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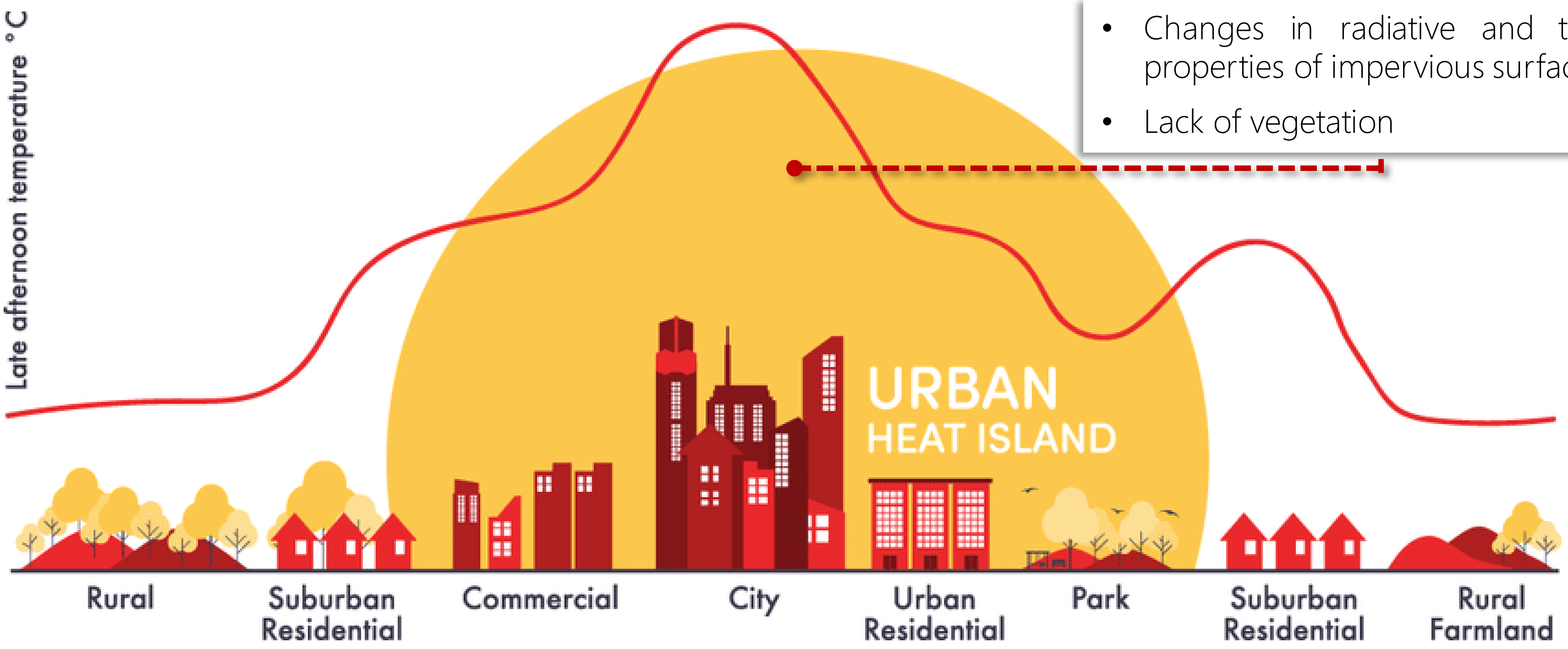
Prírodovedecká fakulta UPJŠ v Košiciach

10. Land surface temperature mapping /urban heat island mapping using ESA EO data

Overview of Urban Heat Islands

Urban Heat Island (UHI) refers to the phenomenon where urban areas experience higher temperatures compared to their surrounding rural areas due to human activities and built infrastructure such as buildings, roads, and concrete surfaces absorbing and retaining heat.

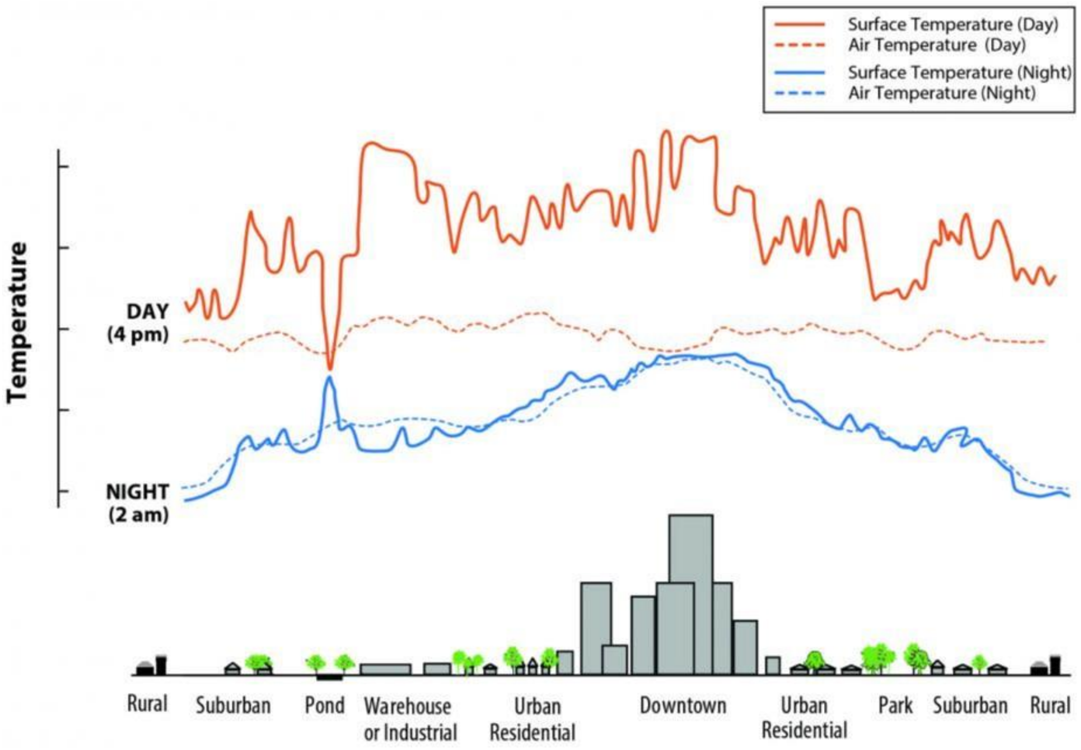
- Changes in radiative and thermal properties of impervious surfaces
- Lack of vegetation



Overview of Urban Heat Islands

- Urban heat islands can emerge during both daytime and nighttime, regardless of the city's size or the season.

- While surface temperatures exhibit greater fluctuations than air temperatures during the day, they become more conspicuous post-sunset owing to the gradual dissipation of heat from impermeable surfaces.

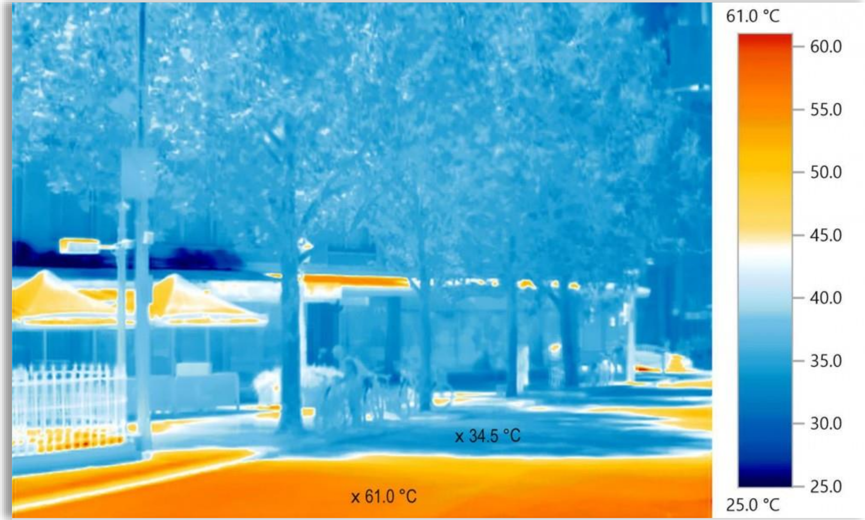


Source: EPA

Factors influencing the formation of the UHI

Main factors contributing to the formation of urban heat islands:

- anthropogenic heat emissions;
- reduction of urban vegetation;
- construction materials with low albedo;
- urban canyons trapping heat released from urban infrastructure;
- weather and geographic location



Source: City of Melbourne (2017)

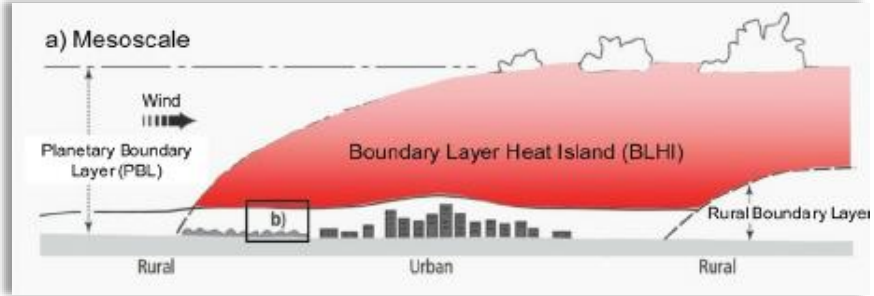
Types of urban heat islands

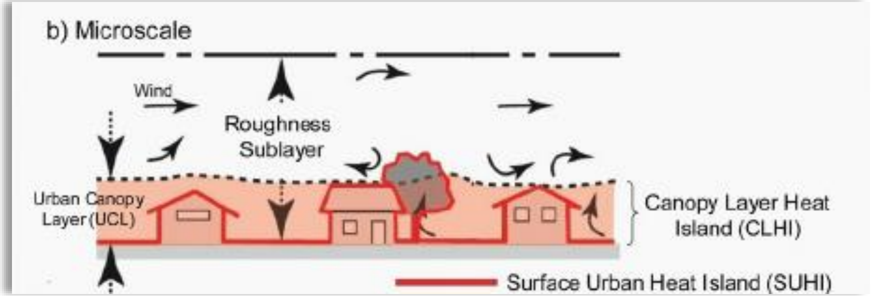
Analysis of urban heat islands in the urban environment typically occurs in one of three urban layers:

- **Surface Urban Heat Island (SUHI)**- measurement of infrared radiation reflected from surfaces.

- **Canopy Layer Heat Island (CLHI)** - the layer of the atmosphere between the Earth's surface and the tops of building roofs or urban greenery where most human activities occur.

- **Boundary Layer Heat Island (BLHI)** - the boundary layer above the urban canopy layer (up to 2 km above the Earth's surface).

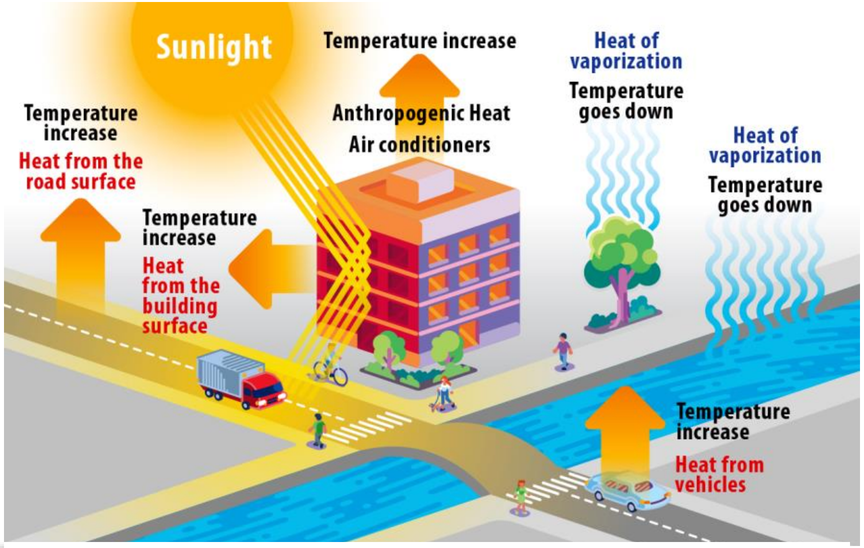




Source: Voogt (2002)

Surface UHI

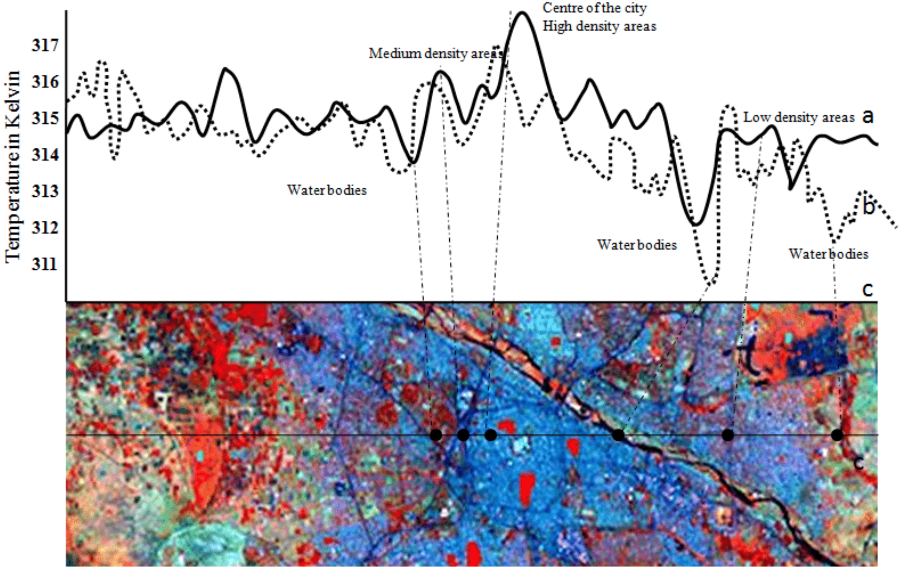
- Represents the temperature contrast in radiation between impervious and natural surfaces
- Usually most pronounced during daylight hours
- Their magnitude fluctuates with seasons, peaking typically in summer.
- Remote sensing in the thermal infrared (TIR) region of the electromagnetic spectrum is the primary method for measuring SUHIs.



https://www.pavetechinc.com/uhi-mitigation/

Atmospheric UHI

- Encompass phenomena occurring within the canopy layer or boundary layer.
- Canopy Layer Heat Island (CLHI) pertains to the atmospheric layer from the surface up to the tops of trees or buildings. CLHI is typically measured using in situ sensors installed on stationary meteorological stations or mobile traverses.
- Boundary Layer Heat Islands (BLHI) extend from the tops of trees or buildings to the point where urban landscapes cease to influence the atmosphere, roughly around 1.5 kilometers in height. BLHI is measured using tall towers, radiosondes, and aircraft.



Source: https://www.researchgate.net/publication/323181233_Study_and_analysis_of_efficient_green_cover_types_for_mitigating_the_air_temperature_and_urban_heat_island_effect/figures?lo=1

Types of urban heat islands

	Surface UHI	Atmospheric UHI
Time occurence	• Present throughout the entire day • Most intense during daytime in summer, especially during anticyclonic weather	• Insignificant/non-existent during the day • Most intense during the night, before dawn, in winter, during anticyclonic weather
Mean intensity	• Higher temperature, spatial, and temporal variability: • Day: 10 – 15 °C • Night: 5 – 10 °C	• Lower temperature, spatial, and temporal variability: • Day: -1 – 3 °C • Night: 7 – 12 °C
Identification method	• Indirect measurement: • Remote sensing of Earth • Manual thermal cameras	• Direct measurement: • Meteorological stations • Temperature data loggers (dataloggers)
Common representation	• Thermal image	• Isothermal maps, temperature tgraphs

Source: U.S. EPA (2017), Akbari (2009)

Consequences of the UHI

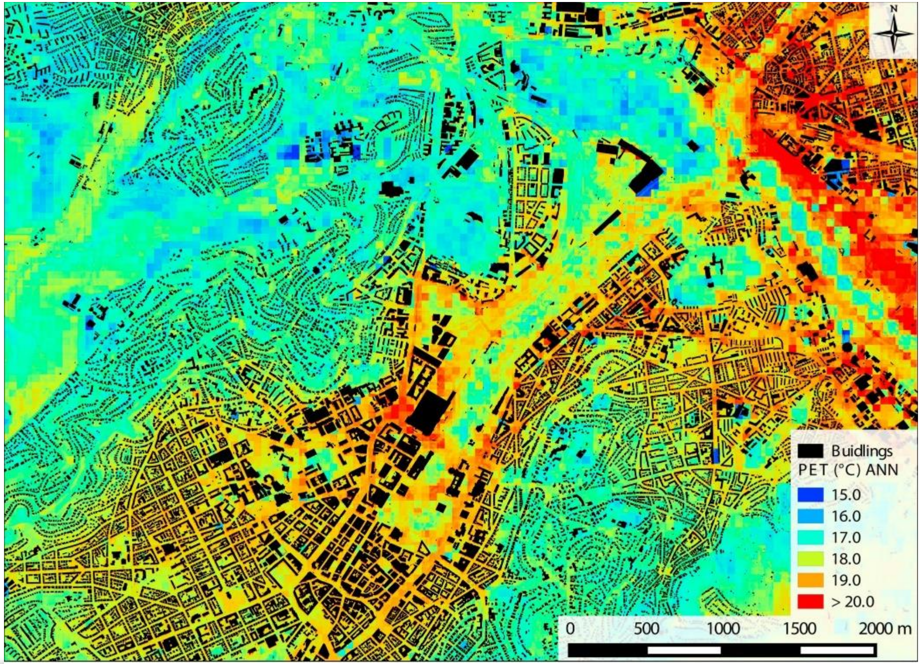
→ Climate change at both local and global scales:

- Depletion of groundwater
- Increased precipitation intensity leading to floods
- Soil erosion
- Formation of urban heat canyons
- Elevated concentration of carbon dioxide
- More frequent occurrence of fog
- Intensification of smog presence during the winter
- Increased risk of heat-related mortality and morbidity
- Disruption of ecosystems

→ Worsening of residents' thermal comfort

Source:

Methods of urban heat island detection



Meteorological data obtained through mobile transects using vehicles were used to derive a physiologically equivalent temperature map (PET) for the city of Stuttgart (Ketterer & Matzarakis, 2016).

Studies of the UHI are generally conducted using one of two approaches:

- Measurement of air temperature using networks of meteorological stations and mobile measurements along transects
- Measurement of surface temperature through aerial or satellite remote sensing.

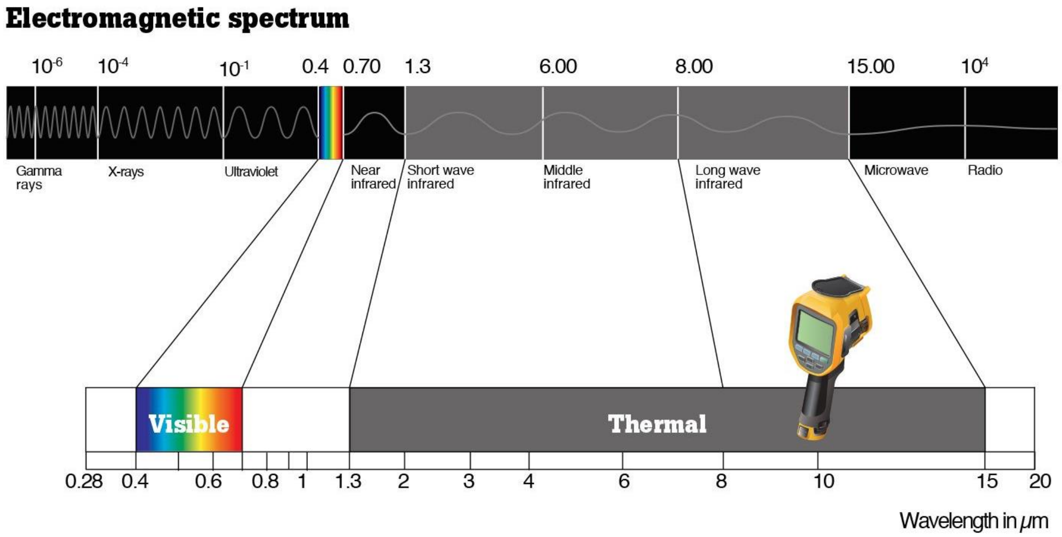
Distribution of surface temperature within the city of Sacramento in California. Image in the visible spectrum (left) and infrared spectrum (right). Source: NASA (2016).

Satellites and Sensors Used in Analyzing UHI

Remote Sensing of LST

- For Land Surface Temperature (LST) estimation, remote sensing typically utilizes wavelengths within the thermal infrared (TIR) spectrum

- Specifically, the wavelengths used for LST estimation usually fall within the range of approximately 8 to 14 μm that is particularly sensitive to thermal emissions from the Earth's surface and allows for accurate measurement of LST variations

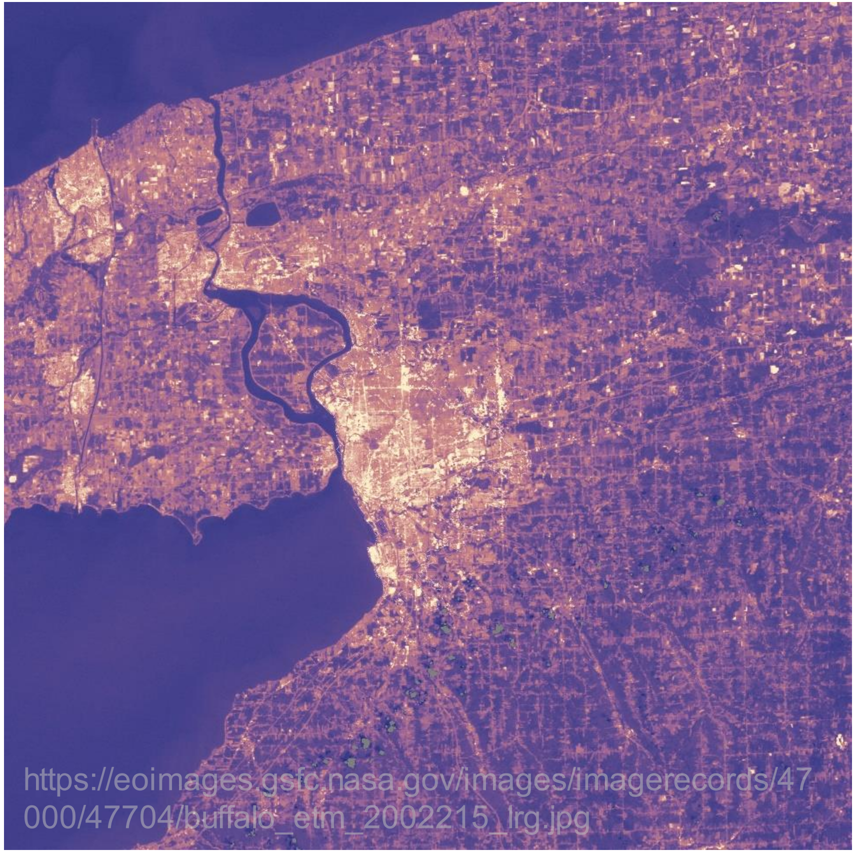


Source: https://reliabilityweb.com/articles/entry/a-practical-guide-to-emissivity-in-infrared-inspections

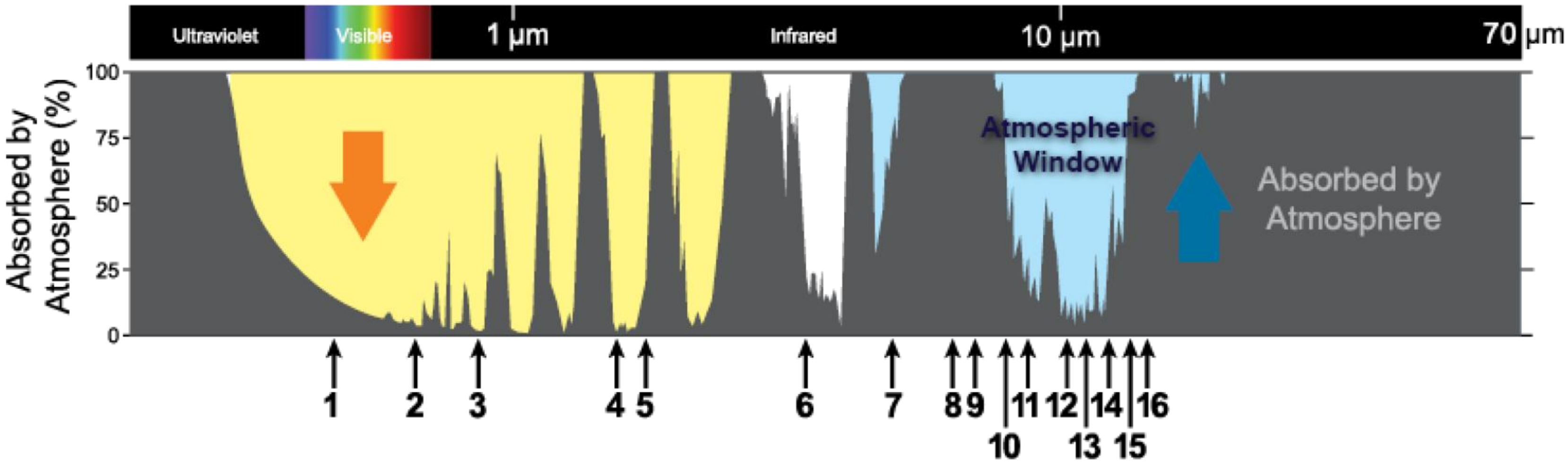
Satellites and Sensors Used in Analyzing UHI

Satellite TIR sensors measure the radiance emitted from the top of the atmosphere (TOA) by the Earth's surface and atmosphere. The TOA radiances are influenced by several factors:

- Surface emissivity: different surfaces have different emissivity values, which affect the amount of radiation emitted and detected by the satellite sensor
- Atmospheric attenuation: the presence of water vapor and aerosols in the atmosphere can absorb or scatter thermal infrared radiation, affecting the amount of radiation reaching the satellite sensor
- Sensor viewing angle: The angle at which a satellite sensor receives radiation from the Earth's surface also influences the observed radiance



Satellites and Sensors Used in Analyzing UHI



- **Atmospheric Window:** Between 10-12 micrometers, the atmosphere exhibits minimal absorption of infrared (IR) radiation emitted by the land surface. Consequently, this spectral range is utilized for Land Surface Temperature (LST) derivation.
- Multiple polar orbiting and geostationary satellites are equipped with sensors that observe in one or more bands within this infrared (IR) spectral range.

Satellites and Sensors Used in Analyzing UHI

Satellite	Sensor	Temporal Coverage
Landsat 4 Landsat 5 Landsat 7 Landsat 8	Thematic Mapper (TM) Enhanced Thematic Mapper (ETM+) Operational Land Imager (OLI) Thermal Infrared Sensor (TIRS)	07/1982 -12/1993 03/1984 - 01/2013 04/1999 - Present 02/2013 – Present
Terra Aqua	Advanced Spaceborne Thermal Emission and Reflection Radiometer(ASTER) & MODIS MODerate-resolution Imaging Spectroradiometer (MODIS)	12/1999 - Present 04/2002 - Present
ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS)	Prototype HyspIRI Thermal Infrared Radiometer (PHyTIR)	06/2018 - Present

Satellites and Sensors Used in Analyzing UHI

Satellite	Sensor	Temporal Coverage
Suomi National Polar Partnership (NSPP) Joint Polar Satellite System-1 (NOAA 20)	Visible Infrared Imaging Radiometer Suite (VIIRS)	10/2011 - Present 11/2018 – Present
NOAA Operational Series Current: NOAA 15,18,19 ESA- Metop-A & B	Advance Very High-Resolution Radiometer (AVHRR)	1979 - Present
NOAA Geostationary Operational Environmental Satellites (GOES) Current: GOES-16 & GOES-17	Imager & Sounder Advance Baseline Imager (ABI)	1975 - Present
ESA - Sentinel 3A & 3B	Sea and Land Surface Temperature Radiometer (SLSTR)	02/2016 - Present 04/2018 - Present
ESA - Sentinel 2A & 2B	MultiSpectral Instrument (MSI)	07/2015 - Present 03/2017 - Present

Spectral bands for LST mapping

Sensor	Spectral Bands (μm)	Spatial Resolution	Temporal Resolution	Sensor	Spectral Bands (μm)	Spatial Resolution	Temporal Resolution
TM ETM+ TIRS	10.40 - 12.50 10.40 - 12.50 10.60 - 11.19 11.50 - 12.51	120 m (30 m) 60 m (30 m) 100 m 100 m	16 days	VIIRS	10.26 - 11.26 11.54 - 12.49	750 m	12 hours
MODIS	10.78 - 11.28 11.77 - 12.27	1 km	12 hours	AVHRR	10.30 - 11.30 11.5 - 12.50	1 km & 4 km	
ASTER	10.25 - 10.95 10.95 - 11.65	90 m	12 hours	VIS SR ABI	10.10 - 10.60 **10.80 - 11.60** **11.80 -12.80** 13.0 - 13.6	2 km CONUS and Full Disk	minutes, hours, day/night
PHyTIR	8.28, 8.79, 9.06, 10.5, 12.05	60 m CONUS only	varies/ every few days	SLSTR	10.45 - 11.24 11.57 - 12.48	1 km	12 hours

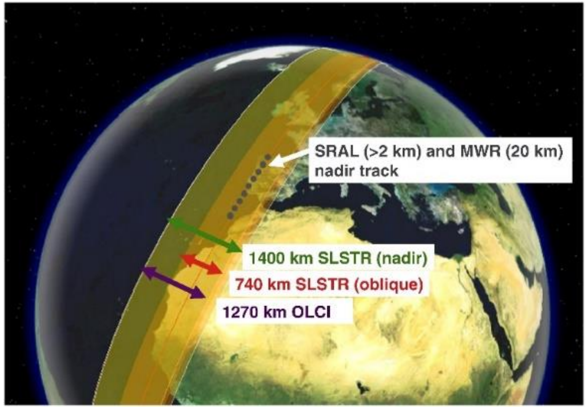
Sentinel-3 – A bigger picture

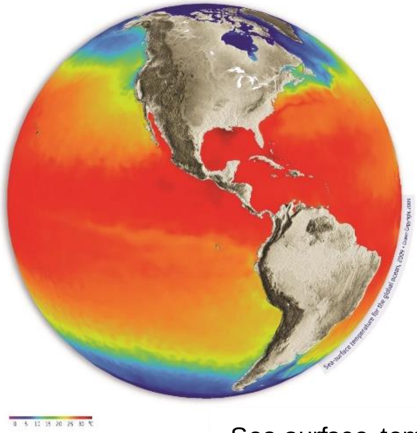
Mission objectives:

- Ocean, inland sea, coastal zone colour measurements
- Sea surface temperature measurements
- Sea surface topography measurements

Mission profile:

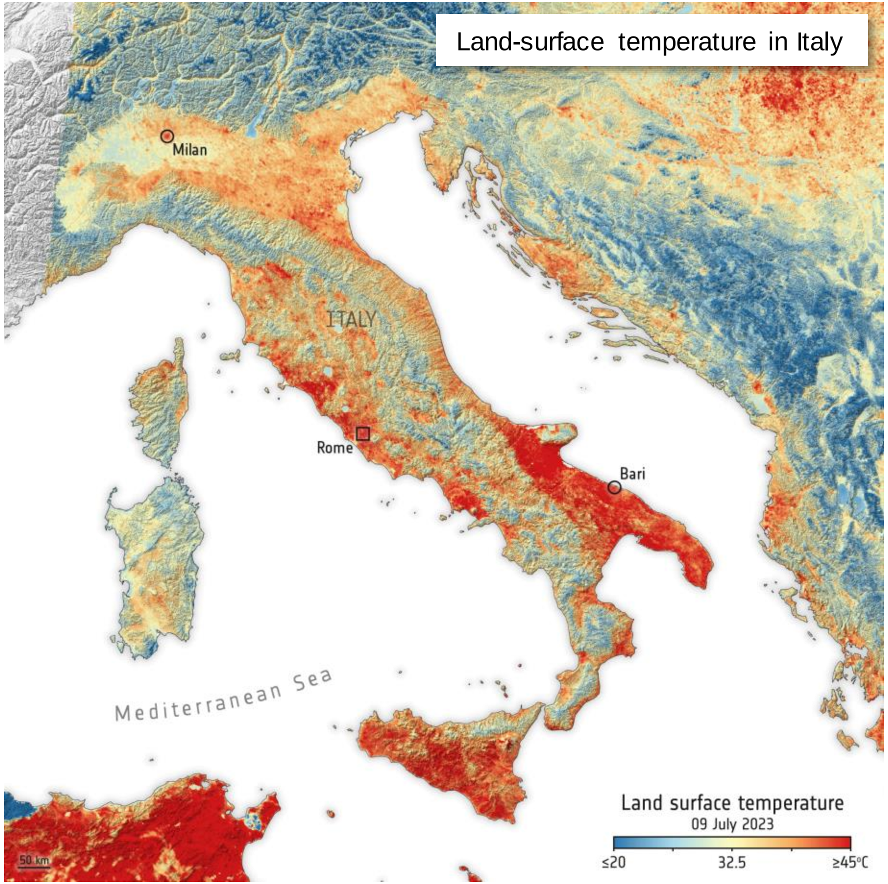
- Operational mission in high-inclination, low Earth orbit
- Orbital cycle is 27 days
- Ocean and Land Colour Instrument (OLCI),
  Sea and Land Surface Temperature Radiometer (SLSTR),
  SAR Radar Altimeter (SRAL),
  MicroWave Radiometer (MWR)
  and Precise Orbit Determination (POD) instruments
- Full performance achieved with 2 satellites in orbit

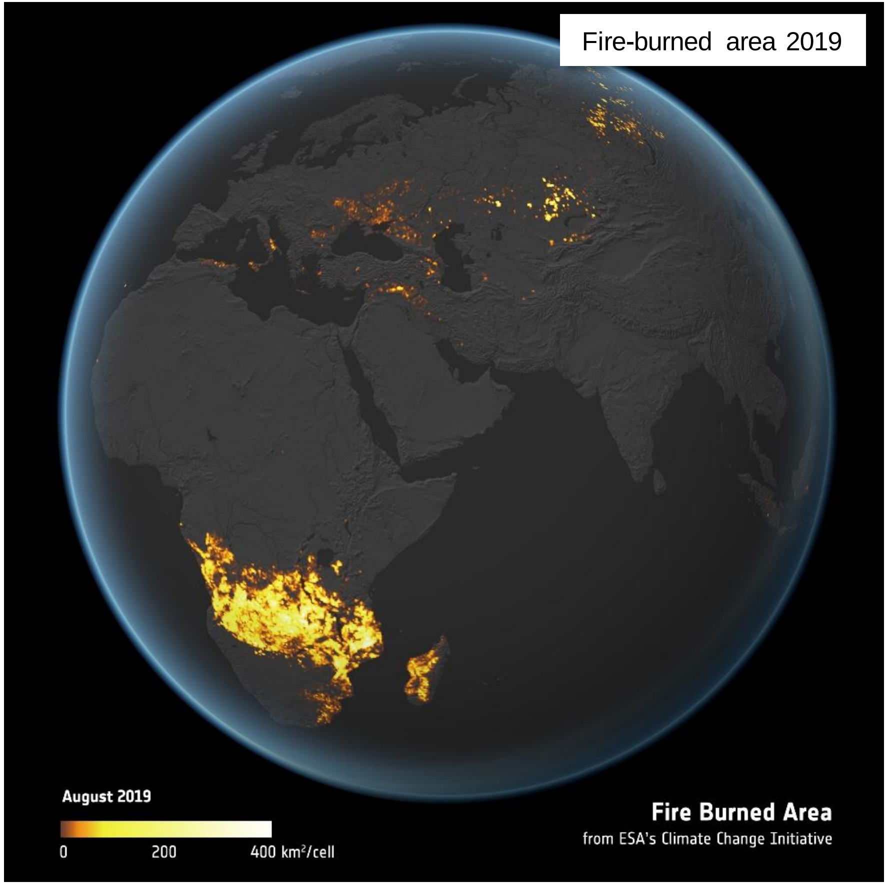




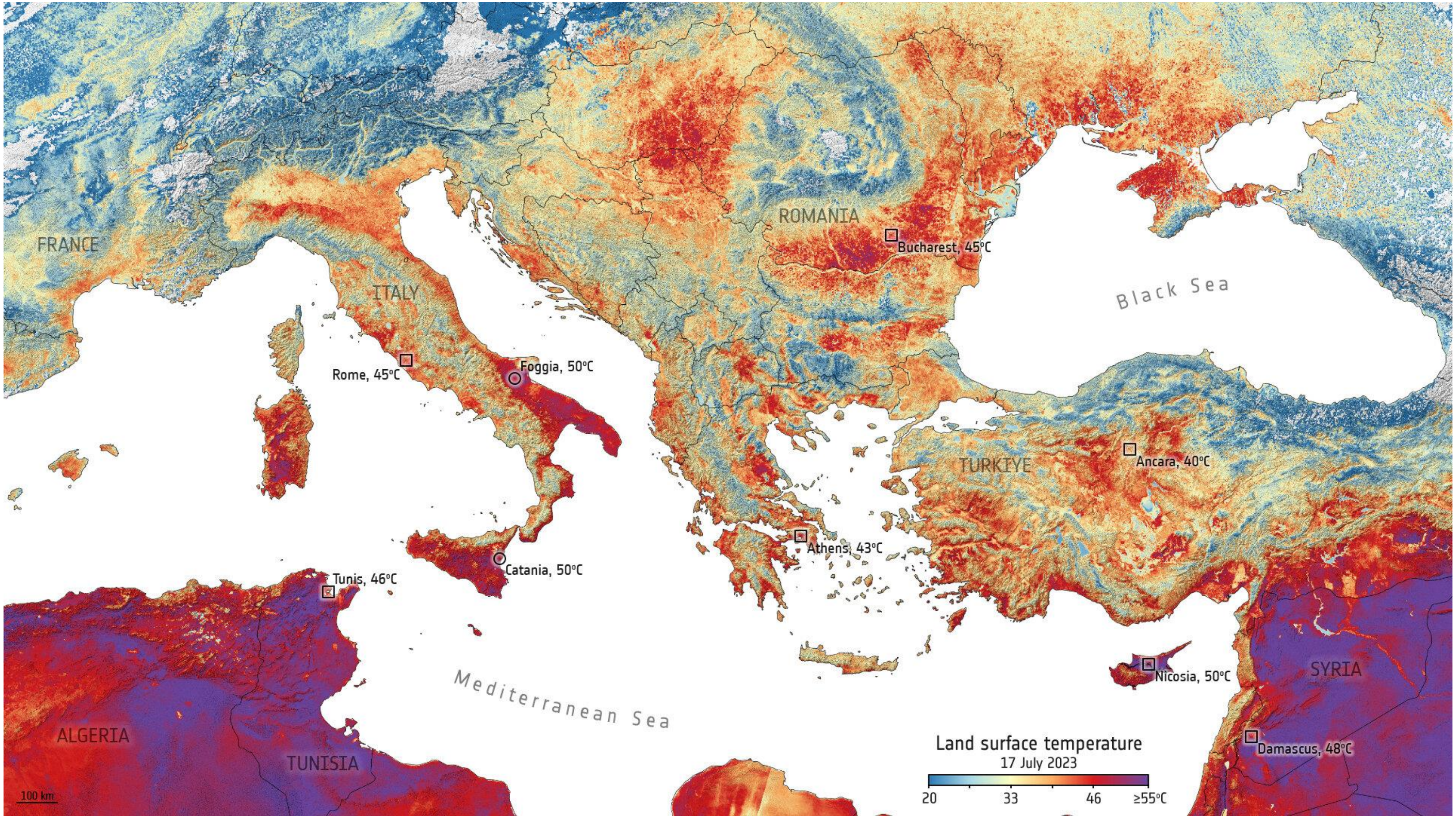
Sea-surface temperature

Sentinel-3 – Applications

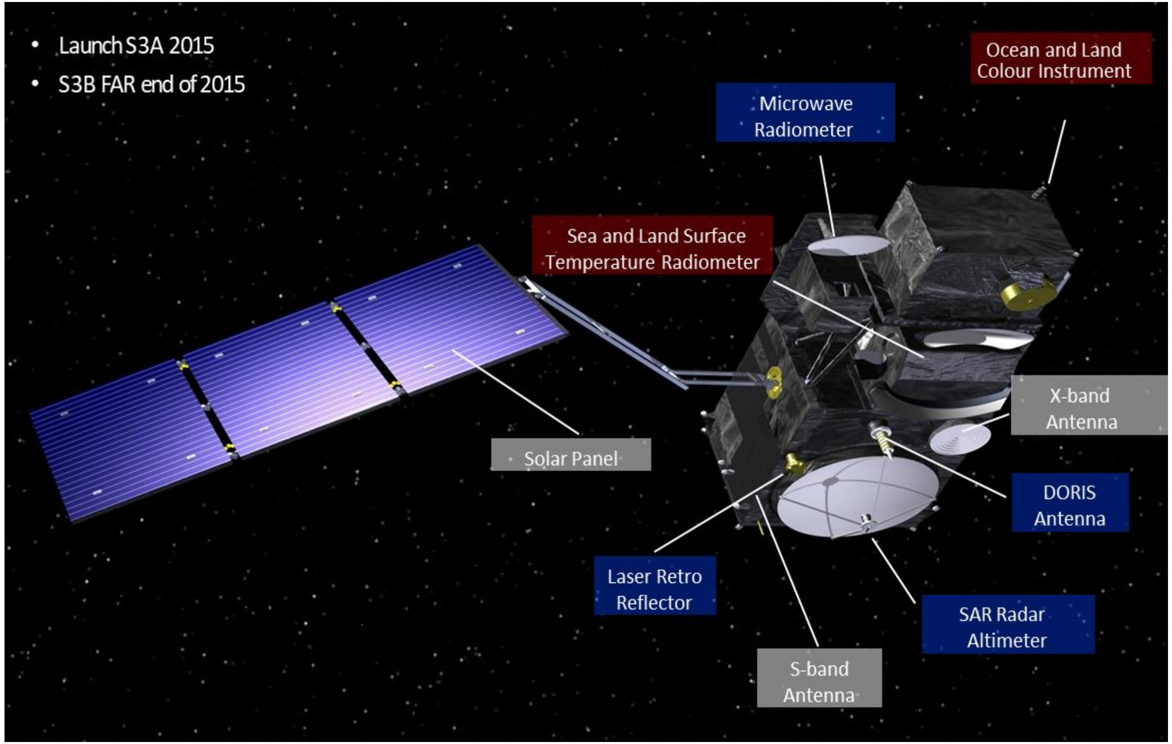




Sentinel-3 – Applications



Sentinel-3 Mission



•Ocean and Land Colour Instrument (OLCI) - 5 cameras, 8 bands (VIS) for open ocean (low res), 15 bands (only VIS) for coastal zones (high res). Spatial sampling: 300m → *MERIS follow-on*

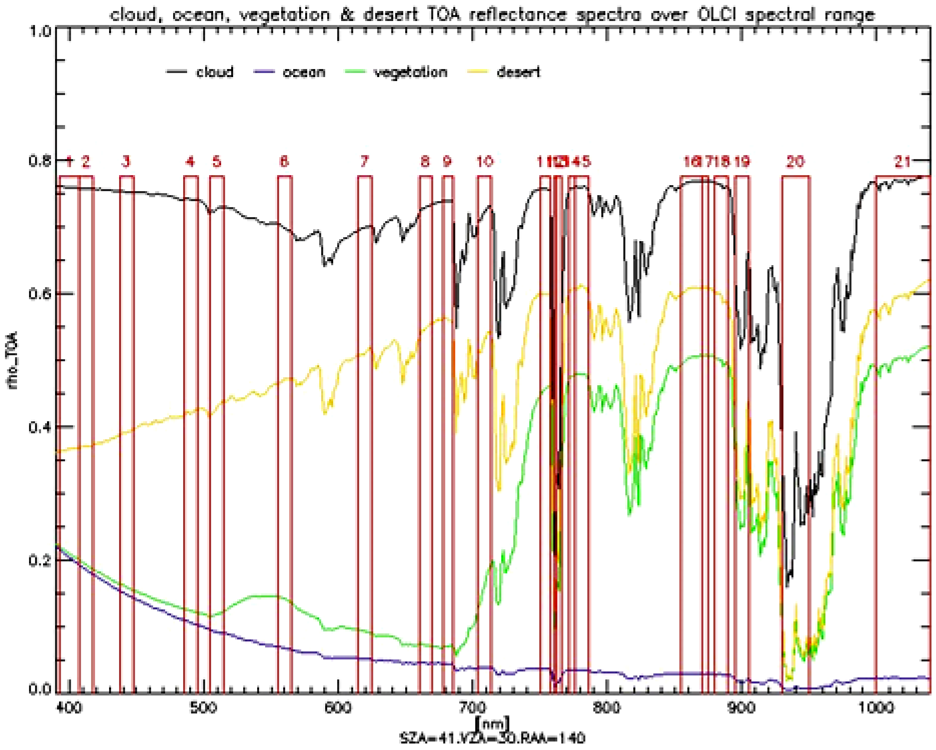
•Sea and Land Surface Temperature (SLST) with 9 spectral bands, 0.5 (VIS, SWIR) to 1 km res (MWIR, TIR). Swath: 180rpm dual view scan, nadir & backwards → *ATSR follow-on*

•Radar Altimeter package - SRAL Ku-C altimeter (LRM and SAR measurement modes), MWR, POD (with Laser Retro Reflector and DORIS)

•

OLCI instrument

Channel	Central wavelength (nm)	Width (nm)
1	400	15
2	412.5	10
3	442.5	10
4	490	10
5	510	10
6	560	10
7	620	10
8	665	10
9	681.25	7.5
10	708.75	10
11	753.75	7.5
12	761.25	2.5
13	764.375	3.75
14	773.75	5
15	781.25	10
16	862.5	15
17	872.5	5
18	885	10
19	900	10
20	940	20
21	1020	40



SLST instrument

Sea & Land Surface Temperature Radiometer

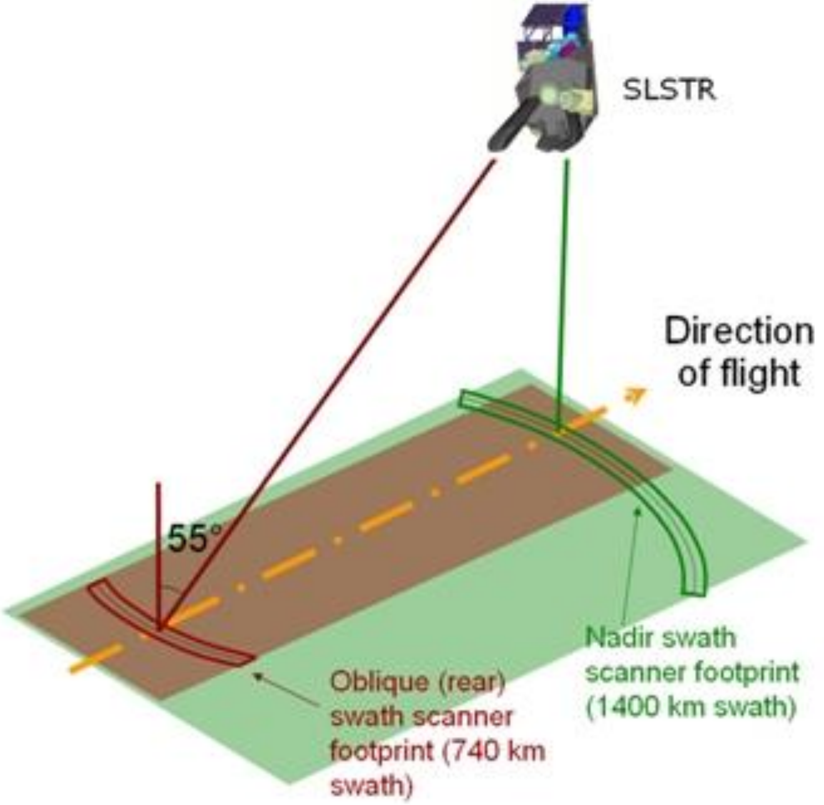
Dual-view (nadir & backward) required for aerosol corrections:

- Nadir swath >74° (up to 1800 km)
- Dual view swath 49° ~ 750 km
- Nadir swath covering OLCI

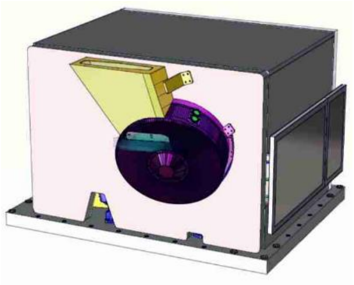
9 spectral bands:

- 3 Visible : 555 – 659 – 865 nm
- 3 SWIR : 1.38 – 1.61 – 2.25 µm
- 3 TIR : 3.74 – 10.85 – 12 µm

One Vis/IR channel used for co-registration with OLCI

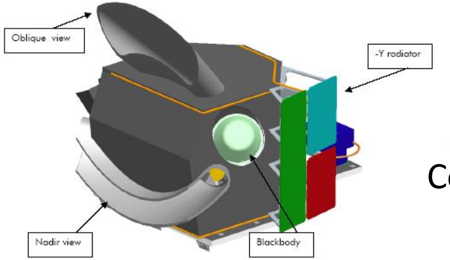


OLCI and SLST spatial resolution



Pushbroom type imager spectrometer
21 Spectral Channels
Full Resolution: Coastal/Land
Reduced Resolution: Open Ocean

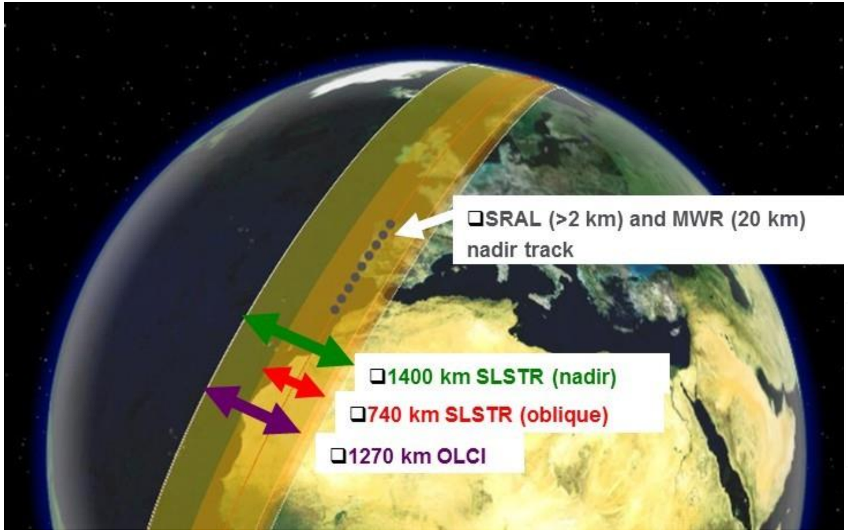
OLCI – Open ocean	1.2 km
OLCI – Coastal ocean	300 m
OLCI - Land	300 m
SLST – Solar channels	500 m
SLST – Thermal channels	1 km



Conical scanning imaging radiometer with dual view capability:
- Near-nadir view
- Inclined view with an OZA of 55º ± 0.1º

9 Spectral Channels + 2 (option) for Active FIRE

Sentinel-3 – revisit capability



Orbit type	❑ Repeating frozen SSO
Repeat cycle	❑ 27 days (14 + 7/27 orbits/day)
LTDN	❑ 10:00 hr
Average altitude	❑ 815 km
Inclination	❑ 98.65 deg

Optical missions:
Short Revisit times for optical payload, even with 1 single satellite

		Revisit at Equator	Revisit for latitude >30°	Specification
Ocean Colour (Sun-glint free)	1 Satellite	< 3.8 days	< 2.8 days	< 2 days
	2 Satellite	< 1.9 days	< 1.4 days	
Land Colour	1 Satellite	< 2.2 days	< 1.8 days	< 2 days
	2 Satellite	< 1.1 day	< 0.9 day	
SLST dual view	1 Satellite	< 1.8 days	< 1.5 days	< 4 days
	2 Satellite	< 0.9 day	< 0.8 day	

Sentinel-3 Product Structure

Sentinel-3 Core Land Products :

Sentinel-3 core products play a crucial role in monitoring and understanding Earth's oceans, land surfaces, and atmosphere, contributing to efforts to address global environmental challenges and ensure the sustainable management of natural resources.

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Thank you for the attention