+HV, VV+VH)	12 days	constellation of two polar-orbiting satellites (S-1A and S-1B), sharing the same orbital plane with a 180° orbital phasing difference	S-1A: 2014 S-1B: 2016 (>7.25 years)	ESA, EC (Europe)	[43, 56, 63, 314]
S-5P	Sentinel-5P (Precursor)	Medium-Large	• first atmospheric composition mission in the frame of the European Earth Observation programme Copernicus • providing routine high spatio-temporal resolution observations of atmospheric trace gases and aerosols products serving air quality, climate and stratospheric ozone applications (tracked gases: BrO, CH_4, ClO, CO, CO_2, H_2O, HCHO, N_2O, NO, NO_2, NO_3, O_2, O_3, O_4, OClO, SO_2, and aerosol)	~900	1.40 m × 0.65 m × 0.75 m	824 sun-synch	*TROPOMI* (TROPOspheric Monitoring Instrument)	100	f/9 × f/10 aperture: 34 mm (cross-track) × 68 mm (along-track)	108°	7 × 7 km² @ nadir	B1:1000 B2: 500 B3: 100	2670 km	8 bands covering: UV and VIS: 270– 500 nm NIR: 675–775 nm SWIR: 2305–2385 nm	B1: 0.55 nm B2: 0.55 nm B3: 0.25 nm	yes: D	12 days	kept within the 3000 km VIIRS swath of Suomi NPP	2017 (7 years)	ESA, NSO (Europe)	[43, 56, 314, 315]
SMOS	Soil Moisture and Ocean Salinity	Medium	• improve our understanding of Earth's water cycle, providing much-needed data for modelling of the weather and climate, and increasing the skill in numerical weather and climate prediction • main goal: demonstrate observations of SSS over oceans and SM over land to advance climatologic, meteorologic, hydrologic, and oceanographic applications	658	1 m × 1 m × 1 m	755 km sun-synch	*MIRAS* (Microwave Imaging Radiometer using Aperture Synthesis)	–	–	–	20 km	–	900 km	L-band: 1.4 GHz	1400-1427 MHz	yes: H, V polarization	1–10 days (for SSS)	–	2009 (>3 years)	ESA	[43, 56]
TOPEX / Poseidon	Topography Experiment / Poseidon	Large	• a cooperative Earth observation mission of the USA and France (NASA/JPL and CNES as partners) with the overall objective to provide high-accuracy global sea level (ocean height) measurements in coordinates relative to the center of the Earth. From this information, ocean circulation patterns can be mapped. The T/P data analysis helps to understand how the oceans interact with the atmosphere, and improve our ability to predict the global climate.	2,388	5.5 m × 6.6 m × 2.8 m	1336 drift	*NRA* (NASA Radar Altimeter) *TMR* (TOPE× Microwave Radiometer) *GPSDR* (GPS Demonstration Receiver) *SSALT) / Poseidon-1* (Single-Frequency Solid-State Altimeter) *LRA* (Laser Reflector Array) *DORIS* (Doppler Orbitography and Radiopositioning Integrated by Satellite)	*NRA:* 1.5 m	–	*NRA:* 1.1º (Ku) 2.7º (C)	–	*NRA:* 3.2 dB (Ku-band) 0.9 dB (C-band)	*TMR:* 35 km	*NRA:* C-band: 5.3 GHz Ku-band: 13.575 GHz *SSALT / Poseidon-1:* Ku-band: 13.65 GHz	*NRA:* C-band: 100 MHz Ku-band: 320 MHz *SSALT / Poseidon-1:* 300 MHz	no	10 days	JASON-1 tandem	1992–2005	NASA / CNES (USA, Frances)	[43, 56]

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TSX	TerraSAR-X	Large	• making multi-mode and high-resolution X-band data available for a wide spec-	1,230	*launch configuration:* 505 km × 533 km sun-synch	*X-SAR* / 5 acquisition modes:	4.78 m × 0.7 m	–	–	HS: 1 m SL: 1 m ES: 1 m	HS: -23 dB SL: -23 dB ES: -20 dB	HS: 5×10 km² SL: 10×10 km² ES: 5×10 km²	X-band: 9.65 GHz / 3.1 cm wavelength	–	yes: S, D, Q	11 days	yes (its twin satellite is TanDEM-X)	2007 (>5.5 years)	BMBF / DLR (Germany)	[43, 56, 57, 63]

			trum of scientific applications in such fields as: hydrology, geology, climatology, oceanography, environmental and disaster monitoring, and cartography (DEM generation) through interferometry and stereometry		5 m (length) × 2.4 m (diameter)		*HS*: High Resolution SpotLight, *SL*: SpotLight, *ES*: Experimental Spotlight, *SM*: StripMap, *SC*: ScanSAR				SM: 3 m SC: 16 m	SM: -22 dB SC: -21 dB	SM: ≤1500×30 km² SC: ≤1500×100 km²			(HH, VV, HV, VH)				
TRMM	Tropical Rainfall Measuring Mission	Large	• goals: global change studies • developing an interdisciplinary understanding of atmospheric circulation, ocean-atmospheric coupling, and tropical biology	3,620	*launch configuration:* 5.1 m (length) × 3.7 m (diameter) *orbit configuration:* 5.1 m (length) × 14.6 m (paddle direction)	350.0–402.5 km (pre-boost – post-boost in 2001) drift	*PR* (Precipitation Radar) *VIRS* (Visible Infrared Scanner) *TMI* (TRMM Microwave Imager) *CERES* (Clouds and the Earth's Radiant Energy System) *LIS* (Lightning Imaging Sensor)	*PR:* 2.0 × 2.0 m *TMI:* 61 cm aperture size	–	*VIRS:* ±45° *LIS:* 80°×80°	*PR:* 4.3–5.0 km *TMI:* 4.4–5.1 km @85.5 GHz *VIRS:* 2.2–2.4 km *CERES:* 10 km @ nadir *LIS:* 4 km @ nadir	–	*PR:* 215–247 km *TMI:* 760–878 km *VIRS:* 720–833 km *CERES:* scan angle: ±78° (global) *LIS:* 600 × 600 km	*PR:* 13.8 GHz *TMI:* 10.7, 19.4, 21.3, 37, and 85.5 GHz *VIRS:* 0.63, 1.6, 3.75, 10.7, and 12 μm *CERES:* 0.3–5 μm 8.0–12.0 μm 0.3–100 μm *LIS:* 0.7774 μm	*VIRS*: ±0.05 μm *TMI*: 100–300 MHz bandwidth	*TMI*: yes: S, D (V, H)	12 hours	yes: GPM constellation (10 satellites including GPM)	1997–2015	NASA / JAXA (USA, Japan)	[43, 56]
WV1	WorldView-1	Large	• successor of QuickBird-2, to provide high-resolution imagery from the next-generation commercial imaging satellites	2,500	3.6 m (height) × 2.5 m (diameter)	496 sun-synch	*WV60* (WorldView-60 camera)	60 cm	f/14.7 8.8 m	2.12°	PAN: 50 cm @ nadir and 55 cm @ 20º off-nadir	–	17.6 km @ nadir	PAN-1: 400–900 nm MS1-NIR1: 770–895 nm MS2-Red: 630–690 nm MS3-Green: 510–580 nm MS4-Blue: 450–510 nm MS5-Red Edge: 705–745 nm MS6-Yellow: 585–625 nm MS7-Coastal: 400–450 nm MS8-NIR2: 860–1040 nm	–	no	≤1.7 days @ 1 m GSD ≤5.9 days @ 20º off-nadir (0.51 m GSD)	WorldView Legion Constellation	2007 (7.25 years)	DigitalGlobe Inc., then acquired by Maxar Technologies Ltd. (USA)	[43, 56]
WV2	WorldView-2	Large	• overall objective of meeting the growing commercial demand for high-resolution satellite imagery	2,800	*stowed configuration:* 4.3 m (height) × 2.5 m (diameter) *deployed solar array configuration:* 7.1 m (width)	*770* *sun-synch*	*WV110* (WorldView-110 camera)	110 cm	f/12 13.3 m	>1.28°	PAN: 0.46 m @ nadir and 0.52 m @ 20º off-nadir MS: 1.8 m @ nadir and 2.4 m @ 20º off-nadir	–	16.4 km	PAN-2: 450–800 nm MS1-NIR1: 770–895 nm MS2-Red: 630–690 nm MS3-Green: 510–580 nm MS4-Blue: 450–510 nm MS5-Red Edge: 705–745 nm MS6-Yellow: 585–625 nm MS7-Coastal: 400–450 nm MS8-NIR2: 860–1040 nm	–	no	1.1 days	WorldView Legion Constellation	2009 (7.25 years)	DigitalGlobe Inc., then acquired by Maxar Technologies Ltd. (USA)	[43, 56, 316]
WV3	WorldView-3	Large	• providing multispectral images with an unprecedented combination of high spatial and spectral resolutions	2,800	*stowed configuration:* 5.7 m (height) × 2.5 m (diameter) *deployed solar array configuration:* 7.1 m (width)	617 sun-synch	*WV-3 Imager* (WV110, the same as in WW-2 satellite) *CAVIS* (Clouds, Aerosols, Vapors, Ice, and Snow)	110 cm	f/12 16.0 m	>1.28°	*WV-3:* PAN: 0.31 m @ nadir and 0.34 m @ 20º off-nadir MS: 1.24 @ nadir and 1.38 m @ 20º off-nadir SWIR: 3.7 m and 4.1 m @ 20º off-nadir *CAVIS:* 30 m	–	13.1 km 10 km SWIR @ nadir	*WV-3:* PAN: 450–800 nm Coastal Blue: 400–450 nm Blue: 450–510 nm Green: 510–580 nm Yellow: 585–625 nm Red: 630–690 nm Red Edge: 705–745 nm NEAR-IR1: 770–895 nm Near-IR2: 860–1040 nm 8 bands in the SWIR in the range: 1195–2365 nm *CAVIS*: 12 bands in the 405–2245 nm	–	no	< 1.0 days @ 1 m GSD ≤4.5 days for an off-nadir angle of 20°	WorldView Legion Constellation	2014 (>7.25 years)	DigitalGlobe Inc., then acquired by Maxar Technologies Ltd. (USA)	[43, 56, 63, 317]

(continued)

WV4	WorldView-4 / GeoEye-2	Large	• next very high resolution imaging satellite providing high resolution and color imagery to commercial, government and international customers • delivering critical geospatial situational awareness and global security information to intelligence analysts, war fighters, decision makers, and commercial users	2,067	*stowed configuration:* 5.3 m (height) × 2.5 m (diameter) *deployed solar array configuration:* 7.9 m (width)	617 sun-synch	SpaceView ™ Imaging System	110 cm	f/12 16.0 m	>1.28°	PAN: 0.31 m @ nadir MS: 1.24 m @ nadir	–	13.1 km @ nadir	PAN: 450–800 nm Blue: 450–510 nm Green: 510–580 nm Red: 655–690 nm NIR: 780–920 nm	–	no	≤3 days	WorldView Legion Constellation	2016–2019	Digital-Globe Inc., then acquired by Maxar Technologies Ltd. (USA)	[43, 56]

* The years of the missions are given as interval when it is a past mission. When only one date is given, this refers to the launch date. The eventual numbers in brackets refers to the expected lifetime as given in the references.