Urban analysis and monitoring with multi-temporal data: challenges and trends

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MultiTemp 2015

Context

- **Urban areas:**
  - 54 % of the world population
  - 3.9 billions people

Sao Paulo (wikipedia)

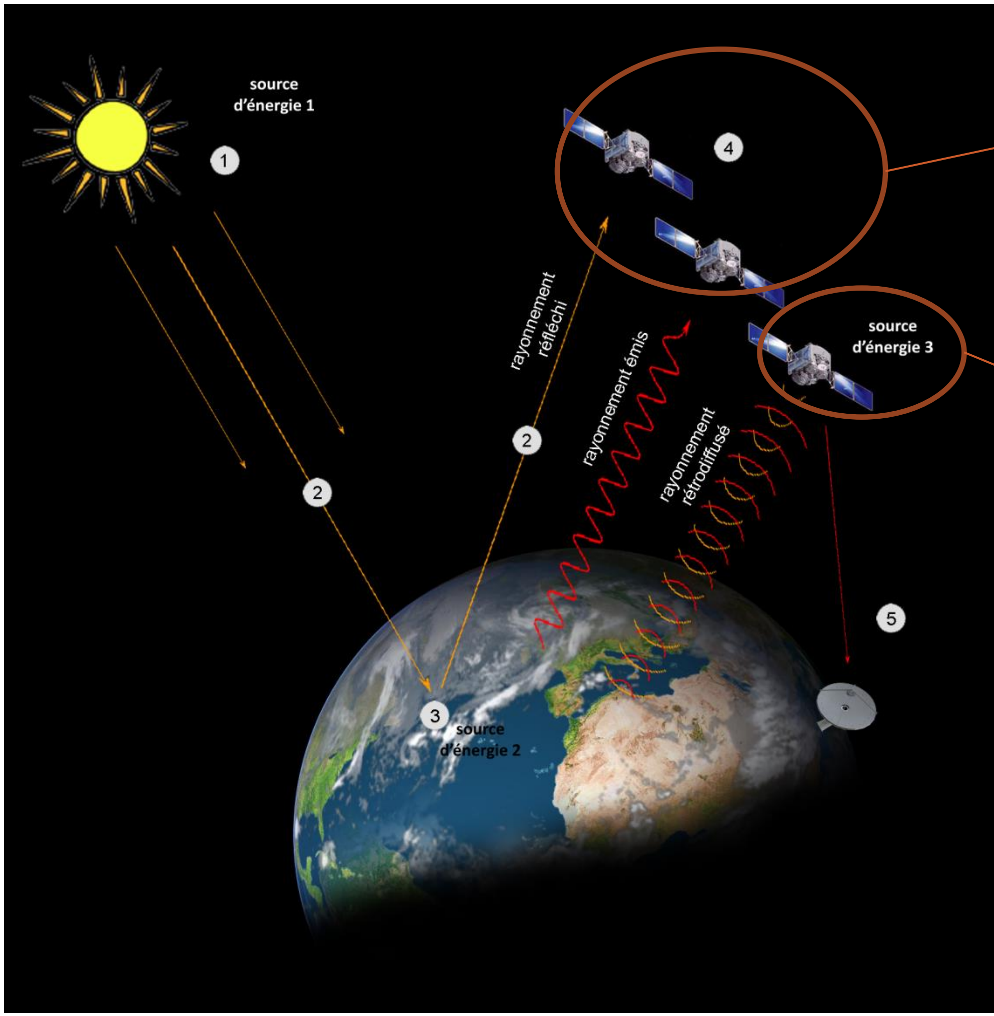
- **Urban analysis and monitoring:**
  - Urban mapping (urban classification, ecological impact study)
  - Urban monitoring (urban growth, building / ground deformation, subsidence,…)
  - Pollution measurement
  - Rapid mapping (building and network damage assesment, …)

⇒ Remote sensing: global coverage of urban areas

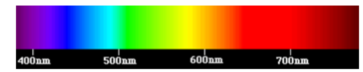
Overview

- Remote sensing data for urban area analysis and monitoring
- State of the art and challenges for urban areas
- Advanced methods to face new needs

Remote sensing for urban areas



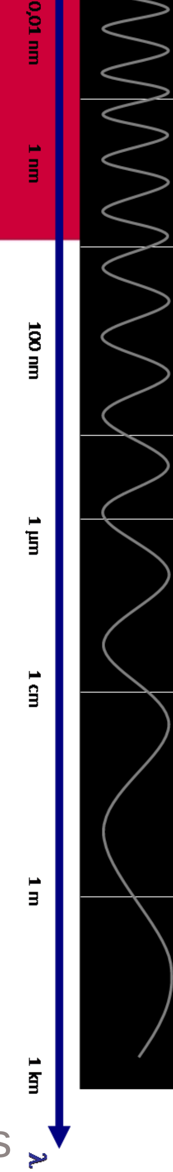
Passive sensors
- optic domain



- IR domain

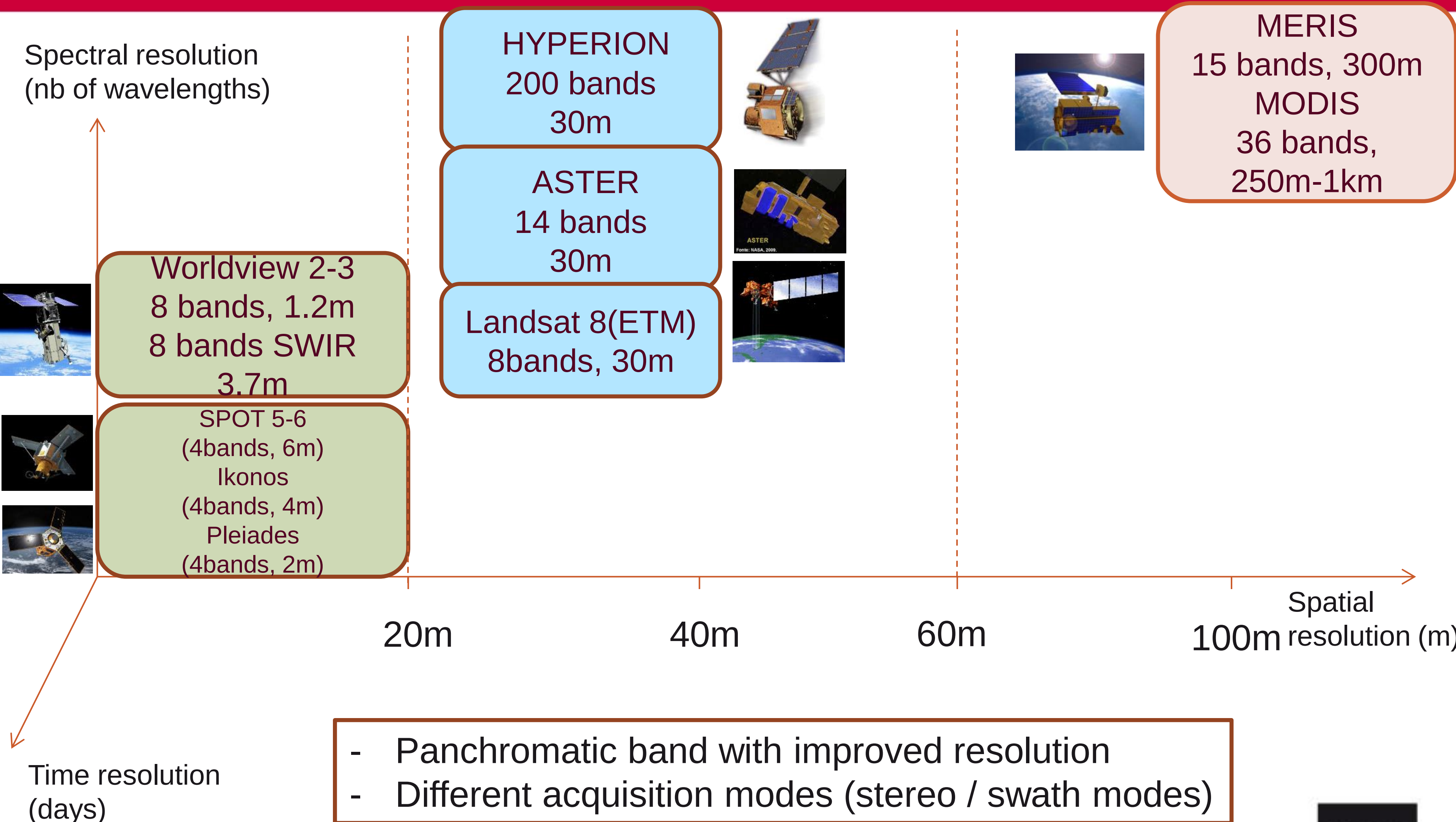
Active sensors
- Radar
- LiDAR

Space sensors
Airborne sensors
Ground-based sensors



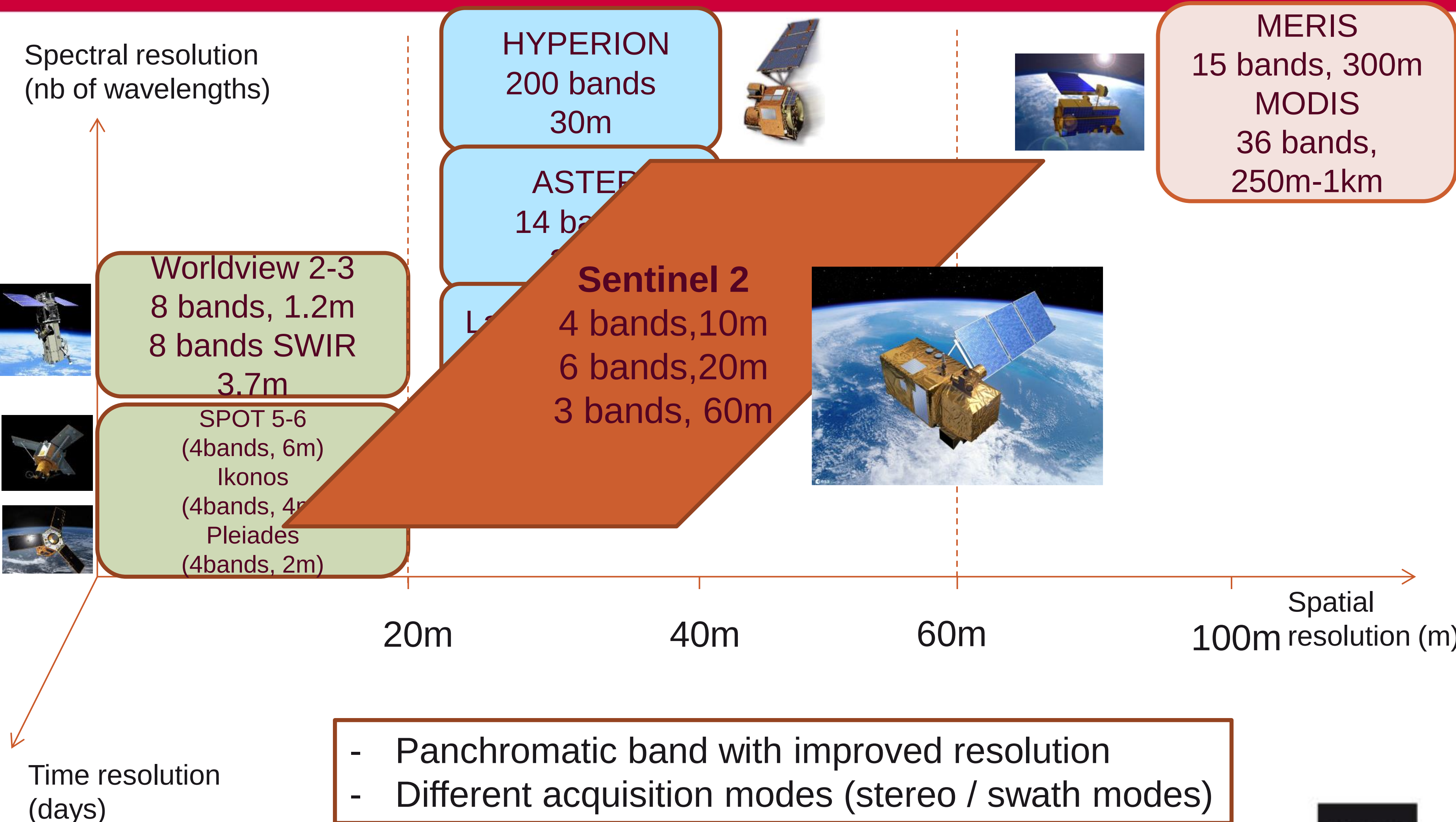
Source figure ENVCAL

Passive sensors – resolutions



- Panchromatic band with improved resolution
- Different acquisition modes (stereo / swath modes)

Passive sensors – resolutions



- Panchromatic band with improved resolution
- Different acquisition modes (stereo / swath modes)

Passive sensors – revisiting time


Pleiades©CNES

- **Angular agility**
- **Sensor constellations**
  - Sentinel (2), Pleiades (2), Worldview (3), …

Allowed angular variation	1 sensor (days)	2 sensors (days)
6°	26	13
20°	7	5
30°	5	4
46°	2	1
47°	1	1

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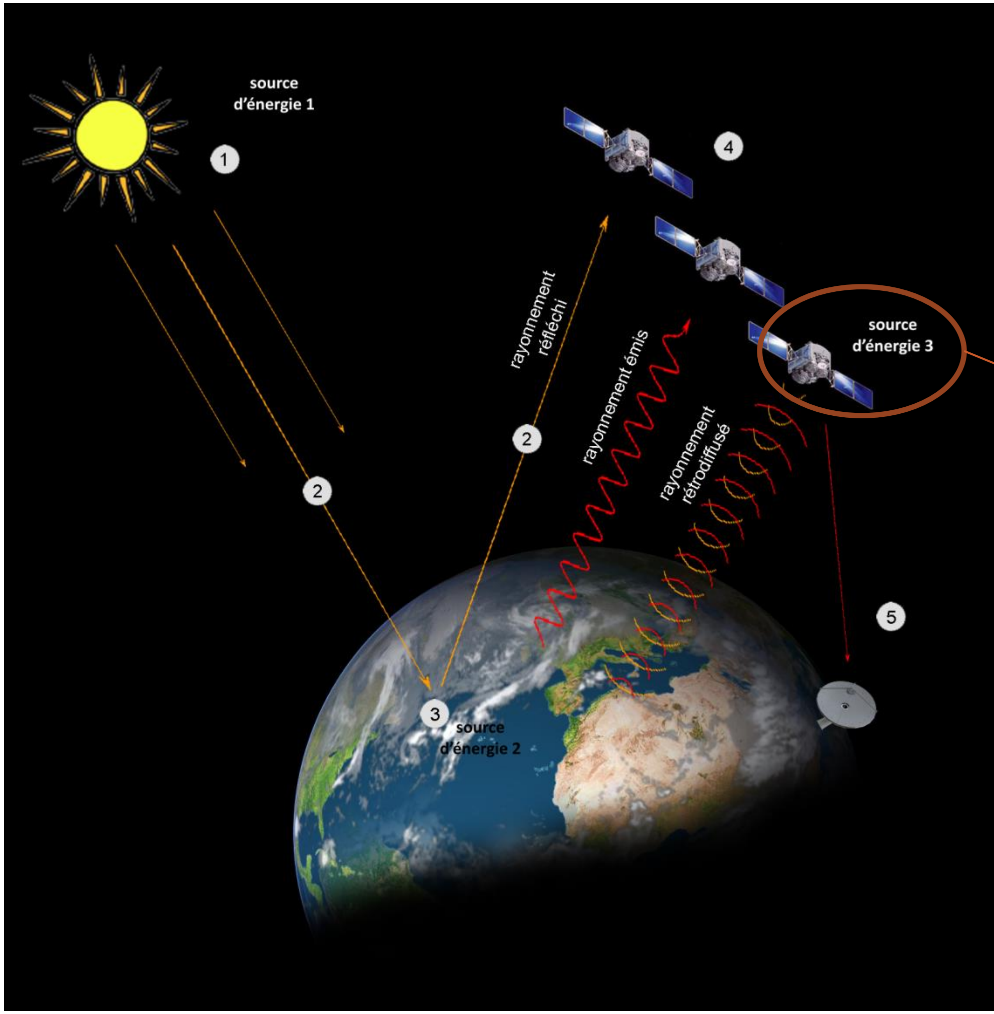
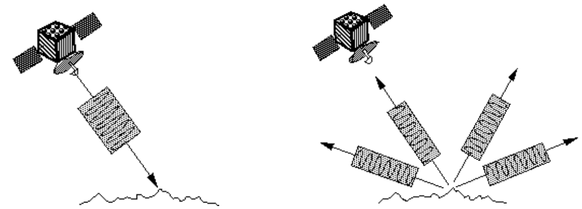
Pleiades - time

Pleiades©CNES

Remote sensing for urban areas

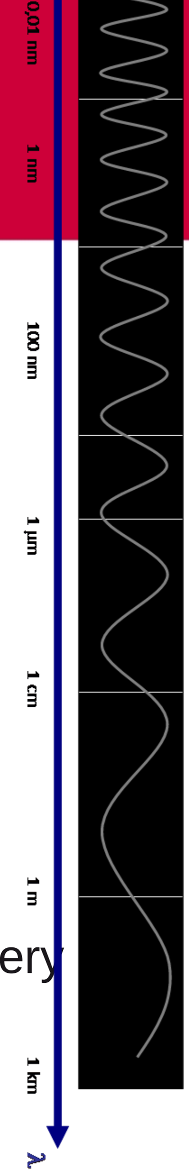




Active sensors

Radar (SAR)

- All time
- All weather
- Coherent imagery
- Interferometry
- Polarimetry



Source figure ENVCAL

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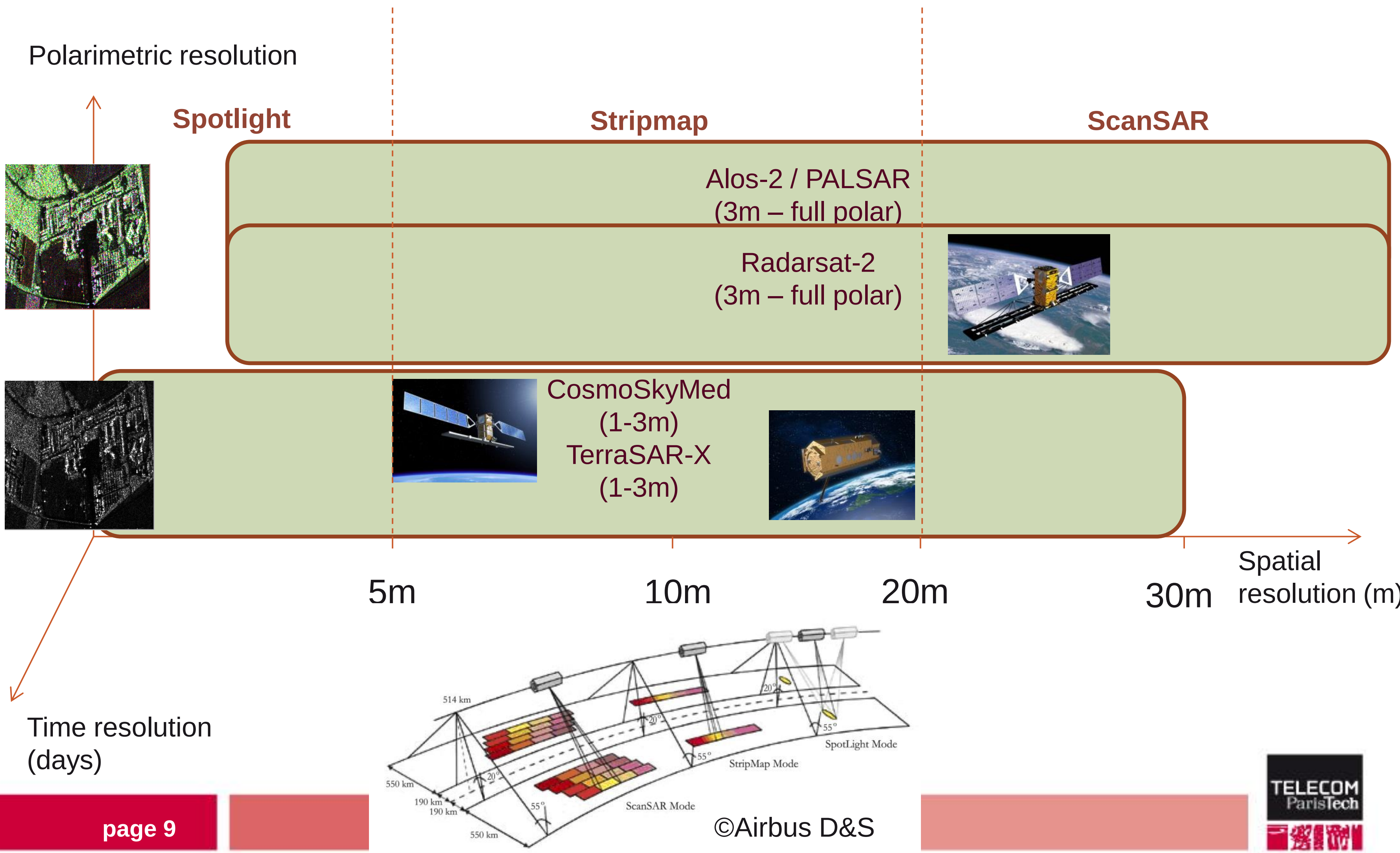
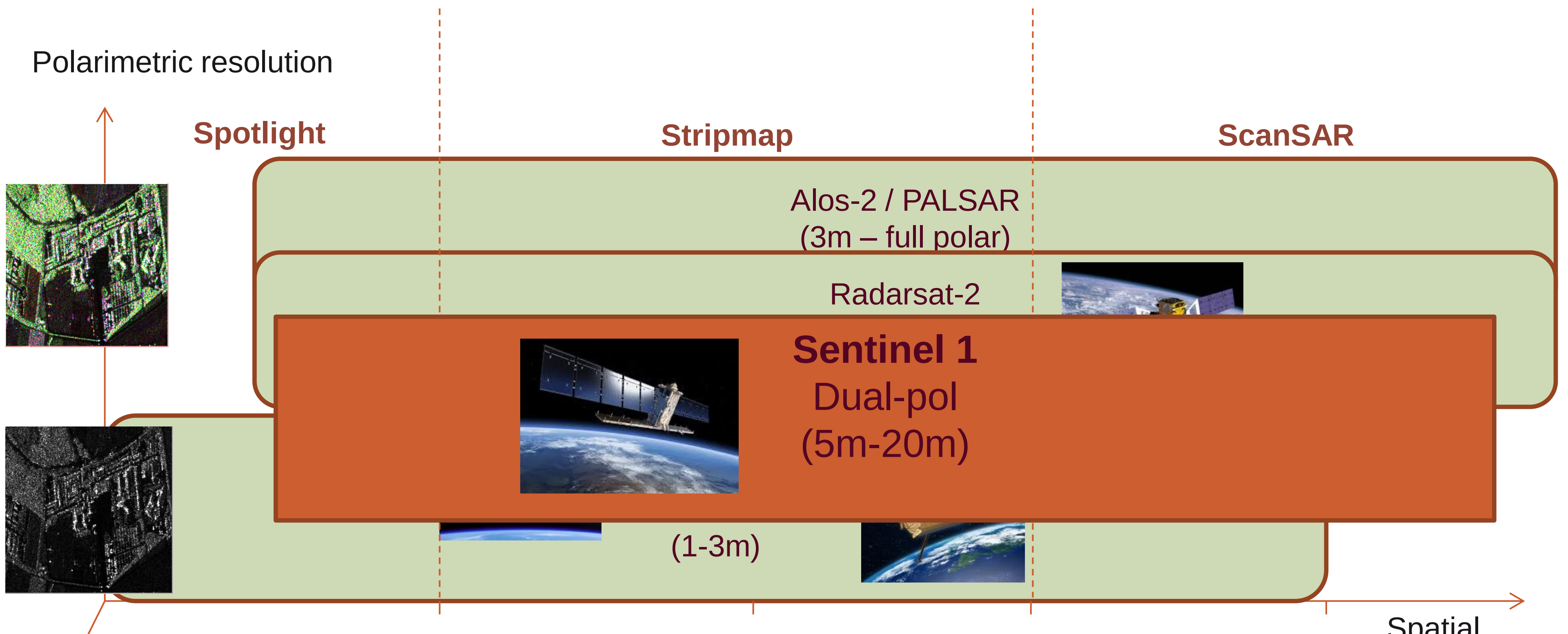
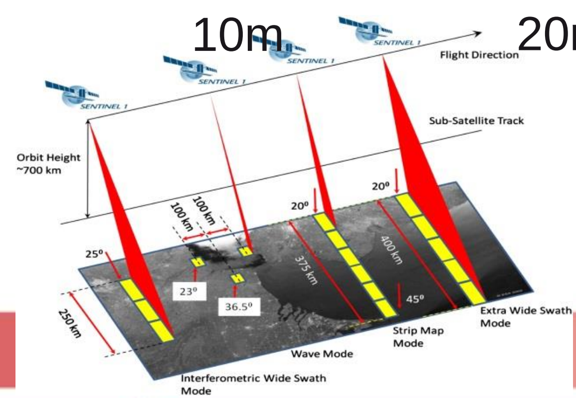
Active sensors – resolutions



Active sensors – resolutions





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Active sensors – revisiting time

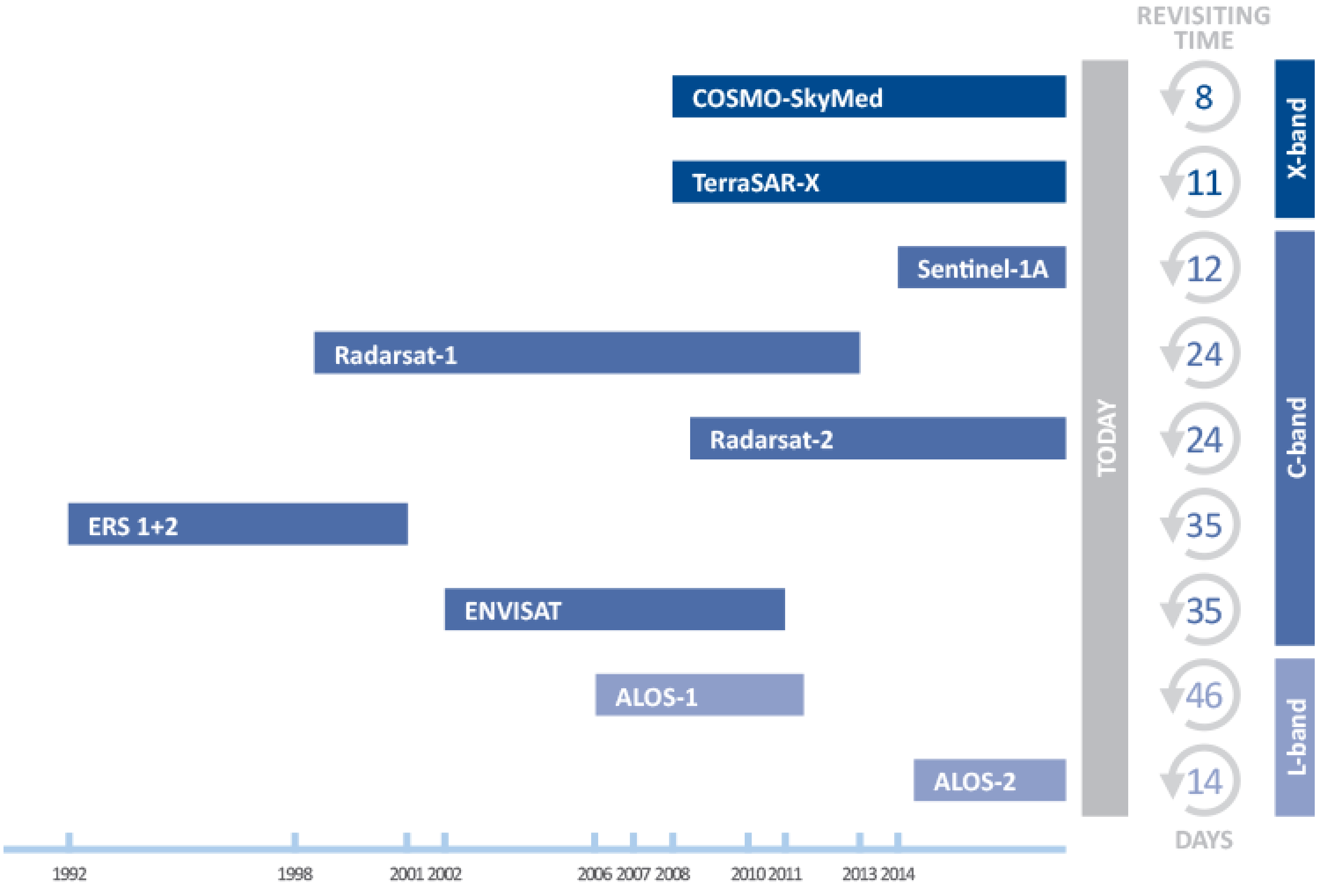
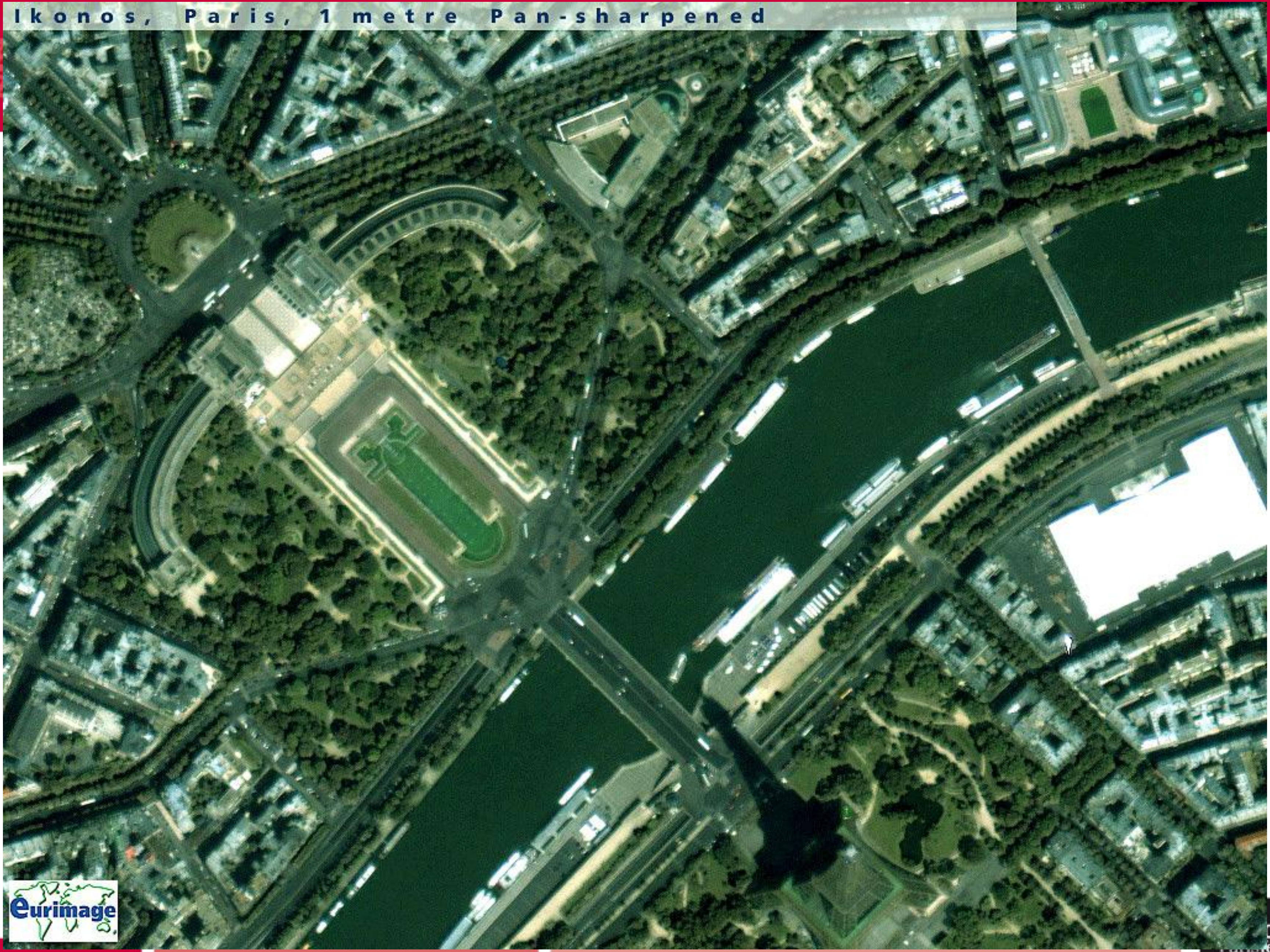


Figure from http://www.treuropa.com

Resolution and urban areas
Paris - Landsat image (30m)

Spot image (10m)

Ikonos, Paris, 1 metre Pan-sharpened



Quickbird (0.60 m), 2001

Paris : Pléiades, 17/01/2012


Country : France
City : Paris
Area : Eiffel Tower
Sensor : WorldView-2
Resolution (GSD) : 0.5 meter

Resolution and urban areas
Paris : ERS (descending) 1991 (12.5m)

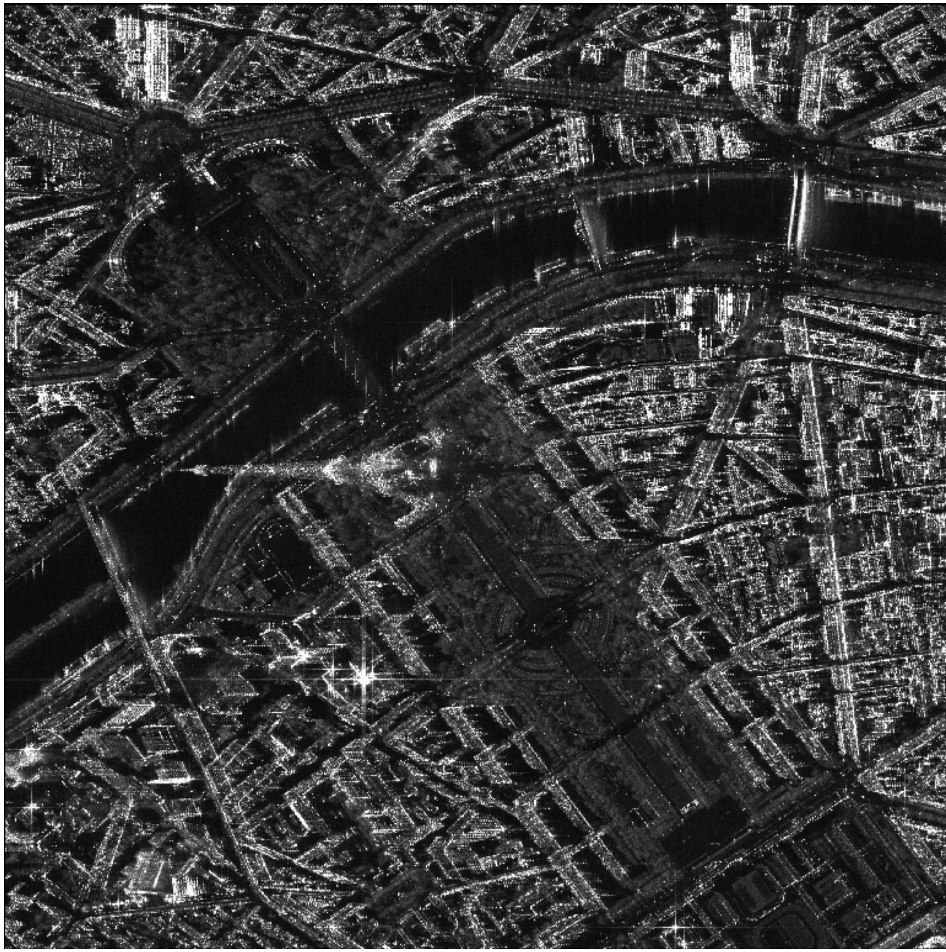
Paris: Radarsat-2 (ascending) 2005 (6m)

Paris: Terrasar-X Spotlight 2007 (1m) ascending pass

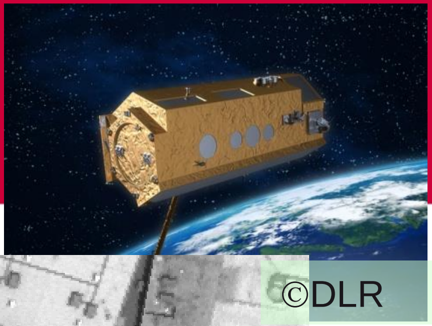
TerraSAR-X
DLR project
LAN 176

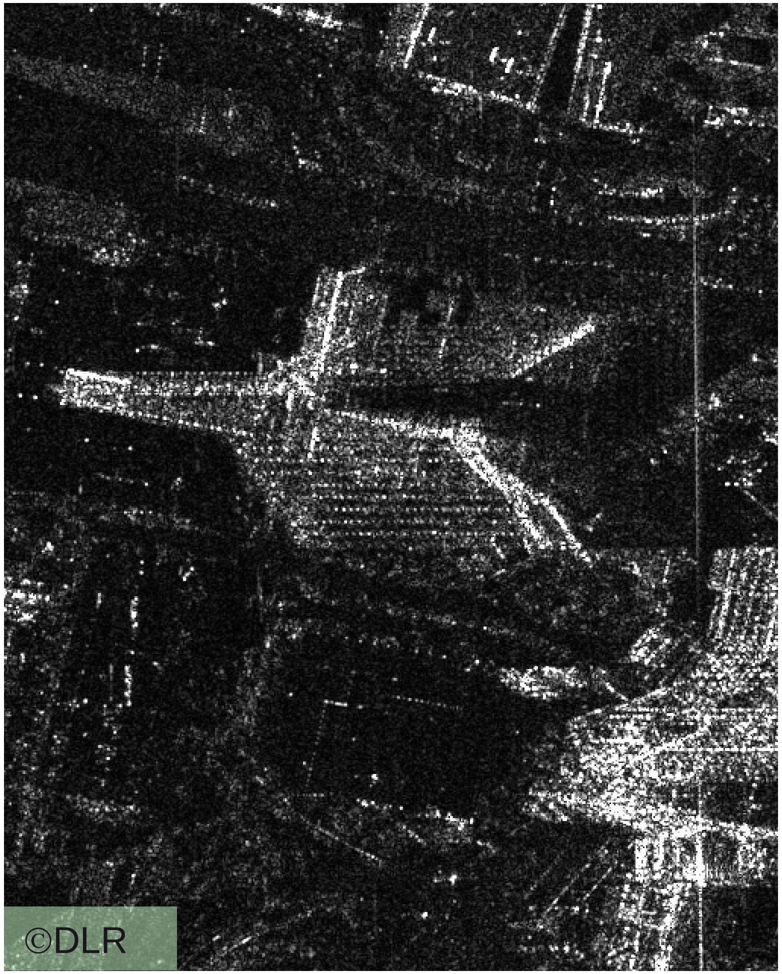
Terrasar-X SpotLight 2007 (1m)
Temporal multi-looking

Urban areas: optic / SAR



Urban areas: optic / SAR





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Multi-spectral vs SAR sensors

Multi-spectral	SAR
+ Object geometry + limited noise + « easy » to interpret	+ all time / all weather + high control of acquisition geometry + phase information
- strong influence of illumination / atm. conditions - clouds	- speckle noise - Strong influence of object geometry / incidence angle - « Difficult » to interpret

Remote sensing data: a big data challenge

Variety
Multi-sensors, multi angles, multi-wavelengths, multi-resolution,…

Volume
Huge amount of data (size, number of channels,…)

Velocity
Rapid mapping, moving targets,…

Urban analysis and monitoring

Overview

- Remote sensing data for urban area analysis and monitoring
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- Advanced methods to face new needs

Challenges for urban areas

Urban mapping
(classification, DEM, …)

Building / ground movement monitoring

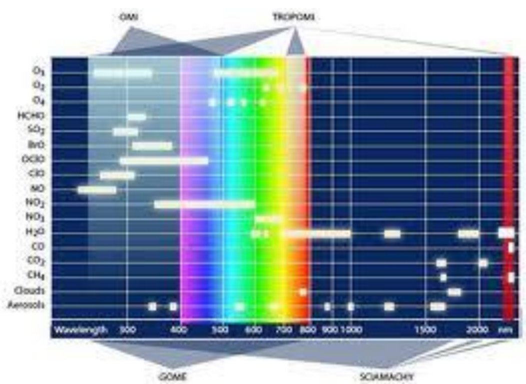
Urban monitoring
(temporal dynamics, urban growth, change detection, rapid mapping, …)

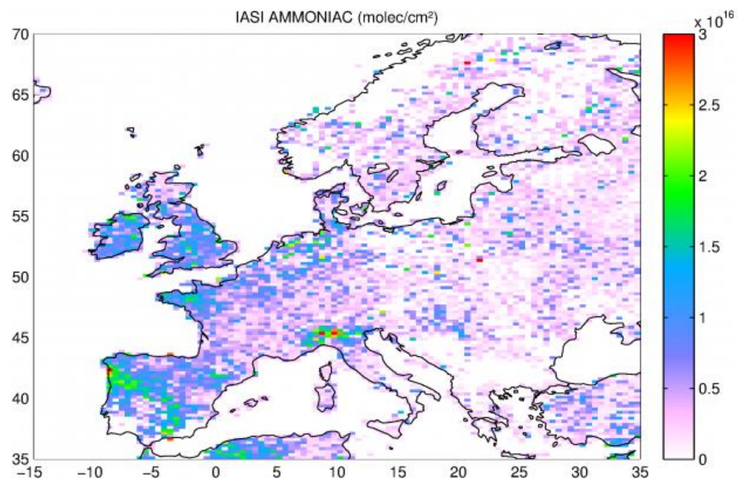
Environmental challenges
(pollution watch, ecological impact of urban growth,…)

Different scales of analysis (local / regional / global)

Challenges for urban areas - environment

TROPOMI – Sentinel 5





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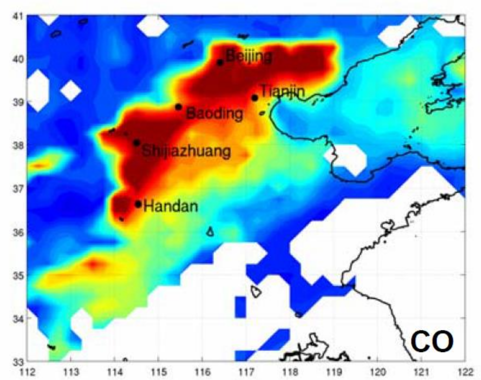
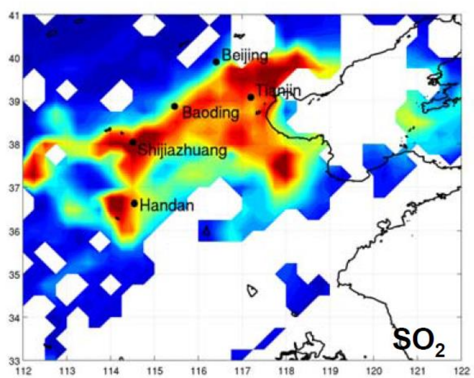




Environmental challenges (pollution watch, ecological impact of urban growth,…)

Regional / global scale

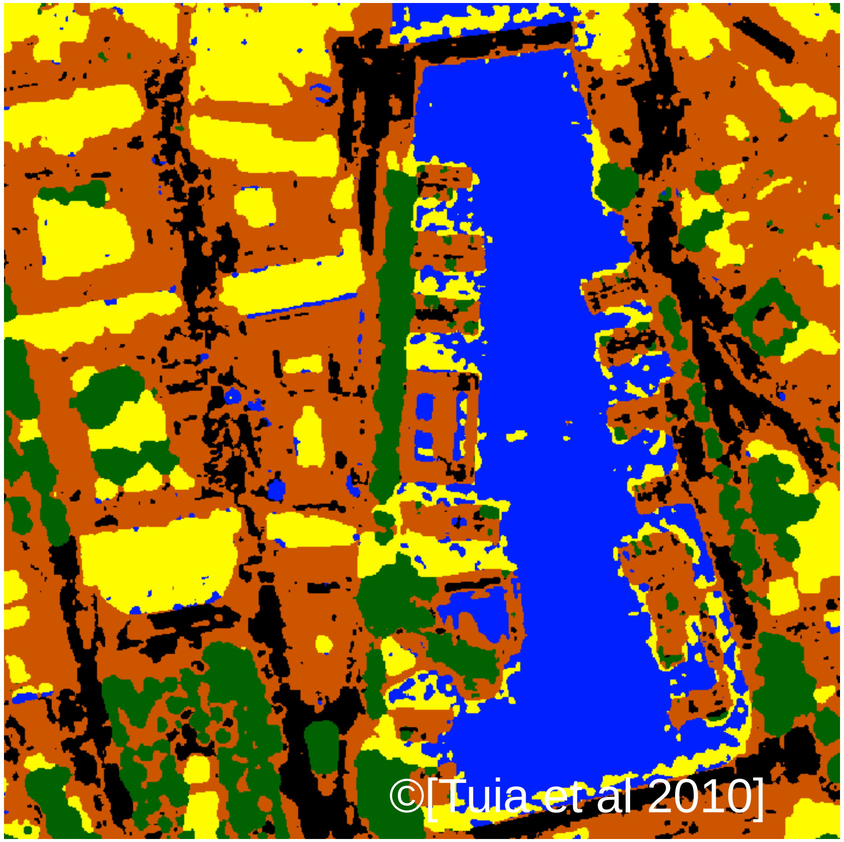
Challenges for urban areas - mapping

Urban mapping
(classification, DEM, …)

- **2D classification**
  - Multi/hyper spectral classification approaches
  - SAR polarimetric classification methods

    [Weissberger et al. 2015]*
  - SAR / optical classification methods
  - *Mono-polarization SAR (regional scale)*

Multi-spectral classification



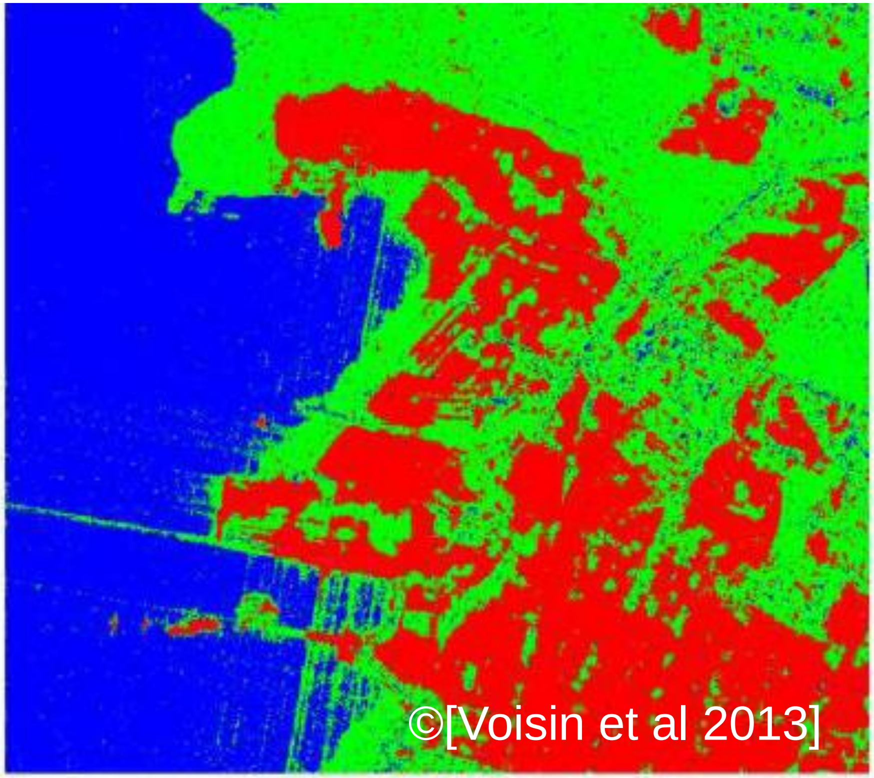
Quickbird satellite image

Spatio-spectral classification with MM [Tuia et al. 2010]

Classification of multi-temporal data [Demir at al. 2013] [Tuia et al. 2015]

SAR classification

CSK image – Stripmap (2.5m resolution)

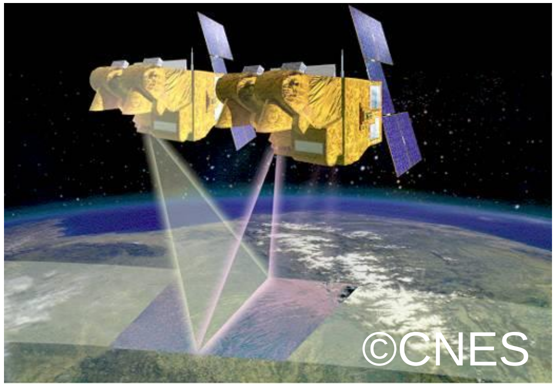


Hierarchical MRF classification [Voisin et al. 2013]

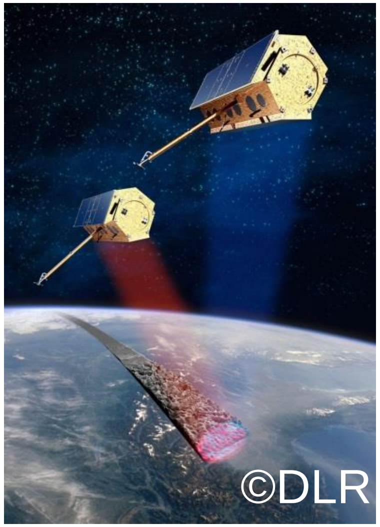
Local scale: limited to simple cases (isolated and specific shape buildings)

Challenges for urban areas - 3D mapping

Urban mapping
(classification, DEM, …)



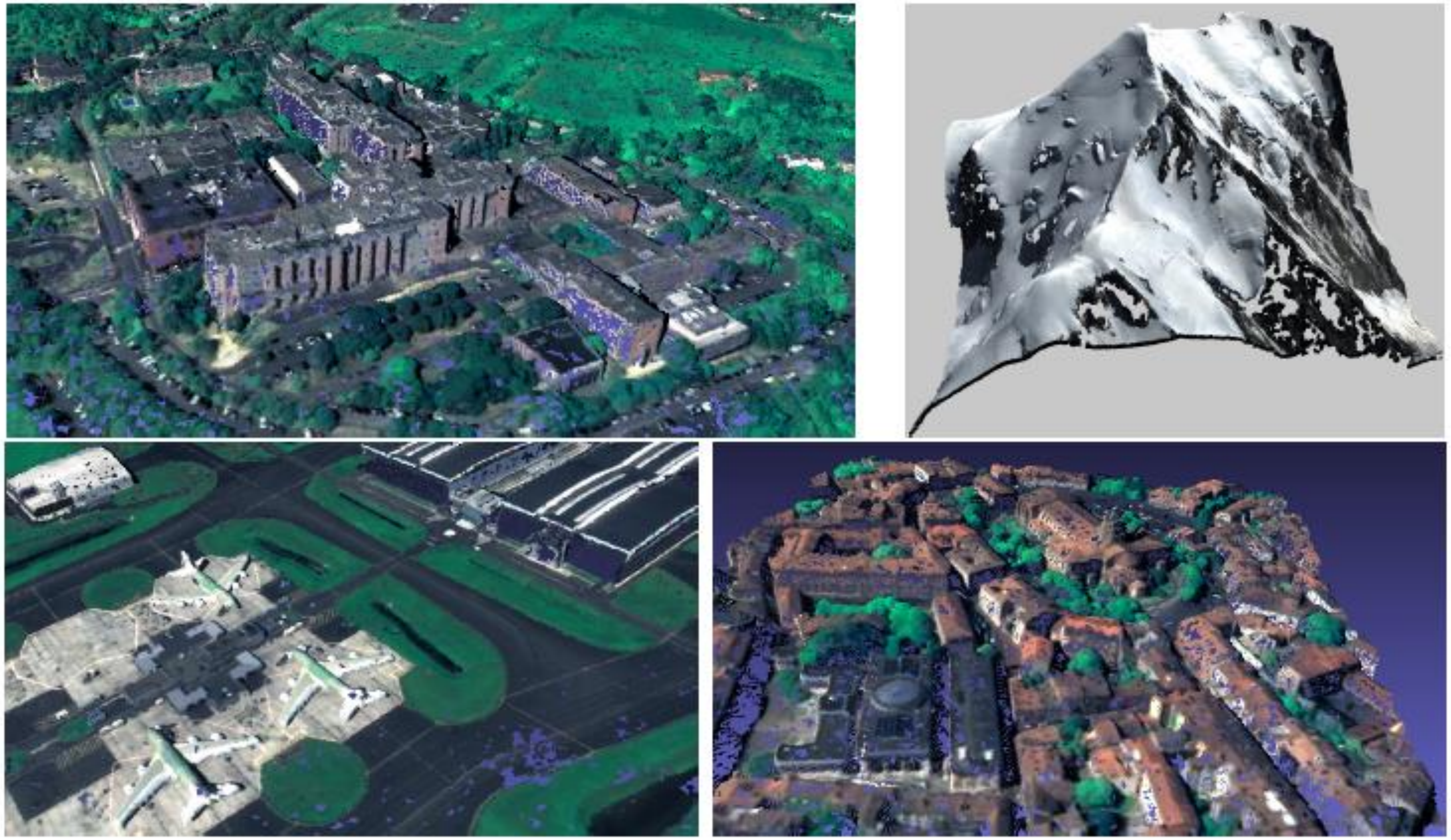
Backward/forward stereo acquisition of SPOT-5



- **3D**
  - Stereo or multi-stereo optic
  - Multi-temporal SAR interferometry (PS, multi-baseline, multi-aspect…)
  - SAR tomography

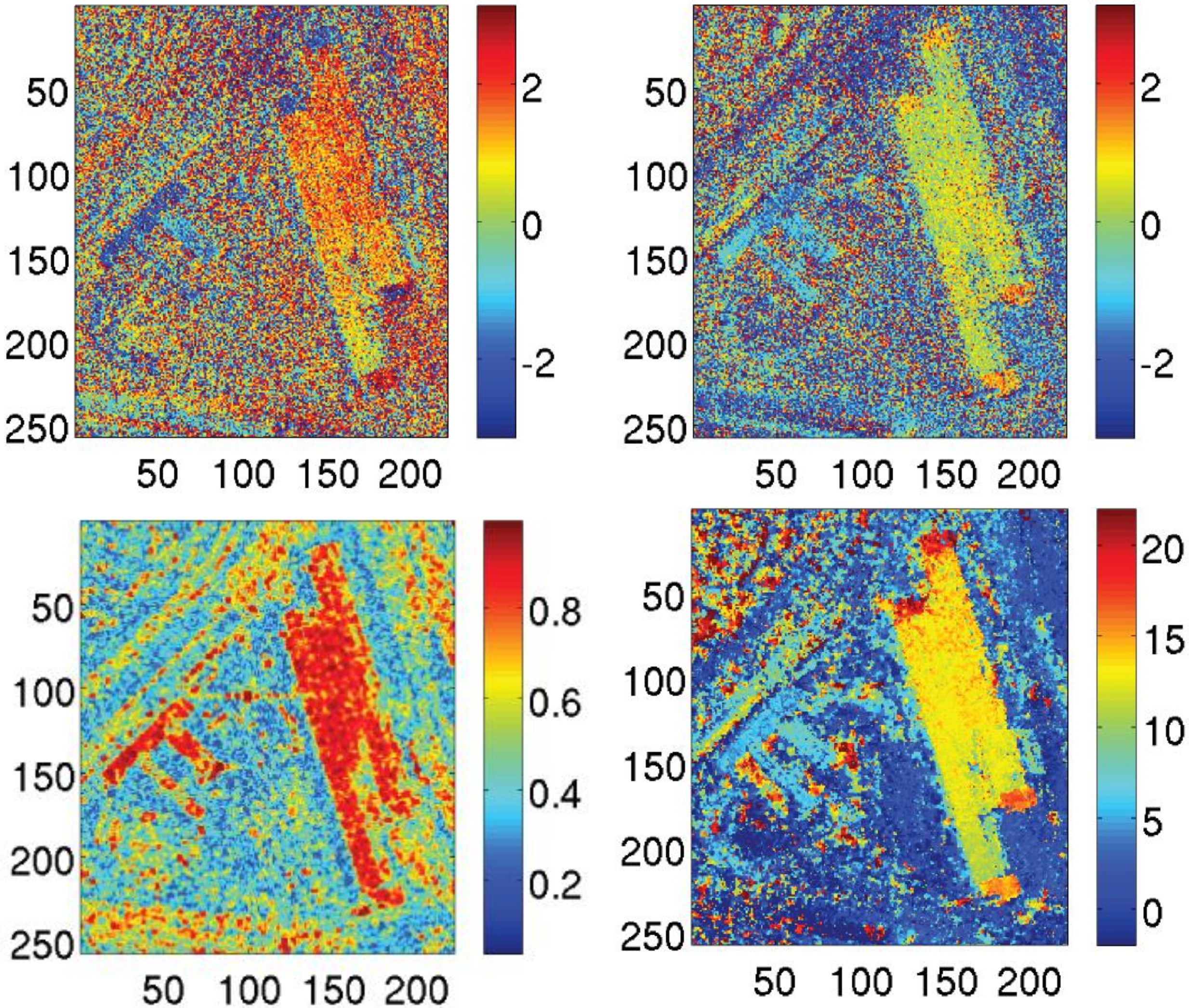
    [Porfiri et al. 2015]*

Multi stereo – optic



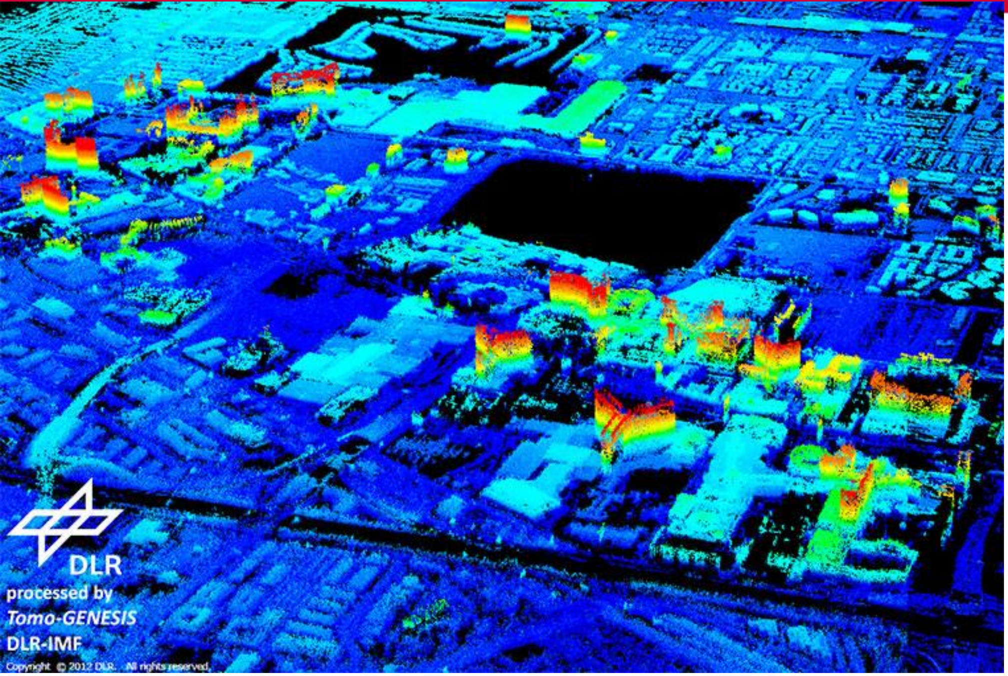
3D point clouds generated from Pleiades tri-stereo datasets
s2p pipeline available on line [De Franchis et al. 2014] / IPOL

Multi-baseline InSAR



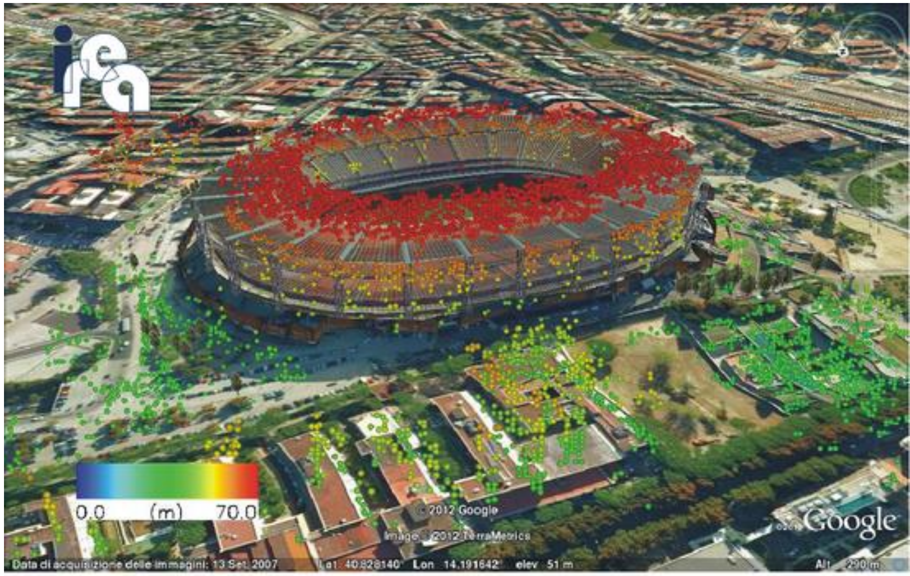
Non-local TV regularization
(3 CSK data)
[Ferraioli et al. 2015]

SAR tomography



Las Vegas reconstruction using tomography © DLR
[Zhu et al. 2014]
24 TerraSAR-X images

Naples stadium reconstruction using tomography © ASI - IREA
[Fornaro et al. 2009, 2014]
29 CSK images



3D reconstruction of the San Paolo Stadium in the city of Naples (South Italy) achieved by a tomographic processing of COSMO/SKYMED data (Courtesy of ASI), overlaid on an optical image taken from Google Earth

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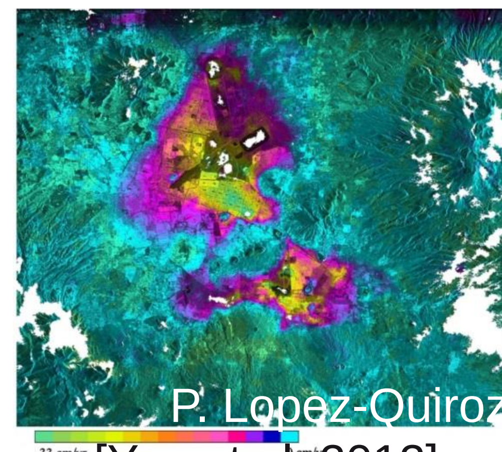
Challenges for urban areas - deformation

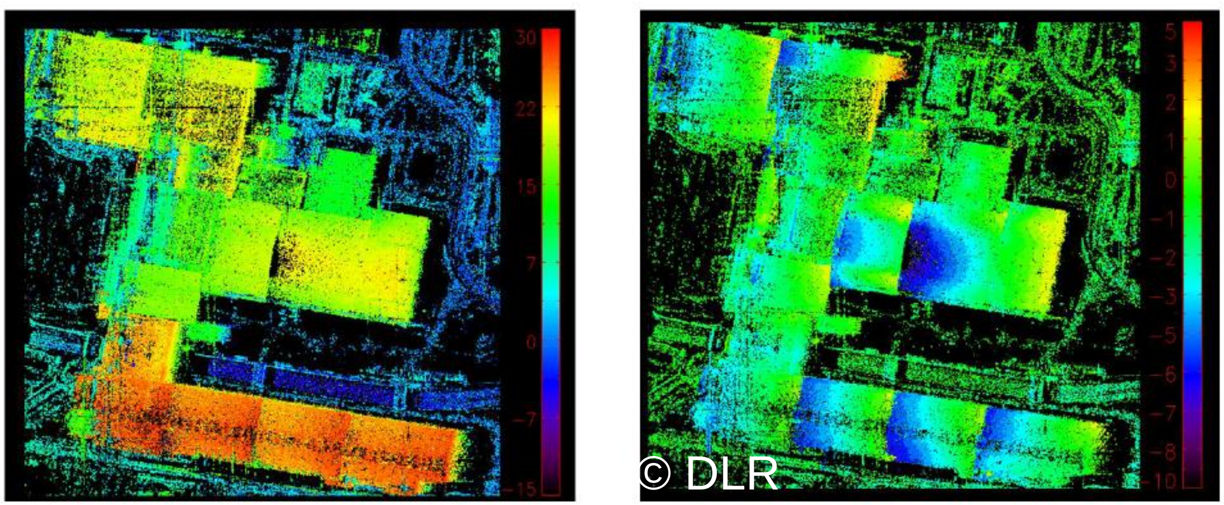
- **Building / ground deformation**
  - Multi-temporal SAR interferometry (PS, multi-baseline,…)
  - 4D SAR tomography

Building / ground movement monitoring



P. Lopez-Quiroz

[Yan et al. 2012]



© DLR

[Zhu et al. 2009]

Figure 11. Left: reconstructed digital surface model (DSM) from differential TomoSAR, [unit: m] and estimated amplitude of seasonal motion using time warp method [unit: mm]

Challenges for urban areas - monitoring

- **Change detection**
- **Exploitation of time series (mono-sensor)**
- **Exploitation of multi-temporal mono- or multi-sensor images**

Urban monitoring
(change detection, rapid mapping, temporal dynamics, urban growth, …)

Change detection: still a challenging task!

- **Optic / multi-spectral sensors :**
  - Mono-sensor: influence of illumination conditions, viewing angle
  - Multi-sensors (passive): pre-processing (registration, calibration, atm. correc. …) => invariant features, DSM, …

SIFT key-points matching for change detection [Dellinger et al. 14]

Change detection: still a challenging task!

- **Optic / multi-spectral sensors :**
  - Mono-sensor: influence of illumination conditions, viewing angle
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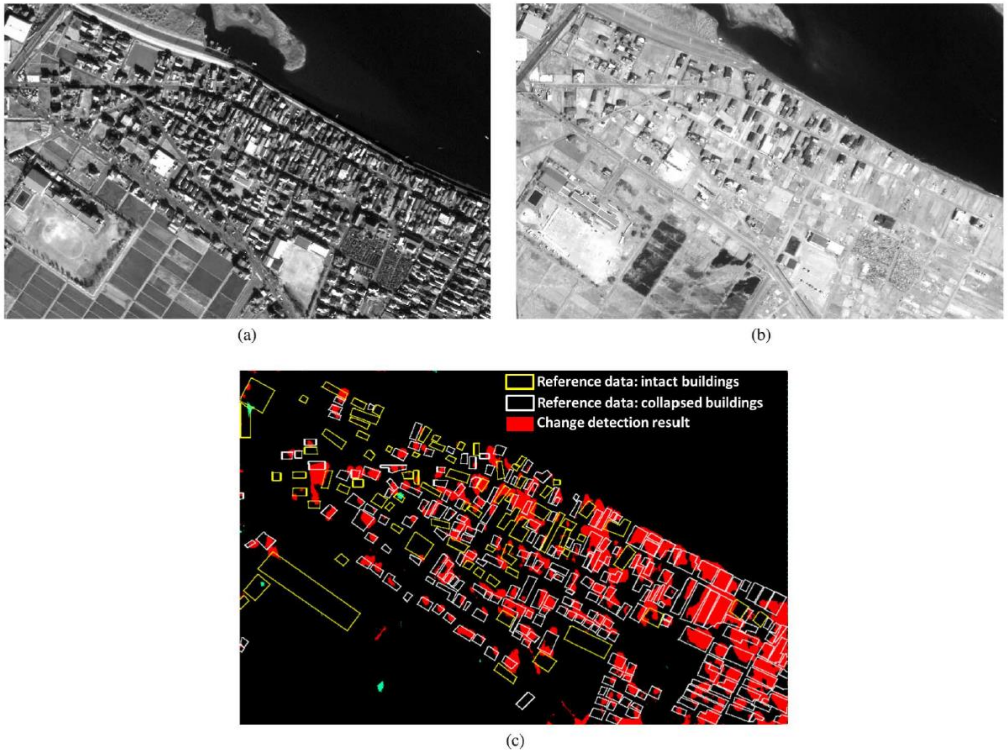
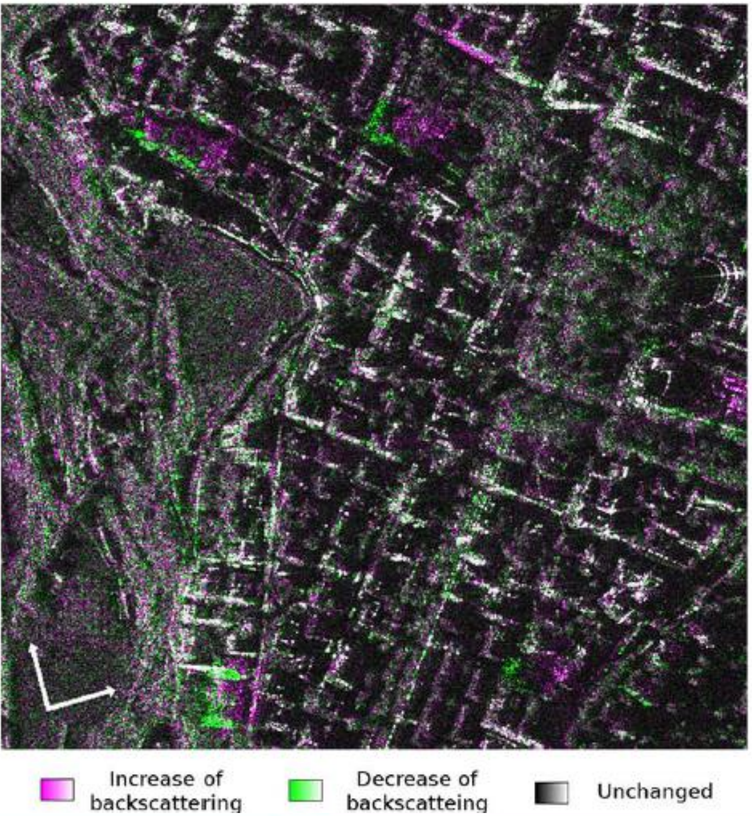


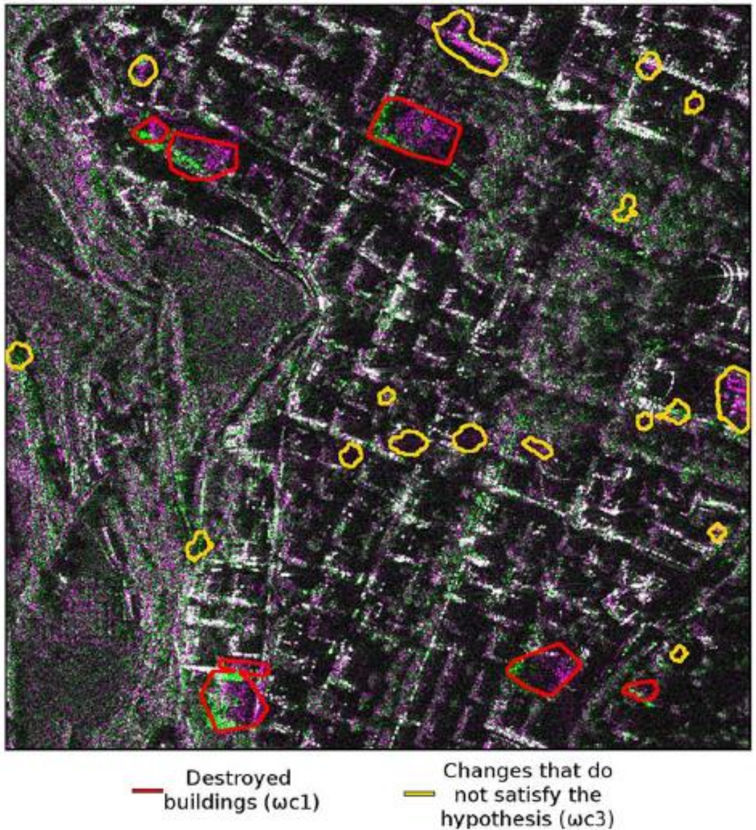
Fig. 11. Change detection of the Sendai coast after the tsunami that hit the region on March 11, 2011: (a) Sendai orthoimage from Ikonos sensor, acquired on December 11, 2010; (b) Sendai orthoimage from Ikonos sensor, acquired on August 13, 2011; (c) change detection result obtained with $\lambda = 4.5$; the black and red areas correspond to the no-change and change classes, respectively. White and yellow polygons correspond to the referenced destroyed and intact buildings, respectively.

DSM comparison for change detection [Guérin et al. 14]

Change detection: still a challenging task!

- **SAR sensors :**
  - Mono-sensor: influence of incidence angle => object level
  - Multi-sensors (active) : pre-processing (registration, calibration, …) => invariant features, object level…

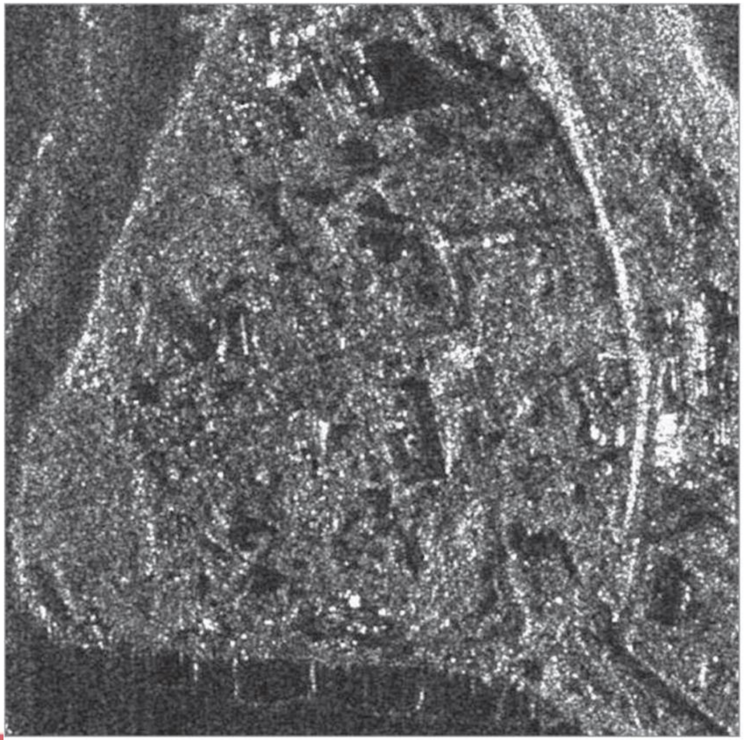




Object level change detection [Marin et al. 15]

Change detection: still a challenging task!

- **SAR sensors :**
  - Mono-sensor: influence of incidence angle => object level
  - Multi-sensors (active) : pre-processing (registration, calibration, …) => invariant features, object level…



Change detection based on object appearance [Brunner et al. 10]

(Satellite Image) Time series analysis

- **SITS analysis :**
  - Mono-sensor
  - *Multi-sensors*

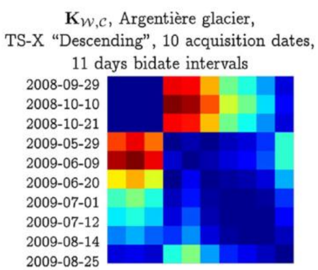
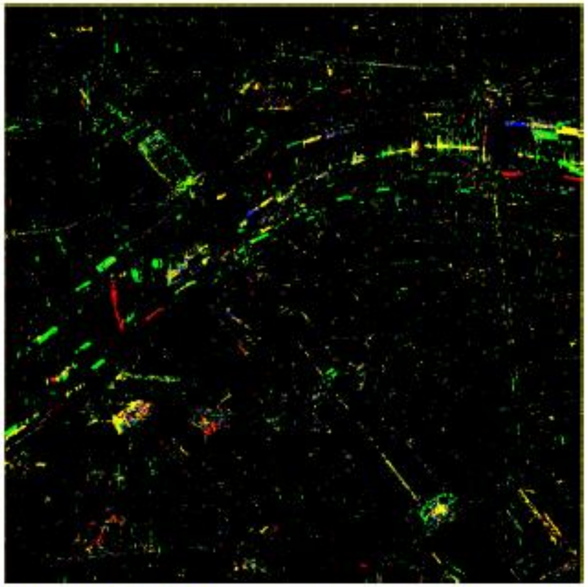


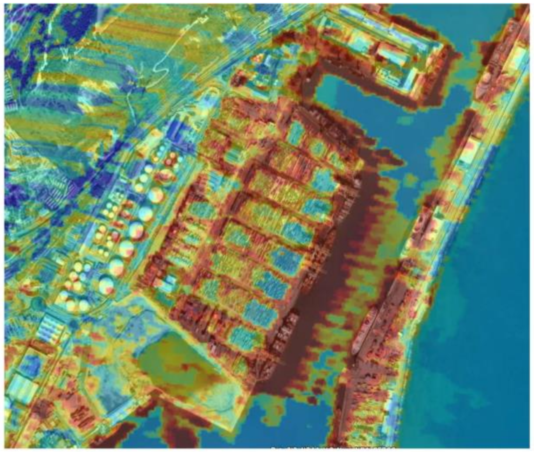
Fig. 7. MDDM $K_{\mathcal{W},c}$ for a sequence of TS-X images acquired over Argentière glacier in descending orbit. Changes are abrupt (the first row of the KL MDDM has a step located at the acquisition date 4 whereas the second diagonal has a unique outlier located at date 4) and progressive (decay of semi-row sequences after acquisition date 4). Images are with size 3072 × 4864.

Multi-date divergence matrix [Atto et al. 2013]



red: step change, green: impulse change, blue: cycle change, yellow: complex change

NORCAMA likelihood ratio change matrix clustering [Su et al. 2015]



Temporal PolSAR BTP [Alonso-Gonzales et al. 2014] [Alonso-Gonzales et al 2015]*

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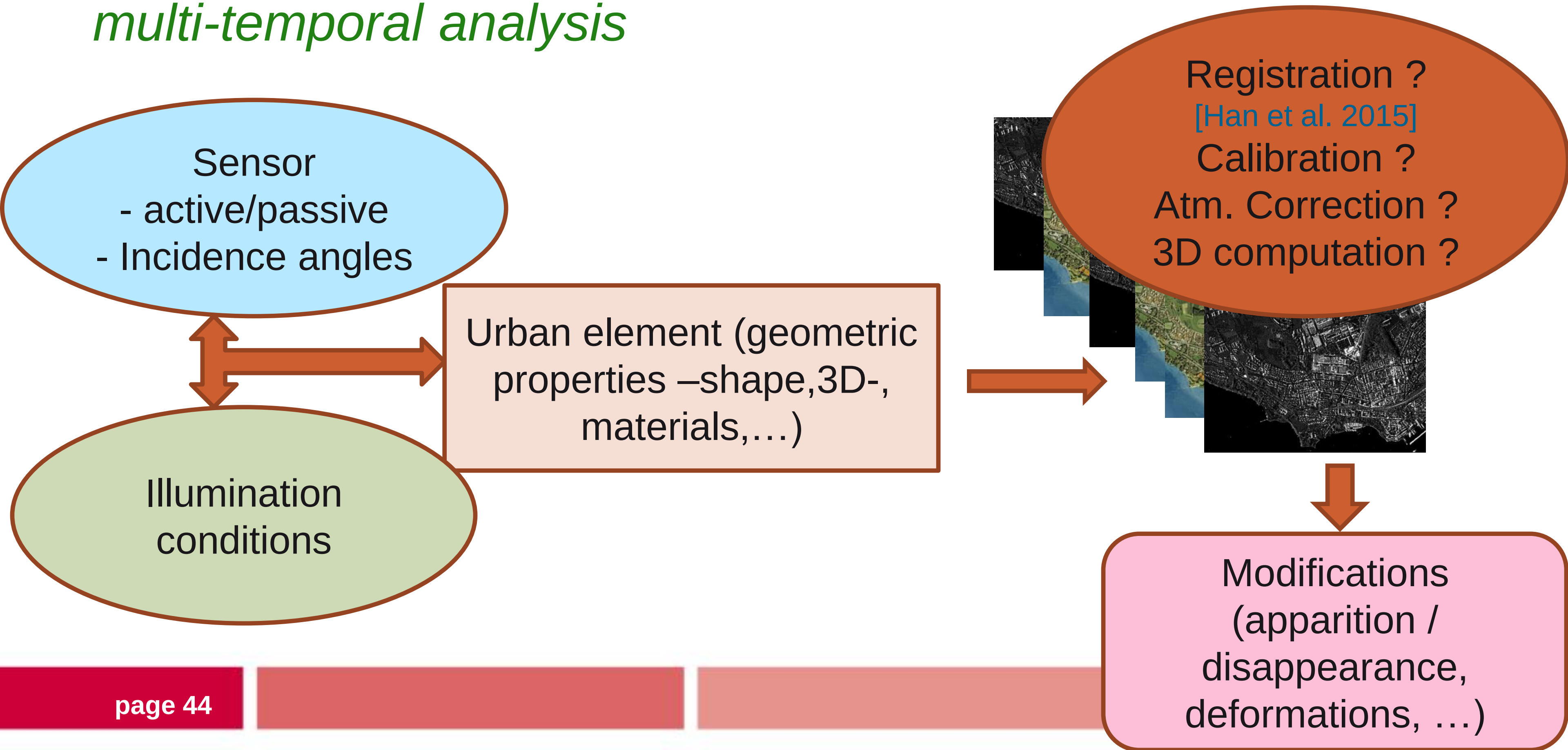
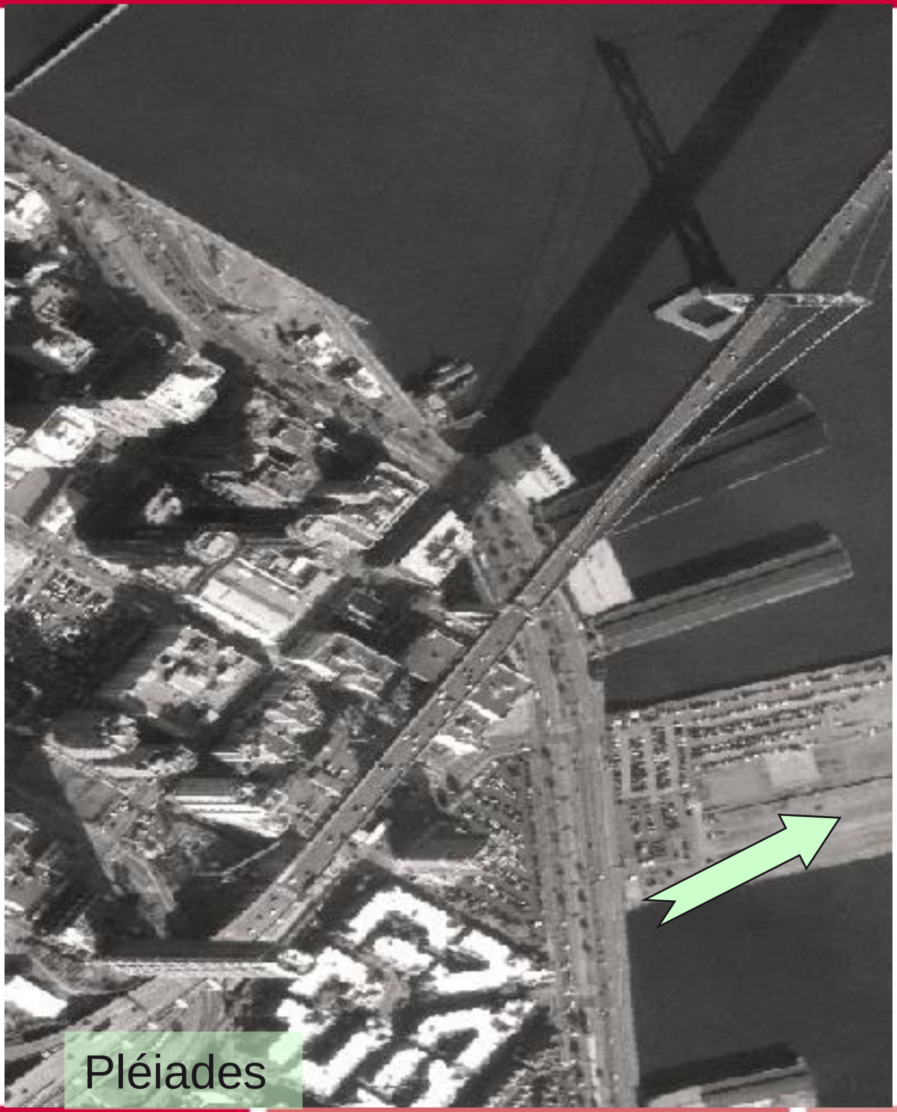
Time series analysis

- **SITS analysis :**
  - Mono-sensor
  - *Multi-angles and / or multi-sensors: still a main challenge of multi-temporal analysis*

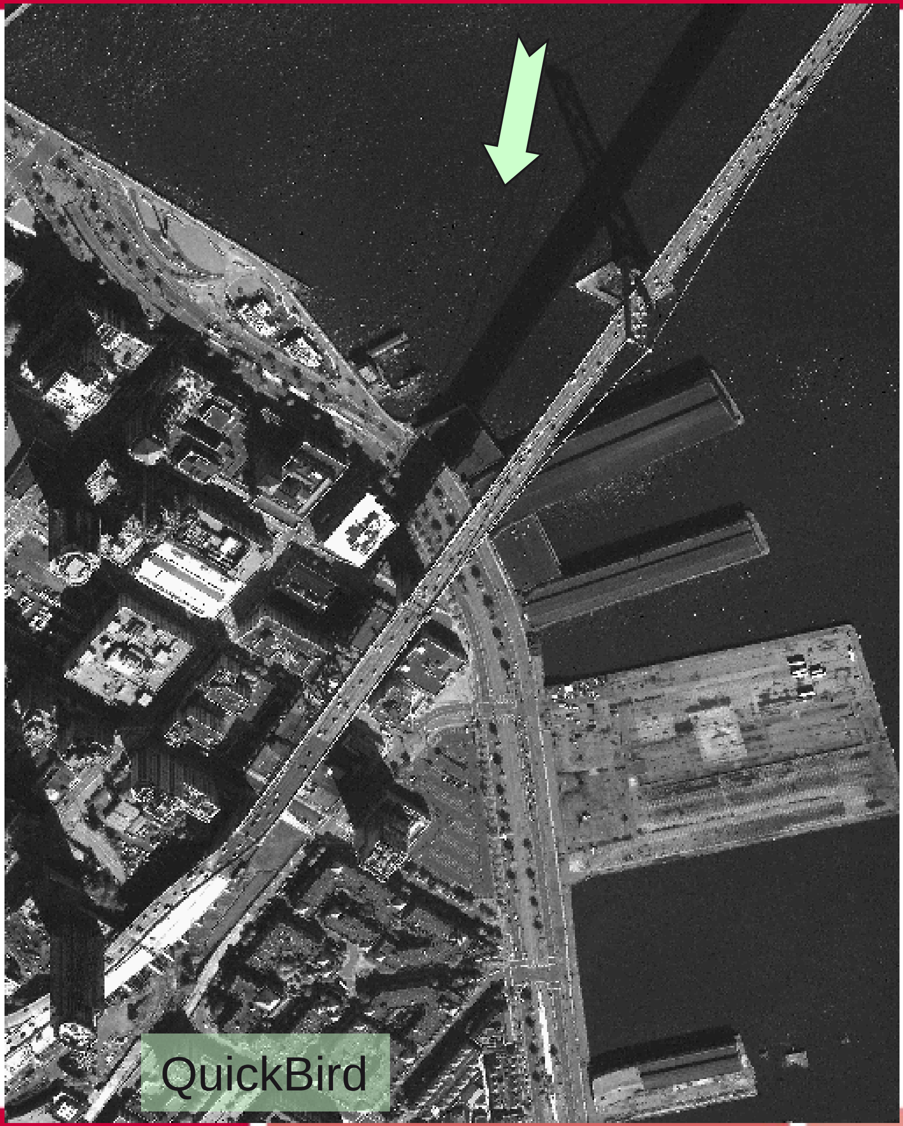



Orbview

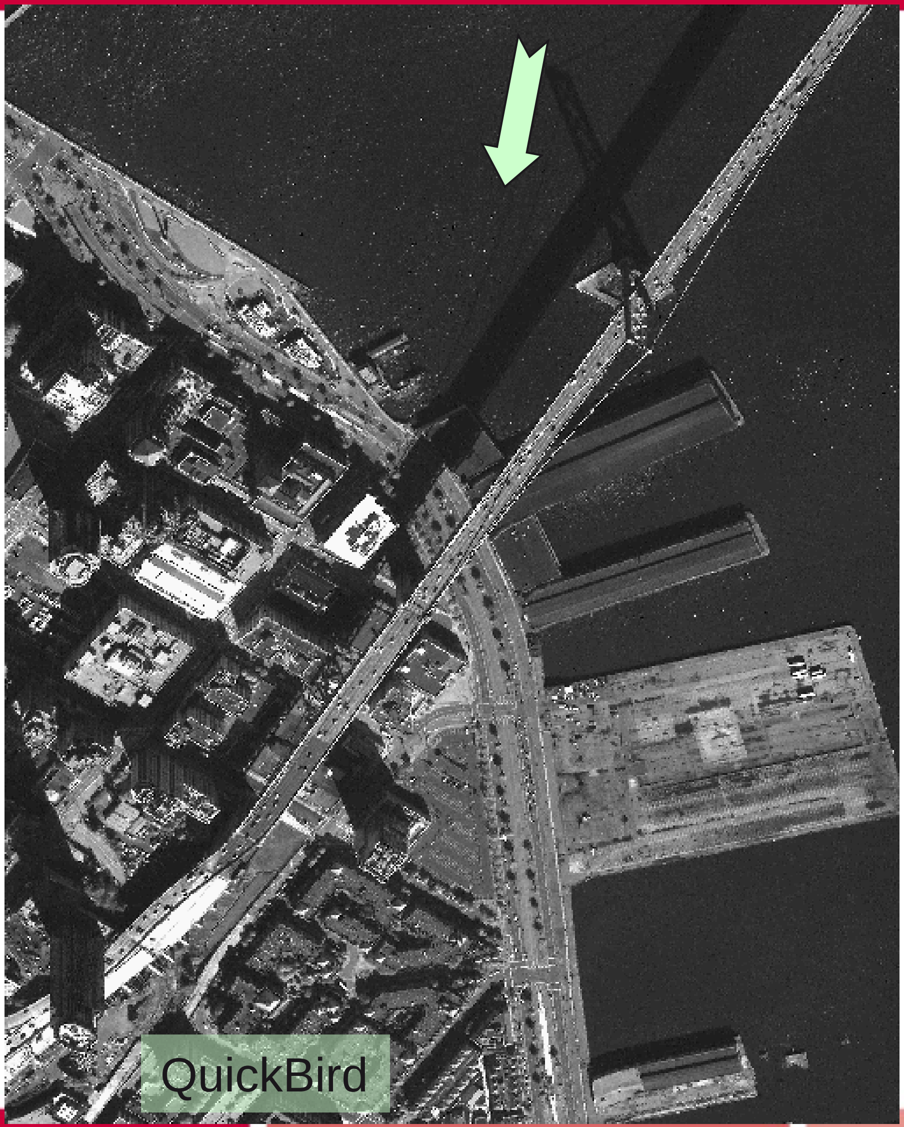

WorldView

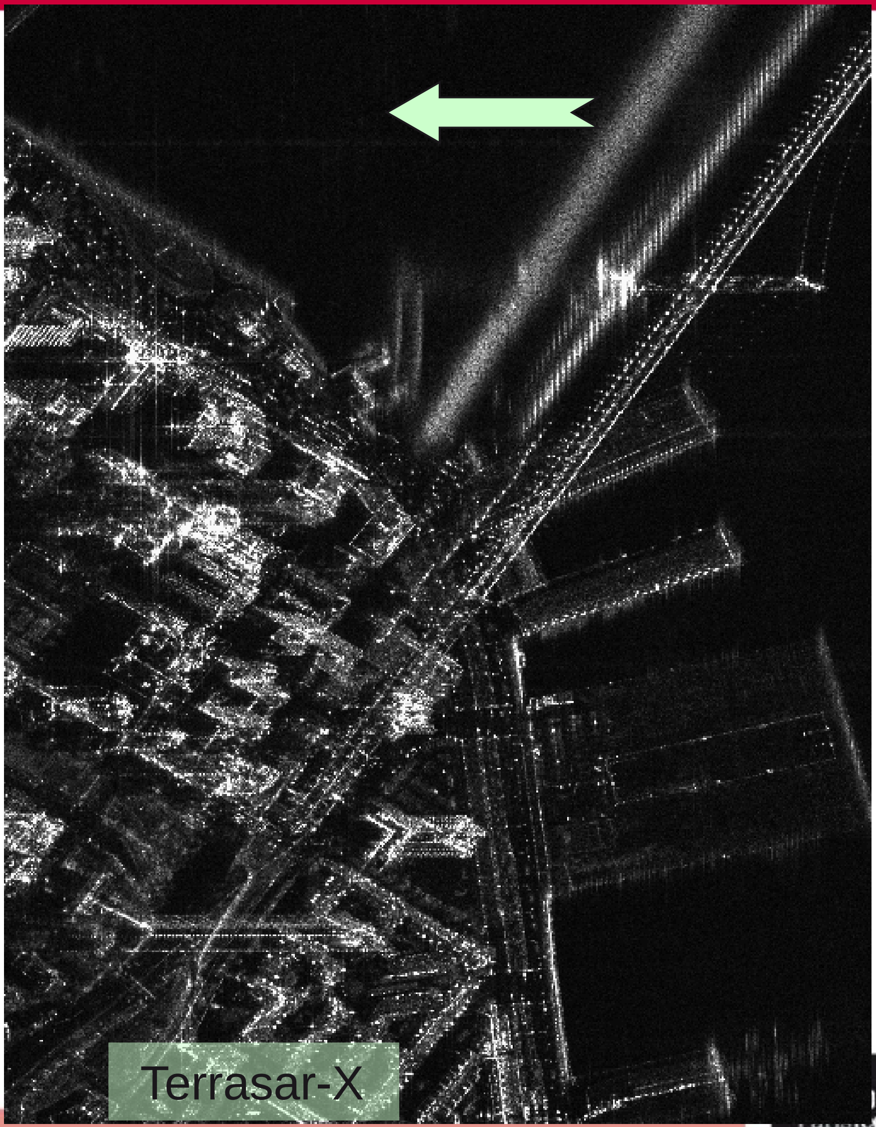

Pléiades


WorldView


QuickBird


WorldView


QuickBird


Terrasar-X

Overview

- Remote sensing data for urban area analysis and monitoring
- State of the art and challenges for urban areas
- Advanced methods to face new needs

Advanced methods

- **Time signal modeling**
  - Huge data sequences :
    - dimensionality reduction
    - non-stationarity modeling

- **Space image modeling**
  - Huge size images :
    - Patch-based modeling (GMM, FoE, …)
    - Parcimonious decompositions [Lobry et al. 2015]
    - Graph-based representations [Pham et al. 2015]
    - Object-level (spatial relationship modeling, knowledge based models …)

Advanced methods

Learning

- Approaches with increased efficiency ?
  - Deep learning
  - Active learning
  - Manifold alignment [Tuia et al. 2014]

Data mining approaches

- Adaptation to urban areas ?
  - Group frequent Sequential Patterns [Julea et al. 2011]
  - Dynamic Time Warping similarity measures [Petitjean 2012]
  - Graph-based kernel comparison [Réjichi et al. 2015]

Conclusion and perspectives

- **Still many challenges to be faced:**
  - Compression / storage
  - Combination of heterogenous data
  - Exploitation of past archives

- **Progress in many areas**
  - Learning
  - Image and signal modeling

- **Towards reproducible research ?**
  - OTB, IPOL, open source codes
  - IEEE GRSS Image Analysis and Data Fusion TC

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