New millennium sensors: Earth Observation (EO)

- Landsat (NASA) 8/9 2013->
- Sentinel (ESA) 2015 ->
- LiDAR / drones
- High resolution satellites 2000->



Landsat 8 (OLI) 2013/2021-> 12 / 14-bit data + Pan band (+ coastal and cirrus bands)



Sentinel Program 2015-> (2014: Radar) European Space Agency (ESA)

Heimay, Iceland Nov 1, 2018 12-bit data



ESA Copernicus program: Sentinel – all free data

1a / b: April 2014 / 2016 RADAR 10m res.

2a / b: June 2015 / March 2017 Optical

290 km swath

Sentinel-2 Bands	Central Wavelength (µm)	Resolution (m)	Bandwidth (nm)
Band 1 – Coastal aerosol	0.443	60	20
Band 2 – Blue	0.490	10	65
Band 3 – Green	0.560	10	35
Band 4 – Red	0.665	10	30
Band 5 – Vegetation Red Edge	0.705	20	15
Band 6 – Vegetation Red Edge	0.740	20	15
Band 7 – Vegetation Red Edge	0.783	20	20
Band 8 – NIR	0.842	10	115
Band 8A - Narrow NIR	0.865	20	20
Band 9 – Water vapour	0.945	60	20
Band 10 - SWIR - Cirrus	1.375	60	20
Band 11 – SWIR	1.610	20	90
Band 12 - SWIR	2.190	20	180

RapidEye 2008 ->

(Germany)

5 identical satellites: 5m pixels

Tachys (rapid)

Mati (eye)

Choma (earth)

Choros (space)

Trochia (orbit)

First commercial satellites to image the Red-edge band (measures variances in vegetation)

Price: \$1.40 / sq km (\$2.50 rectified)



Green 520 – 590 nm Red 630 – 685 nm Red Edge 690 – 730 nm Near-Infrared 760 – 850 nm	– 590 nm – 685 nm – 730 nm	Green 5 Red 6
Red 630 – 685 nm Red Edge 690 – 730 nm Near-Infrared 760 – 850 nm	– 685 nm – 730 nm	Red (
Red Edge 690 – 730 nm Near-Infrared 760 – 850 nm	– 730 nm	Ded Edge
Near-Infrared 760 – 850 nm	7.50 mm	Kea Eage
	– 850 nm	Near-Infrared 7
400 nm 500 nm 600 nm 700 nm 800 nm 	600 nm 700 nm 800 nm	400 nm 500 nm

Table 1: RapidEye's Spectral Bands



relation to the RapidEye spectral bands



Figure 2: Example for a Relative Chlorophyll Map

Sept 5 2011: Iunctus Geomatics Corp. of Lethbridge, Alberta, Canada's exclusive distributor of French Spot optical satellite data, purchased Germany-based RapidEye for ~13 million euros (\$19m)

http://www.rapideye.de/gallery/index.htm



GEOBASE SPOT 4/5: Canada/France agreed to cover Canada 2005-2010 at 10/20m resolution; 100% cloud free is not guaranteed



https://open.canada.ca/data/en/dataset/d799c202-603d-4e5c-b1eb-d058803f80f9

SPOT 6 and 7: 2012 / 2014 ->

products can be available in the following modes:
Panchromatic image at 1.5m resolution
Pansharpened colour image at 1.5m resolution

Multispectral image in 4 bands at 6m resolution
Panchromatic: 0.450-0.745µm
Blue: 0.450-0.520µm
Green: 0.530-0.590µm
Red: 0.625-0.695µm
Near-infrared: 0.760-0.890µm

Highest resolution imagery in the old millennium

1959-72 Corona spy photos: 1.8 – 7.5 m 1986: SPOT 1 PAN 10m Multi 20m



Indian Remote Sensing IRS-1C 1995: Panchromatic (PAN) camera of 6 m res. (right)

Linear Imaging Self Scanner (LISS-3) 23.6m (left) Wide Field Sensor (WiFS)189m centre





Toronto



High resolution corporate satellites

Ikonos: launched 1999; image data sold Jan 1, 2000 -> 2015 Resolution: Pan 1m Multispectral (BGRN) 4m;



Owner	GeoEye → now part of DigitalGlobe
Resolutions	4m multispectral 1 panchromatic
Bands	Blue (445-516nm) Green (506-595nm) Red (632-698nm) NIR (770-888nm) PAN (450-900nm)
Operational Dates	Jan 2000 to 2015
Data Cost	\$10 to \$45 per km ² (from landinfo.com)
equatorial time	10:30 am
Revisit time	11 days but can be as little as 3 days with 45 degree viewing angle
Viewing angle	Can be rotated up to 45 degrees off nadir
Individual Image coverage	11km x 11km = 121km ²
Altitude	681 km sun synchronous

Can be used to create DEMs by viewing from 2 different angles

Quickbird 2001-15 Pan 60cm MS 2.4m

100





GeoEye (launched by Google) 2008 41 / 46cm PAN 1.65m MS Obama Inauguration (Jan 2009)





 \rightarrow GeoEye 2 - PAN 31cm 2016 (Trump Inauguration ? \odot)

Worldview 3 2014

Rainbow Range Chilcotin, BC 31cm PAN: 31cm VNIR: 1.24m SWIR: 3.72m ** 8 bands VNIR, 8 SWIR



EarthExplorer datasets



Ikonos/Orbview (high res.) image data on EarthExplorer



Fusion / Merge	/Pansharpening
Satellite sensor	PAN MS (metres)
Landsat 7 ETM+	15 / 30
Landsat 8 / 9 OLI	15 / 30
SPOT 1-4	10/ 20
SPOT 5	5 / 10
SPOT 6-7	1.5 / 6
High-resolution	
Ikonos	1 / 4
Quickbird	0.6 / 2.4
Worldview	0.31 / 1.24

Selected New millennium High resolution sensors Launched by corporations, not always countries

Date	Sensor	Bands*	Pixel (m)	Swath (km)	Orbit (km)	Data
1999	Ikonos	RGBN	1/4	11.3	681	11 bit
2001	Quickbird	RGBN	0.6/2.4	16.5	450	11
2003	Orbview 3	RGBN	1/4	8	470	11
2007	Worldview 1	RGBN	0.5 / 2	17.6	496	11
2008	GeoEye 1	RGBN	.41 / 1.65	15	681	11
2009	Worldview 2	VNIR+	.46 / 1.85	16.4	770	11
2014	Worldview 3	16+12	.31 / 1.24	13.1	617	11
2016	Worldview 4 :	= GeoEye2	= same as Wor	Idview 3	617	11

* and higher resolution Panchromatic band

https://www.satimagingcorp.com/satellite-sensors/other-satellite-sensors/

More New millennium High resolution sensors

Date Sensor	Bands	Pixel (m)	data	Country
2009 Deimos 1	GRN	22	8-10 bit	Spain/UK
2011 Pleiades	RGBN	0.5/2.0	8 bit	France
2012 Kompsat	RGBN	0.7/2.8	14 bit	S.Korea
2017 Formosat	RGBN	0.5/2.0	14 bit	Taiwan

Also: Gokturk, DubaiSat, KoreaSat, KazeoSat, CartoSat, Gaofen

https://www.satimagingcorp.com/satellite-sensors/other-satellite-sensors/

DigitalGlobe Constellation



Planet Labs – constellation of nanosatellites mapping the planet



NORTHWEST TRADE

Surrey, British Columbia, Canada Mar 31, 2021

Source: Skysat

Logs float on the Fraser River, waiting to be loaded onto waiting cargo ships in this SkySat image collected on March 31, 2021. Planet's latest SkySats—<u>16-18</u> and <u>19-21</u> operate at an altitude of 400 kilometers (250 miles), providing an even higher-resolution look at global trade.

Are you a geospatial intelligence analyst?

Explore our imagery

https://www.planet.com/ Map the planet every day at 1-5m resolution

India successfully launches 104 satellites

Launch sets a record for most satellites launched at once

The Associated Press Posted Feb 15, 2017 9:18 AM ET | Last Updated: Feb 15, 2017 11:54 AM ET



This photograph released by Indian Space Research Organisation shows its polar satellite launch vehicle lifting off from a launch pad at the Satish Dhawan Space Centre in Sriharikota, India, Wednesday, Feb.15, 2017, (Indian Space Research Organization

The launcher started placing the satellites into polar Sun-synchronous orbits after a flight of 16 minutes and 48 seconds. <u>nanosatellites</u>: two from India, one each from Kazakhstan, Israel, the Netherlands, Switzerland, and the United Arab Emirates, along with 96 from the USA.

Of these 96, 88 <u>CubeSats</u> (doves) were owned by <u>Planet Labs</u>, a private <u>Earth</u> <u>imaging</u> company based in San Francisco

Holding a dove in Winnipeg Not a rocket scientist



Russian tanks invading Ukraine, Feb 24, 2022



Hyperspectral remote sensing ('Image spectroscopy')

= Very high <u>spectral</u> resolution: - also usually high spatial resolution

Multispectral systems contain~4-15 bands, 70-400 nm wide Superspectral: 16-60 (e.g. MODIS, Worldview 3/4) Hyperspectral: 100-200+ bands 0.38 - 2.5µm, 5-10nm each Bands are contiguous and high spectral resolution



Some <u>airborne</u> hyperspectral systems

Sensor	Wavelength (nm)	Band width (nm)	# bands
AVIRIS	400-2500	10	224
TRWIS III	367-2328	6	335
HYDICE	400-2400	10	210
CASI (ITRE	s) 400-900	1.8	288
OKSI AVS	400-1000	10	61
ESSI Probe	-1 400-2450	15	128

Spectral signatures: Landsat TM v hyperspectral



http://www.ccrs.nrcan.gc.ca/hyperspectral/isst_e.php



http://www.murraystate.edu/qacd/cos/marc/projects/nasa98/veg_library/lbispec.git

Quantifying structural physical habitat attributes using LIDAR and hyperspectral imagery

Environ Monit Assess (2009) 159:63-83





<- LIDAR DEM

NIR image and 10 class ISODATA classification





SOME APPLICATIONS:

wetland and coastal vegetation
mineral composition and soils
agricultural crops
forest structure

ITRES, Calgary

http://www.itres.com/



7.5 cm microCASI Imagery

Satellite borne hyperspectral systems

Hyperion: on Earth Observing 1 (EO-1), Dec 2000; 50km behind Landsat7;



CHRIS

(Compact High Resolution Imaging Spectrometer)

on PROBA (2001) (PRoject for On-Board Autonomy) - Belgian !

CHRIS provides 200 narrow bands in the VNIR range (400 - 1050 nm) at 30 m. Each nominal image forms a square of 13 km x 13 km.

Launch: http://www.esa.int/SPECIAL S/Proba/index.html



The Niau atoll, in the central South Pacific Ocean, acquired on 6 October 2005 with the Compact High Resolution Imaging Spectrometer (CHRIS).

Initial lifetime of 2 years, it's now ESA's longest running EO mission

PROBA-2 2009 includes SWAP telescope to observe the Sun

PROBA-3 2020

Low cost 'smallsat' 60 x 60 x 80cm

