Urban Remote Sensing Applications

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Outline

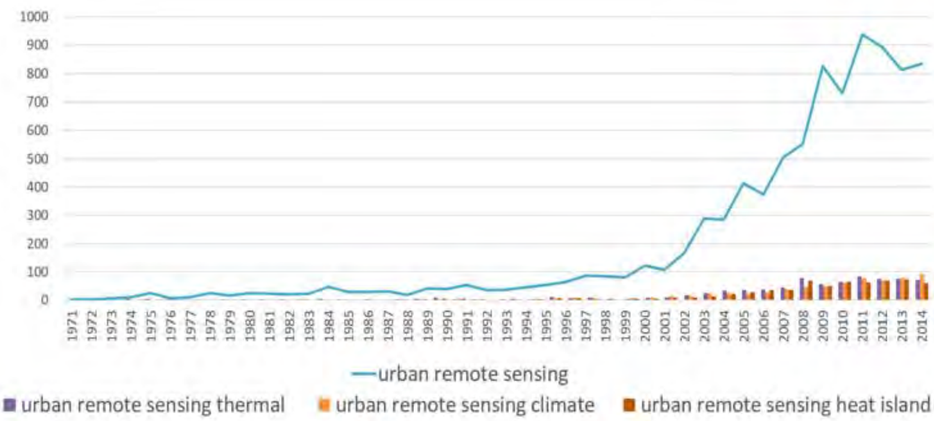
- Introduction
- EO products:
  - ✓ Urban Surface Morphology
  - ✓ Urban Surface Cover
  - ✓ Urban Surface Albedo and Temperature
- EO-based Applications:
  - ✓ Urban Planning
  - ✓ Urban Environmental Security
  - ✓ Urban Air Quality
  - ✓ Urban Metabolism
- EO Trends and Synergies

Introduction

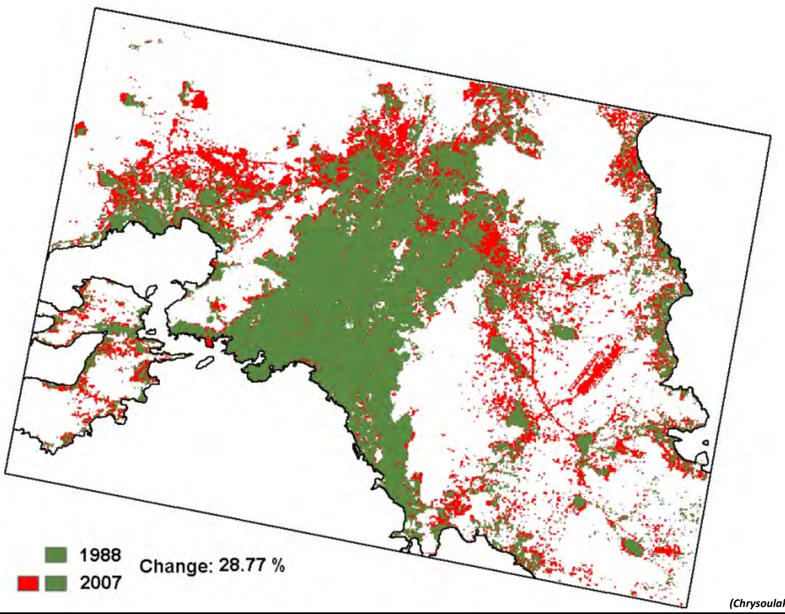
- **10 reasons** why cities hold the key to climate change and global health

(The Guardian 2015)

Introduction



Introduction



(Chrysoulakis et al. 2013)

Introduction

Commercial

Industrial

Transportation

High-density residential

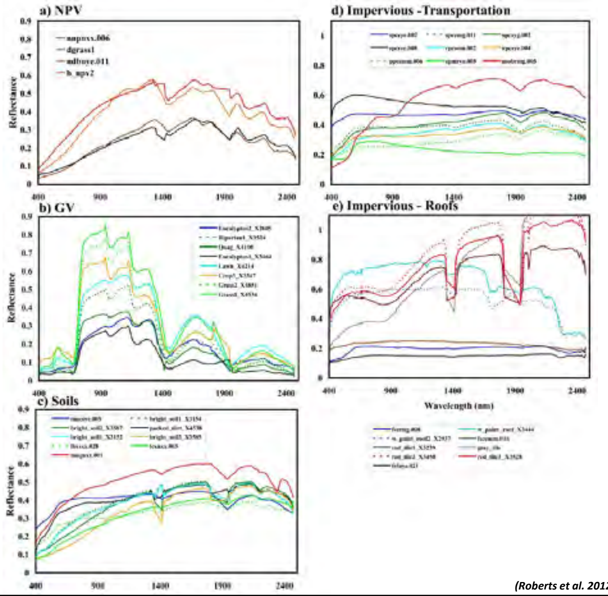
Med-density residential

Low-density residential

(Weng 2010)

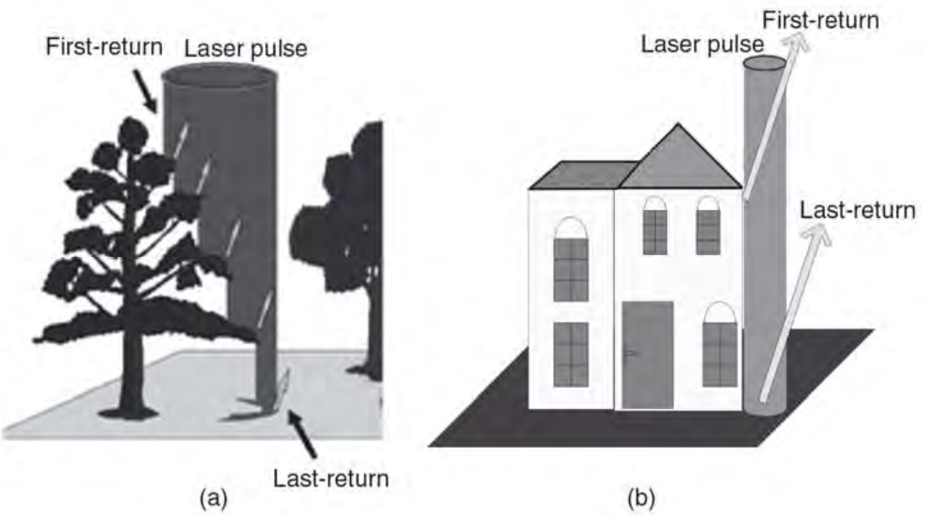
Introduction

- Spectral signature



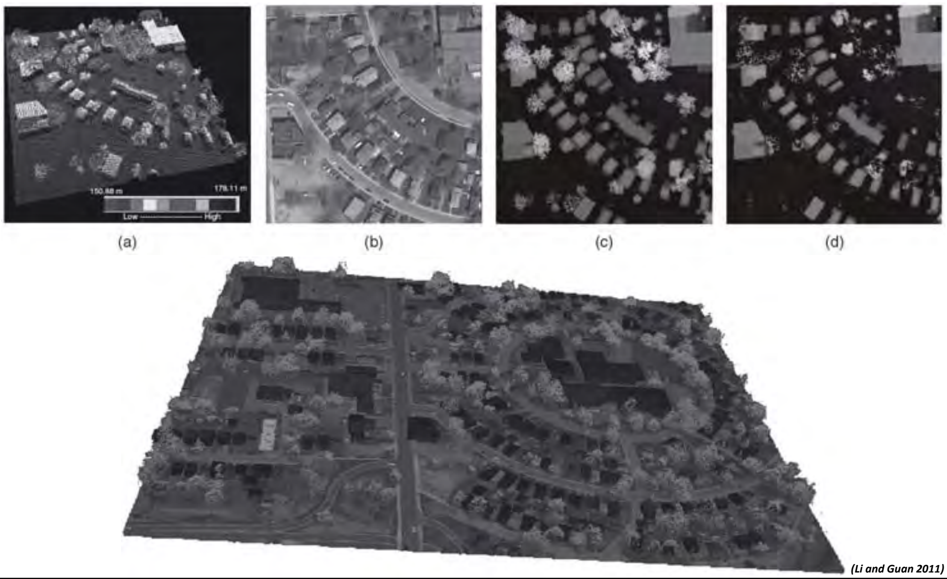
(Roberts et al. 2012)

Urban surface morphology



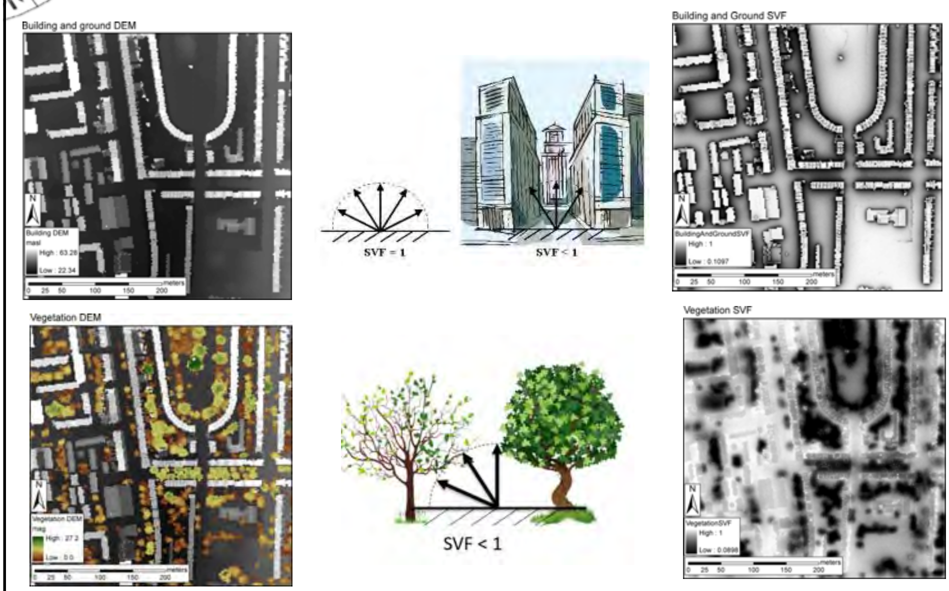
(Li and Guan 2011)

Urban surface morphology



(Li and Guan 2011)

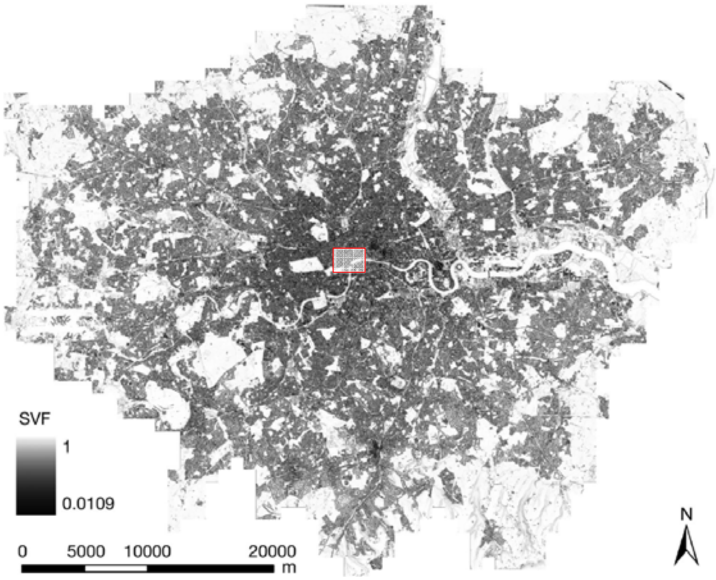
Urban surface morphology



(Lindberg and Grimmond 2010)

Urban surface morphology

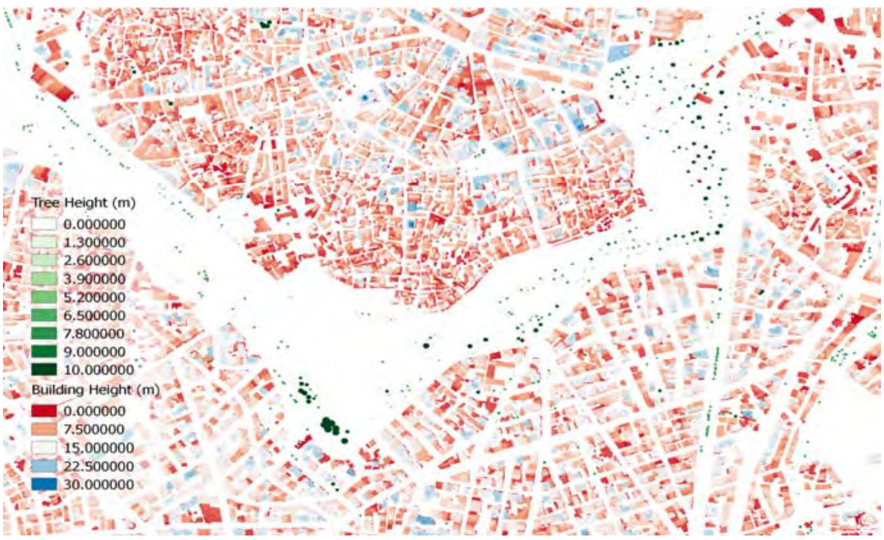
- SVF:



(Lindberg and Grimmond 2010)

Urban surface morphology

- Building + trees



Urban surface morphology

- **Plan Area Fraction (λ_p)** is computed by dividing building plan a rea (A_p) by total plan area (A_T).

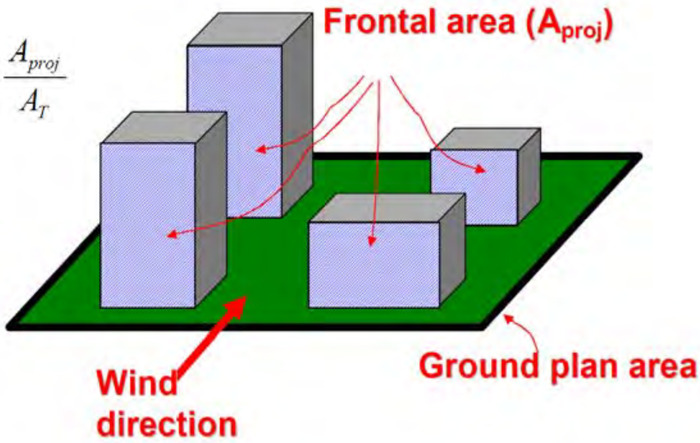
$$\lambda_p = \frac{A_p}{A_T}$$

(Burian et al. 2002)

Urban surface morphology

- **Building Frontal Area Index (λ_f)** . The frontal area (A_{proj}) is the total area of the faces exposed to the oncoming wind.

$$\lambda_f(\theta) = \frac{A_{proj}}{A_T}$$

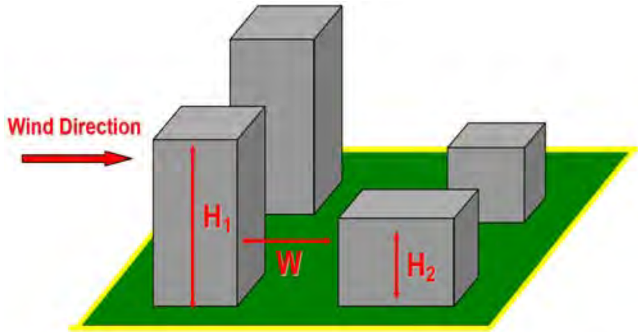


(Burian et al. 2002)

Urban surface morphology

- **Canyon Aspect Ratio (λ_S):** the ration of the average height and the distance between the two buildings (H_1 is the height of the upwind building, H_2 is the height of the downwind, S_{12} is the distance between them).

$$\lambda_S = \frac{(H_1 + H_2)/2}{S_{12}}$$



(Burian et al. 2002)

Urban surface morphology

- λ_S: affects surface air flow and radiational heating/cooling.

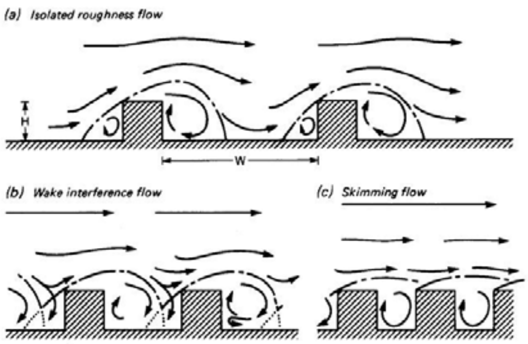


Fig. 1. The flow regimes associated with air flow over building arrays of increasing H/W.

(Oke 1988)

Urban surface morphology

- **Aerodynamic Roughness Parameters:** displacement height (z_d) and roughness length (z_0).
- z_d can be conceptualized as **the height of a surface formed by distributing** the aggregate volume of roughness elements and their wake re-circulation cavities uniformly over the underlying surface.
- z_0 is directly related to **the overall drag of the surface**. It represents the distance above the displacement height plane at which the velocity goes to zero.

(Burian et al. 2002)

Urban surface morphology

$$\frac{z_d}{z_H} = 1 - \left\{\frac{1-\exp\left[-(c_{d1}2\lambda_f)^{0.5}\right]}{(c_{d1}2\lambda_f)^{0.5}}\right\}$$

$$\frac{z_o}{z_H} = \left(1-\frac{z_d}{z_H}\right)\exp\left(-k\frac{U}{u_*}+\psi_k\right)$$

$$\frac{u_*}{U} = \min\left[(c_S + c_R\lambda_f)^{0.5}, \left(\frac{u_*}{U}\right)_{\max}\right]$$

z_H is the average building height, ψ_k is the roughness sublayer influence function, U and u* are the large-scale wind speed and the friction velocity, respectively, c_S and c_R are drag coefficients for the substrate surface at height z_H in the absence of roughness elements and of an isolated roughness element mounted on the surface, respectively, and c_{d1} is a free parameter and k is the von Kármán constant (0.4).

Suggested values: $\psi_k = 0.193$, $(u^*/U)_{max} = 0.3$, $c_S = 0.003$, $c_R = 0.3$, and $c_{d1} = 7.5$.

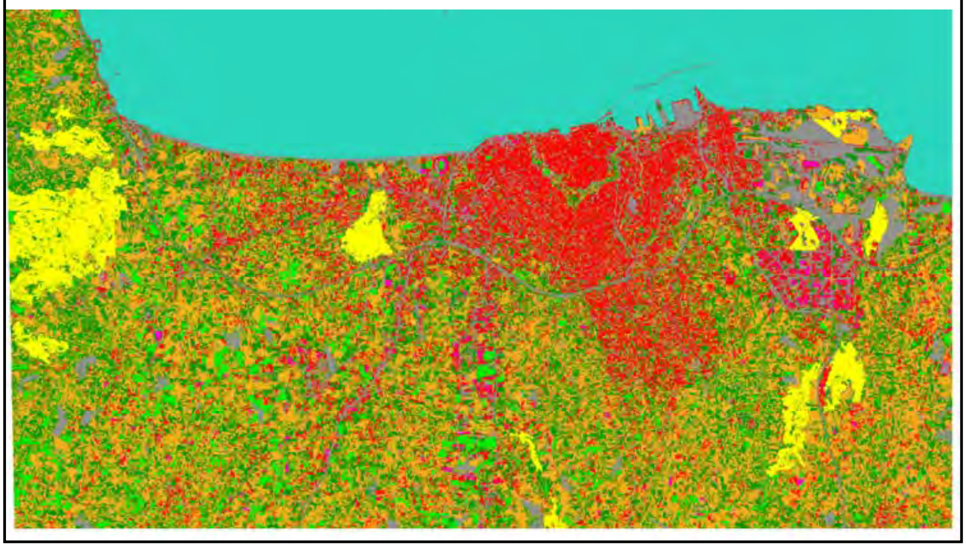
(Burian et al. 2002)

Urban surface cover

- GEOBIA - segmentation:
  a) Over-segmentation;
  b) correct segmentation;
  c) Under-segmantation.

(a) (b) (c) *(Deay et al. 2014)*

Urban surface cover



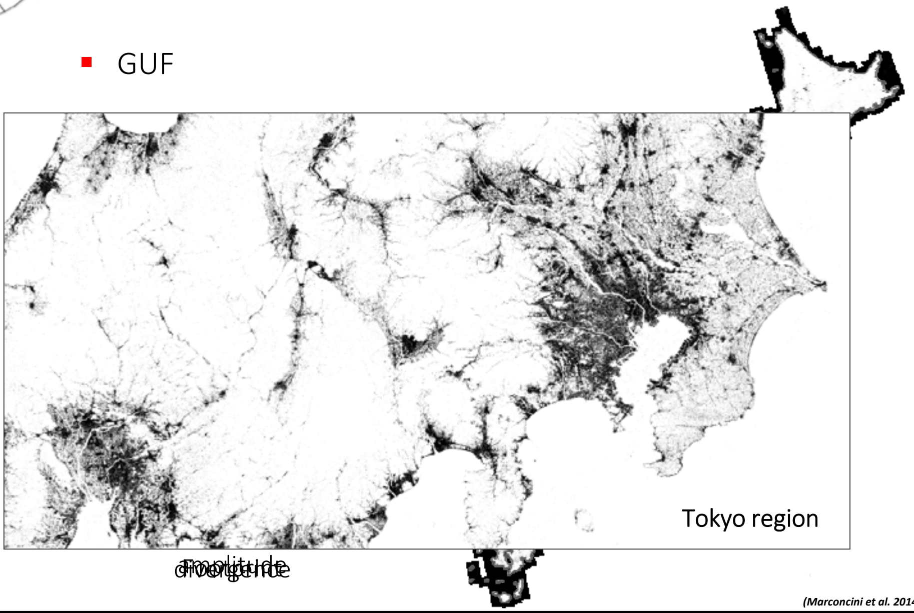
Urban surface cover

- Global Urban Footprint (**GUF**):
  - ✓ Worldwide inventory of human settlements, using one global coverage of SAR data with 3 m ground resolution collected by the satellites TerraSAR-X / TanDEM-X.
  - ✓ Analysis of 182.249 images (308 TB), processing and management of >20 million data sets.
  - ✓ Output is binary settlement mask with spatial resolution of 0.4'' (12m) for scientific and commercial use.
  - ✓ Release of public domain GUF with ~2.8'' (84m) spatial resolution for any non-profit use in 2016.

(Esch et al. 2015)

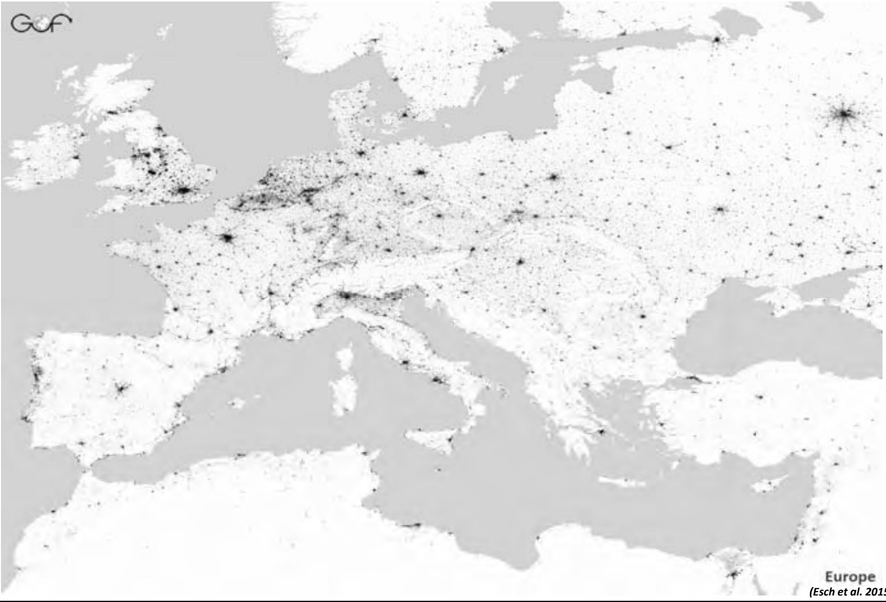
Urban surface cover

- GUF



(Marconcini et al. 2014)

Urban surface cover



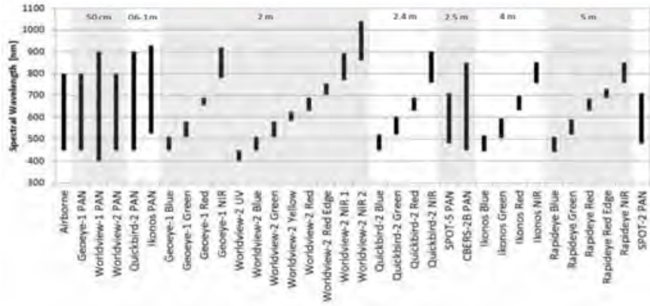
Urban surface cover

- Global Human Settlement Layer (**GHSL**):
  - ✓ Fine-scale, global, open and free-access data
  - ✓ Any sensor input data and fully automated classification engine design
  - ✓ Land cover / use integration with environmental, socio-economical and census data
  - ✓ Information supporting policies
    - ➢ Information for action, policy
    - ➢ Evidence-based policy support
  - ✓ Indicators for international frameworks
    - ➢ Sendai (DRR), SDGs, Clima

(Pesaresi et al. 2015)

Urban surface cover

- GHSL



50Millions km^2

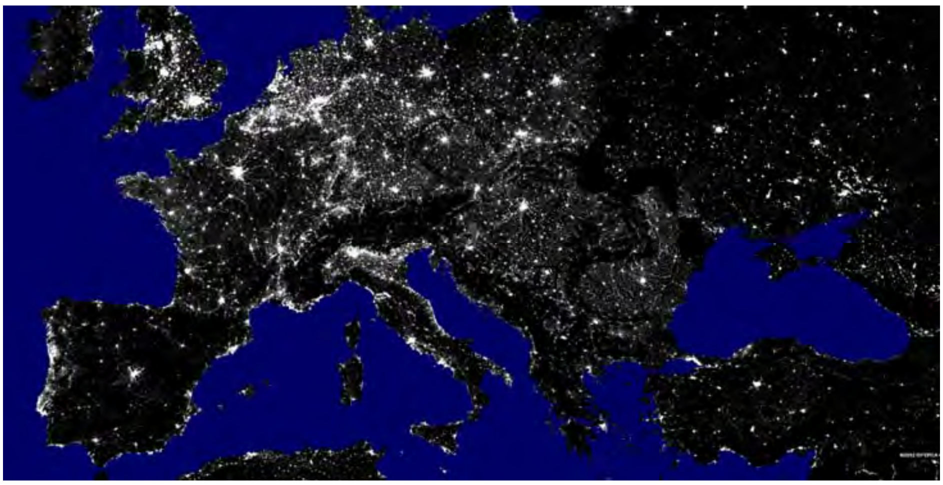
Large set of sensors under test

Input resolution 0.5m – 10m

(Pesaresi et al. 2015)

Urban surface cover

- GHSL



(Pesaresi et al. 2015)

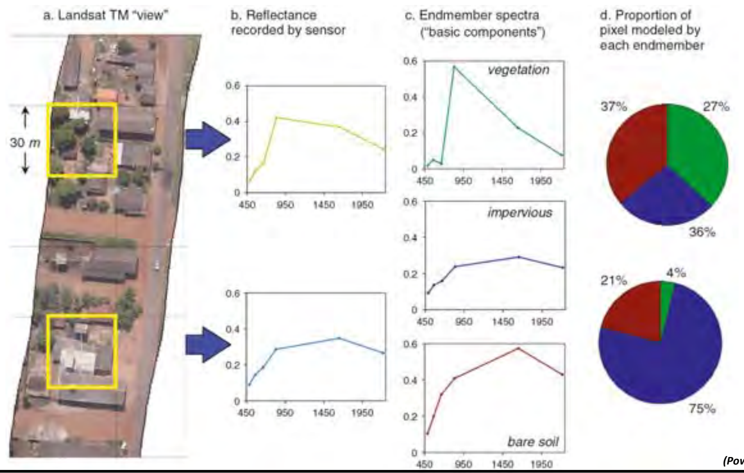
Urban surface cover

Level 1	Level 2: Land cover types	Level 3: Material types	Level 4: Surface materials
Man-made/artificial surfaces	Buildings/roofs	Mineral materials	Asbestos *Bitumen roof sheeting* *Clay tiles* Concrete slabs Concrete tiles *Fiber cement* Glass *Gravel* Slate
		Metallic materials	*Aluminum* Copper *Zinc* *Steel with protective coating* Corrugated metal sheet *Lead* Gold leaf Tin
		Hydrocarbon materials	*Coated corrugated metal sheet (PVC, Polyethylene, coating color)* *Polyvinylchloride (PVC)* *Polyethylene (PE)* *Polyisobutylene (PIB)* *Plexiglas* *Tar Paper*
		Biomass materials	*Green roof* Thatched roof Wood shingles
	Artificial open spaces	Partially impervious surfaces	*Cinder* *Clay-baked paving stones* *Cobblestone pavement* *Concrete paving stones* *Gravel* Grass pavers *Loose chippings* *Railway tracks*
		Fully impervious surfaces	*Asphalt* Concrete *Flagstone (Granite)* *Synthetic turf* *Tartan*
		Water bodies with artificial bottom	*Pool* Garden pond

(Roessner,et al. 2011)

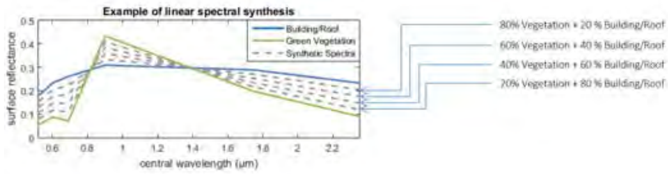
Urban surface cover

- Output of SMA: a set of images representing the fractional cover of endmembers and an image that summarizes the difference between the modeled and measured spectrum.

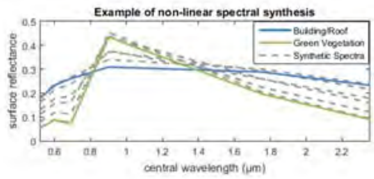


(Powell 2011)

Urban surface cover



$$\rho_i = \sum_{j=1}^{M} a_j(i) \cdot \rho_j$$



$$\rho_i = \sum_{j=1}^{M} a_j(i) \cdot \rho_j + \sum_{j=1}^{M} \sum_{l=j}^{M} b_{j,l}(i) \cdot \rho_j \rho_l$$

Urban surface cover

$$R_i = \sum_{k=1}^{n} a_k R_{ik} + \mathrm{ER}$$

$i = 1, \ldots, p$ spectral band

p the number of bands

n The number of end-membrs

R_{ik} the spectral response of the end-member k in channels n

ER the error of the model

$$\begin{bmatrix} R_1 \\ \vdots \\ R_p \end{bmatrix} = \begin{bmatrix} R_{11} & \cdots & R_{1n} \\ \vdots & \ddots & \vdots \\ R_{p1} & \cdots & R_{pn} \end{bmatrix} \begin{bmatrix} a_1 \\ \vdots \\ a_k \end{bmatrix} + ER$$

Observation spectra

Spectral response of end-member 1

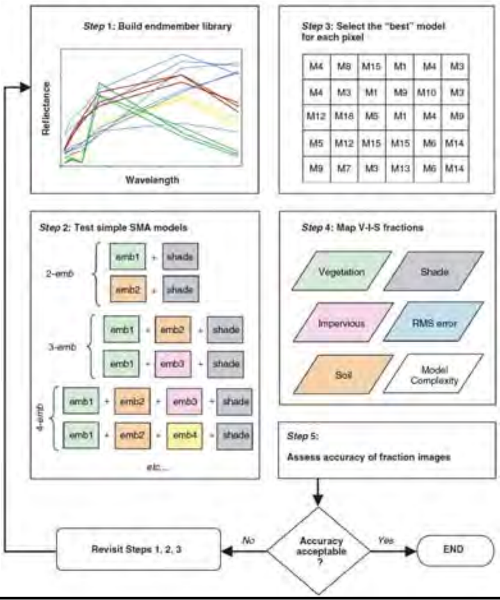
abundances

Constraints:

$$\sum_{k=1}^{n} a_k = 1$$

$$a_k \geq 0 \text{ για } k = 1, \ldots, n$$

Urban surface cover

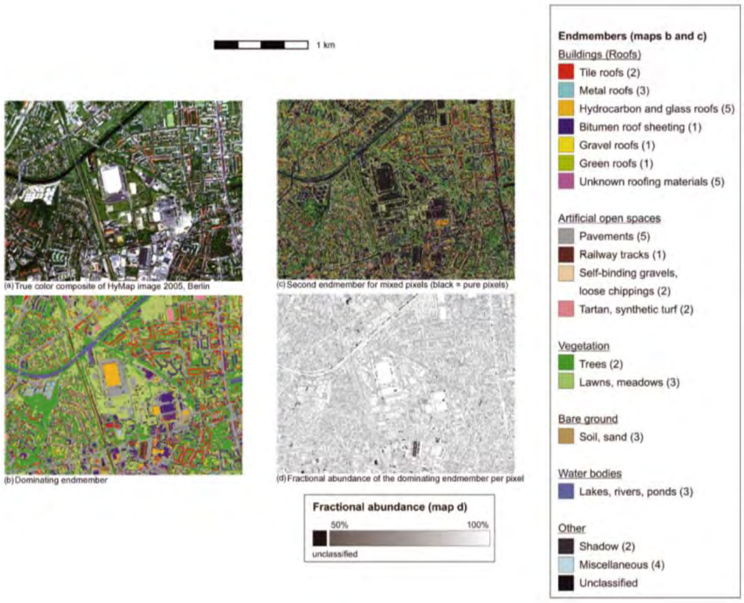


(Powell 2011)

Urban surface cover

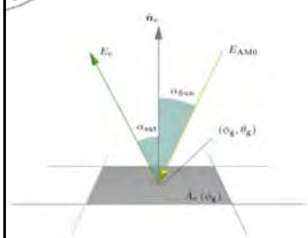
Level 1	Level 2	Level 3	Level 4	...
Built-up	Bright materials	Buildings/roofs	Concrete, Tar	
			Tiles (red/grey)	
	Dark materials	Transportation areas	Gravel, Asphalt	
			Metal	
		Other built surfaces	Sport areas (artificial)	
			...	
Vegetation	Green vegetation	Tree	Deciduous Tree	
		Herbaceous	Evergreen Tree	
	Non-photosynthetic vegetation (NPV)		Coniferous Tree	
			...	
Non-urban bare surface	Bare soil	Red soils		
		Grey soils		
	Bare rock	Sand		
Water bodies	Natural/quasi-natural water bodies			
	Swimming pools			

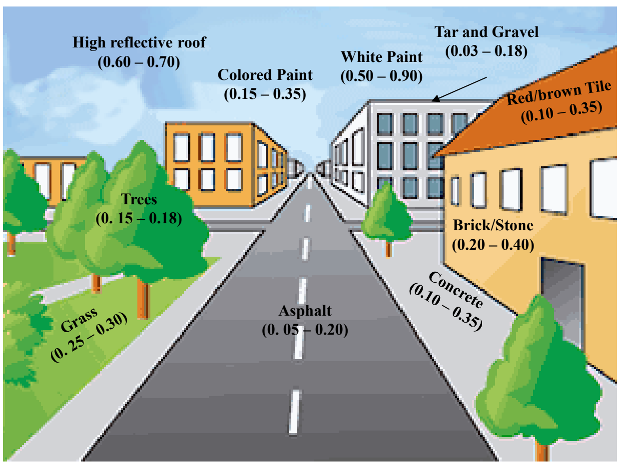
Urban surface cover



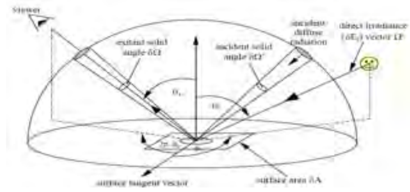
(Roessner,et al. 2011)

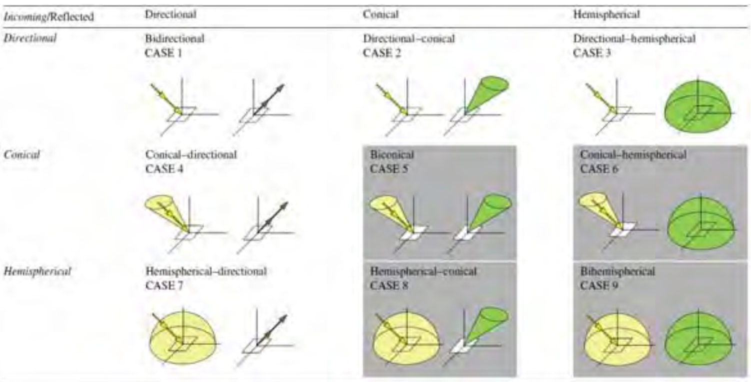
Urban surface albedo





Urban surface albedo



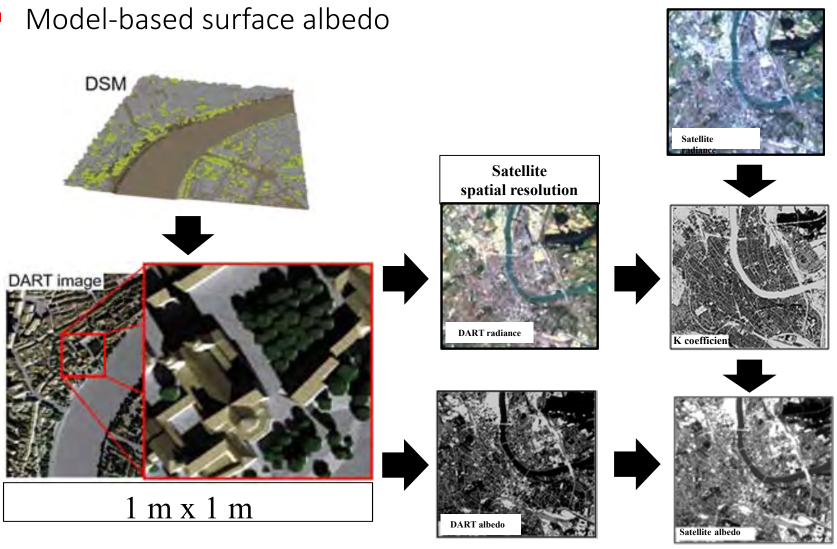


Incoming/Reflected	Directional	Conical	Hemispherical
Directional	Bidirectional CASE 1	Directional–conical CASE 2	Directional–hemispherical CASE 3
Conical	Conical–directional CASE 4	Biconical CASE 5	Conical–hemispherical CASE 6
Hemispherical	Hemispherical–directional CASE 7	Hemispherical–conical CASE 8	Bihemispherical CASE 9

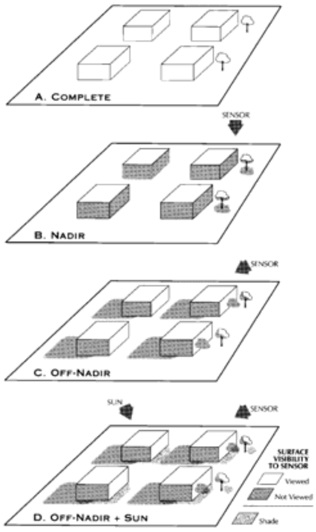
(Schaepman-Strub et al. 2006)

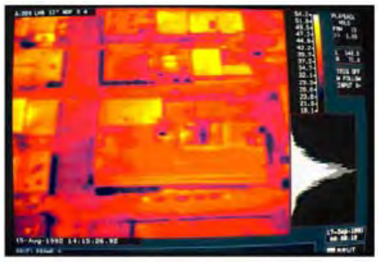
Urban surface albedo

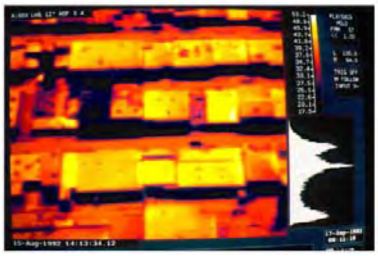
- Model-based surface albedo



Surface temperature







(Voogt and Oke 1998)

Surface temperature

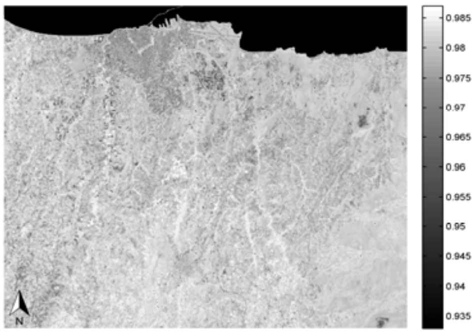
$$L_i^{sat} = \int_{\lambda_1}^{\lambda_2} f_i(\lambda)\varepsilon(\lambda)B(\lambda,T_S)\tau(\lambda)d\lambda + \int_{\lambda_1}^{\lambda_2}\int_{p=0}^{p_s} f_i(\lambda)B(\lambda,T_p)\frac{d\tau}{dp}\,d\lambda\,dp$$

$$+\ 1/2\int_{\lambda_1}^{\lambda_2}\int_{\theta=0}^{\pi/2}\int_{\phi=0}^{2\pi}(1-\varepsilon(\lambda))f_i(\lambda)L^{\propto}(\lambda,\theta,\phi)\tau(\lambda)\sin 2\theta\,d\lambda\,d\theta\,d\phi$$

- λ wavelength; i channel; λ_1, λ_2 lower/upper limits of spectral range;
- f_i normalized channel response function;
- θ zenith angle, ϕ azimuth angle;
- p pressure, p_s pressure at Earth's surface;
- τ(λ) spectral atmospheric transmissivity;
- ε(λ) surface spectral emissivity; T_S surface temperature;
- $L^{\propto}$(λ,θ,ϕ) downwelling irradiance divided by π;
- T_p mean air temperature at pressure level p.

Surface temperature

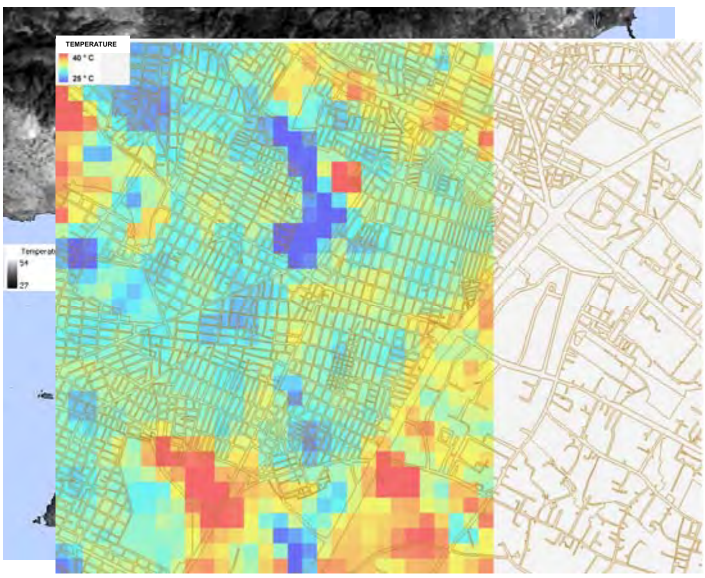
- Emissivity based on **fractional land cover**:
  - ✓ Linear Spectral Mixture analysis
  - ✓ Constraint using mean absolute deviations
  - ✓ End members selection.
  - ✓ Emissivity assignment to each end member.



  - ✓ Emissivity estimation as: $\varepsilon = \sum_{k=1}^{n} \varepsilon_k \cdot f_k$

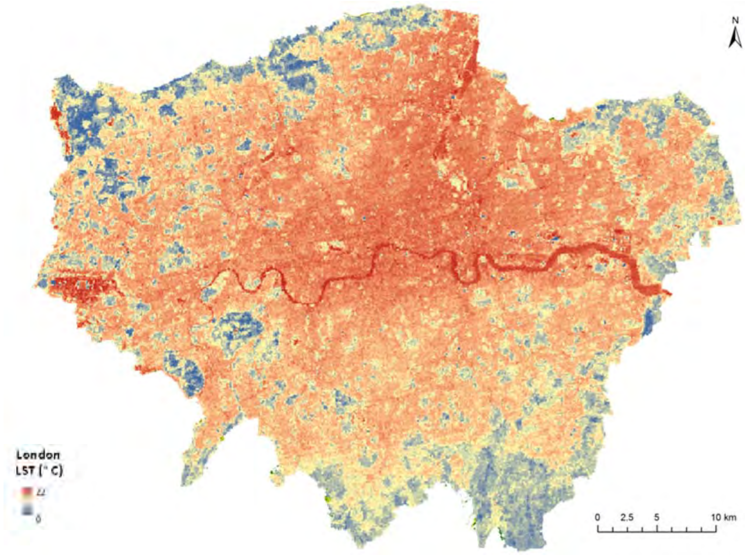
(Mitraka et al. 2012)

Surface temperature



(Chrysoulakis et al. 2011)

Surface temperature

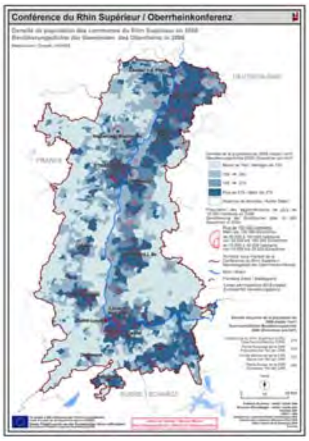


Urban Planning

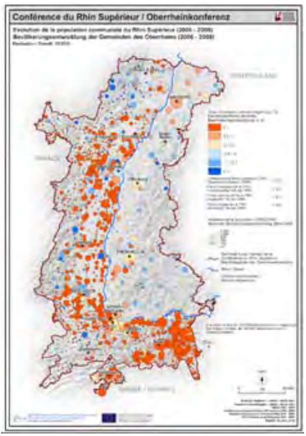
- All the available EO data on many case studies is useless, if the link between the EO scientists and the urban planning community is missing.

Urban Planning

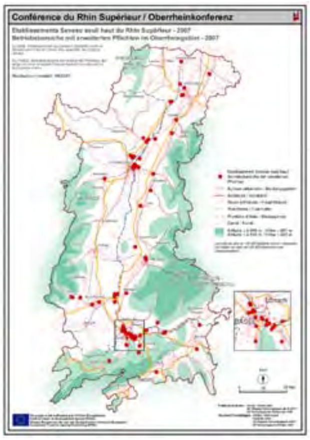
- The **GEOURBAN** Project: *http://geourban-fp7-eranet.com*
- EO is particularly important at the regional scale:



Population Density



Population Evolution



SEVESO Companies

Urban Planning

EO Data

↓

EO Products

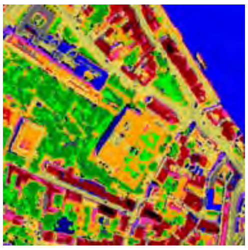
↓

EO-based Indicators

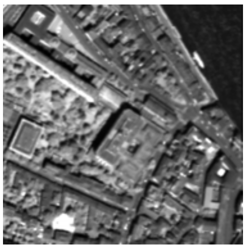
- The main EO products
  - ✓ DEM/DSM
  - ✓ Buildings height and density
  - ✓ Land cover
  - ✓ Fractional land cover
  - ✓ Albedo
  - ✓ Emissivity.
  - ✓ LST
  - ✓ AOT

Urban Planning

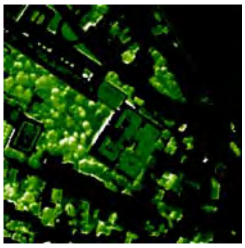
surface material classification



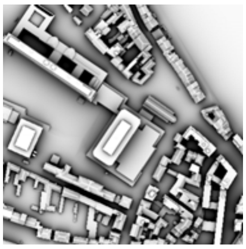
broadband albedo



vegetation indices

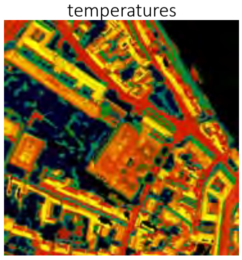


SVF



shortwave downward radiation (modelled)

Surface brightness temperatures

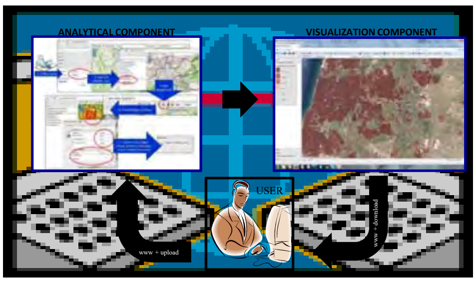


(Parlow et al. 2012)

Urban Planning

- The GEOURBAN Indicators and WIS

Categories of Indicators		Indicators
Urban Surface Structure	Density indicators	Built-up density
		Building density
		Open Space Density
		Green Space Density
	Area/Edge indicators	Edge Density
	Ratio indicators	Imperviousness-Open space ratio
		Imperviousness-Green space ratio
	Diversity indicators	Class Richness Density
		Ecological Effectiveness Ratio
Urban Surface Type		Imperviousness
		Fractional Land Cover
		Surface Albedo
		Surface Emissivity
Urban Sprawl		Urban Fringe
		Change Detection
Urban Environmental Quality		Surface Urban Heat Island
		Aerosol Optical Thickness
Vulnerability to hazards		Distance to critical services
Socioeconomics		Exposure to PM



- Follow-up: the SEN4RUS Project: *http://sen4rus.eu*

(Chrysoulakis et al. 2016)

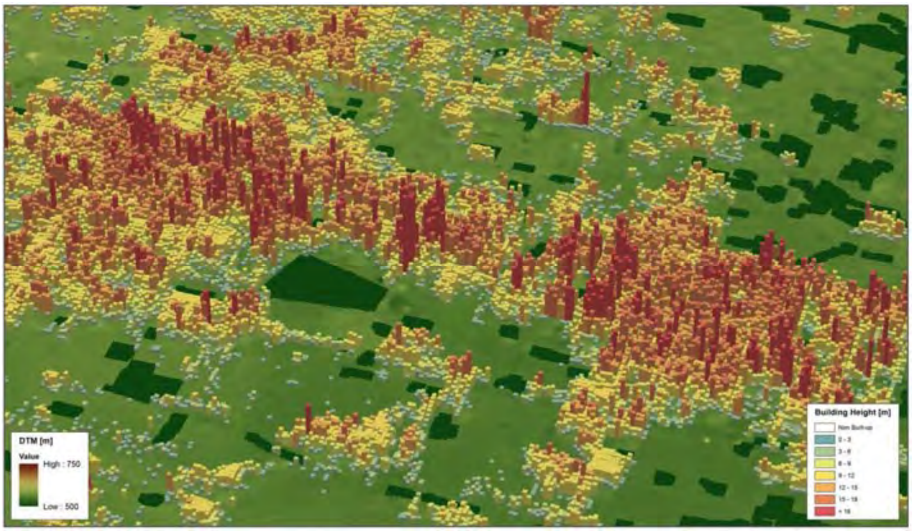
Urban Planning

- Indicators estimation:

(Marconcini et a. 2014)

Urban Planning

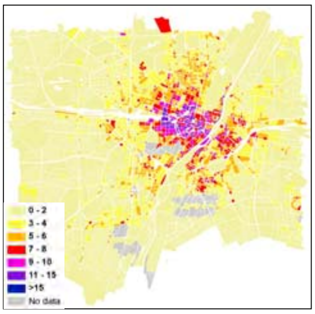
- Indicators examples:



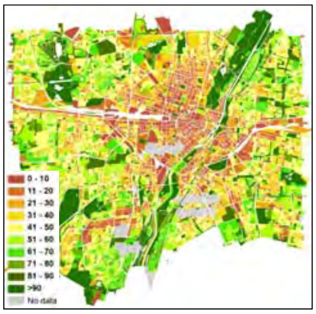
(Esch et al. 2012)

Urban Planning

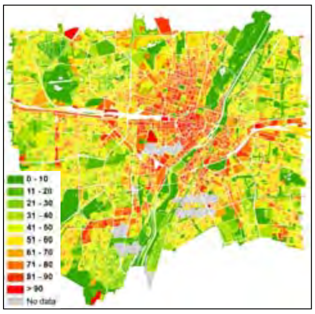
- Indicators examples:



Building volume [m³]



Vegetation density [%]



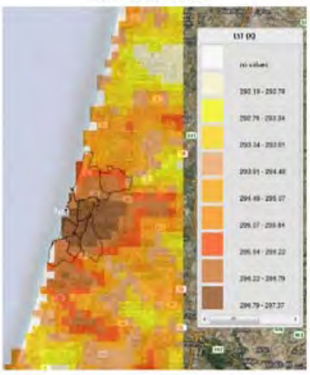
Impervious surface [%]

(Esch et al. 2012)

Urban Planning

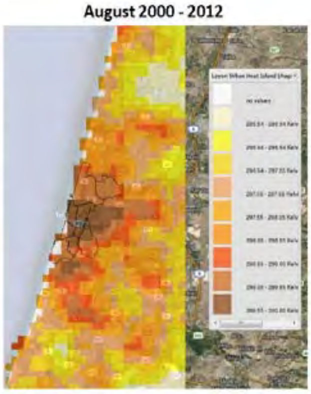
- Indicators examples:

June 2000 - 2012



July 2000 - 2012

August 2000 - 2012



(Triantakonstantis et al. 2015)

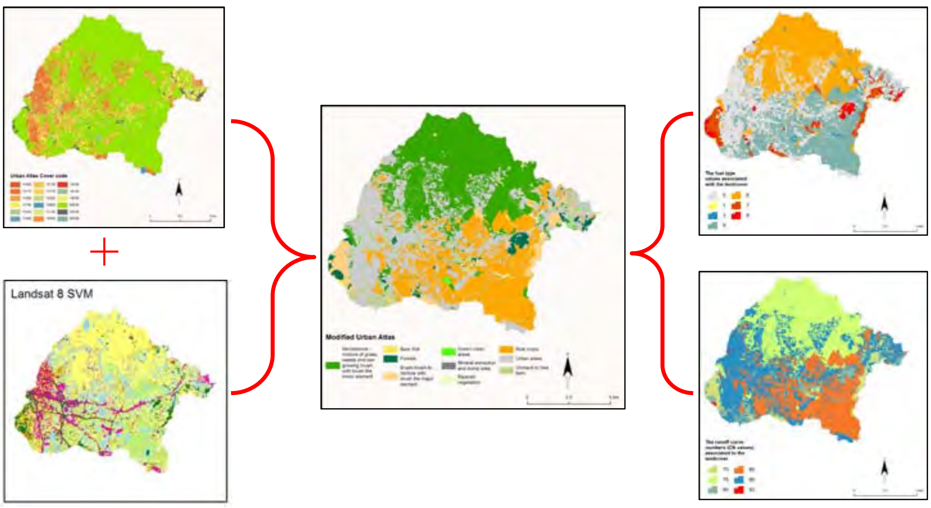
Urban Environmental Security

- The **FLIRE** Project: *http://flire.eu*

✓ Common base data are needed for the efficient planning and confrontation

✓ A DSS was developed for both wildfires and flash floods risk assessment and management.

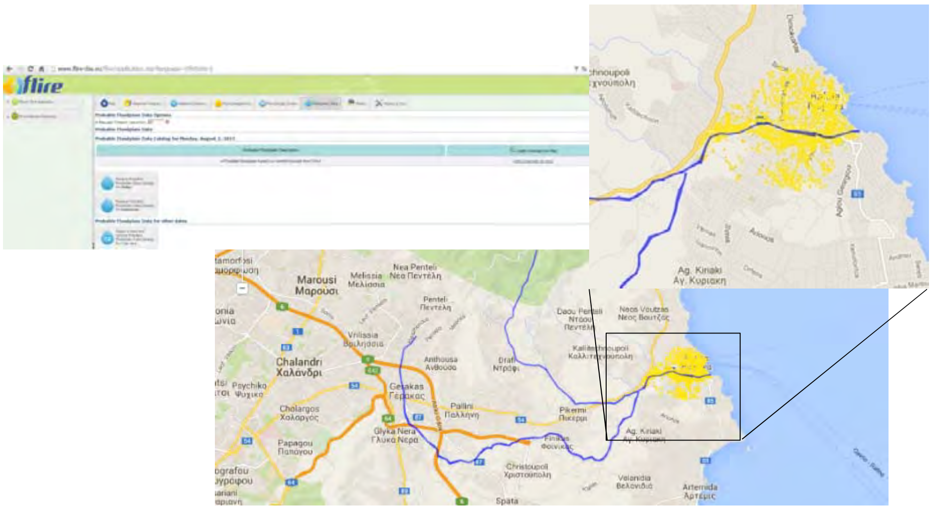
Urban Environmental Security



(Poursanidis et al. 2015)

Urban Environmental Security

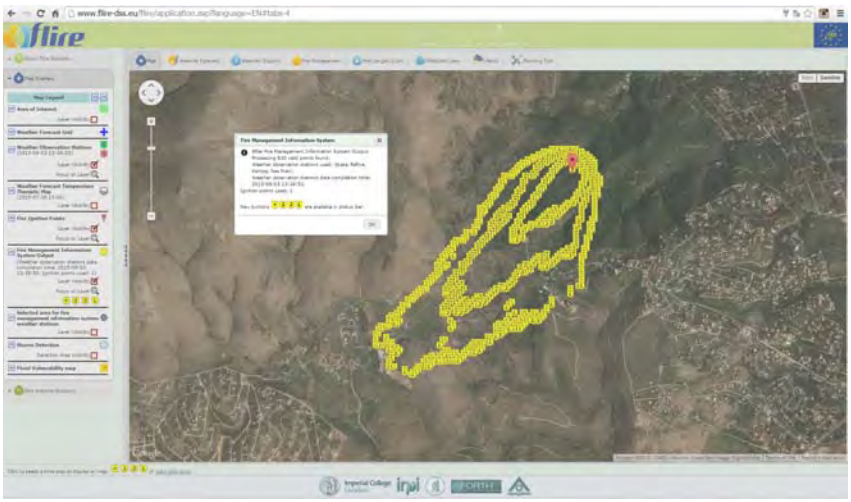
- Flood simulation example:



(Kochilakis et al. 2016)

Urban Environmental Security

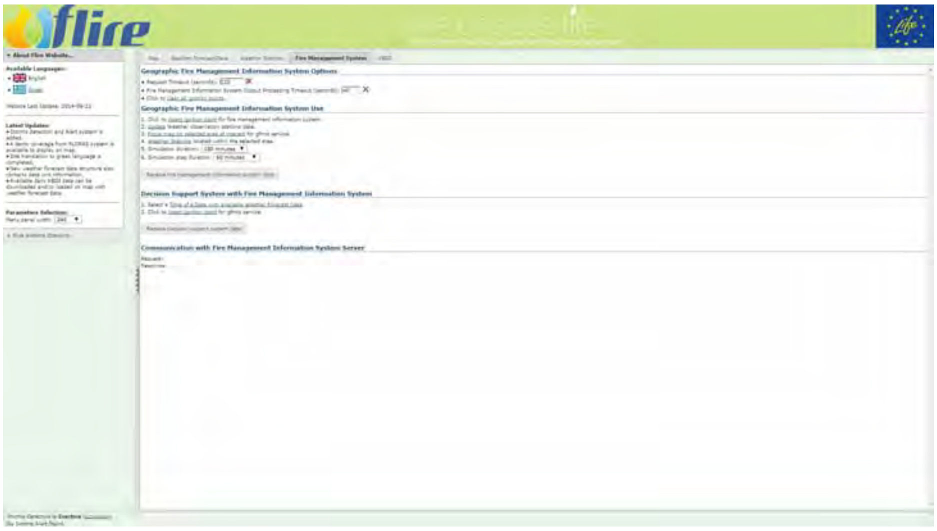
- Fire propagation example:



(Kochilakis et al. 2016)

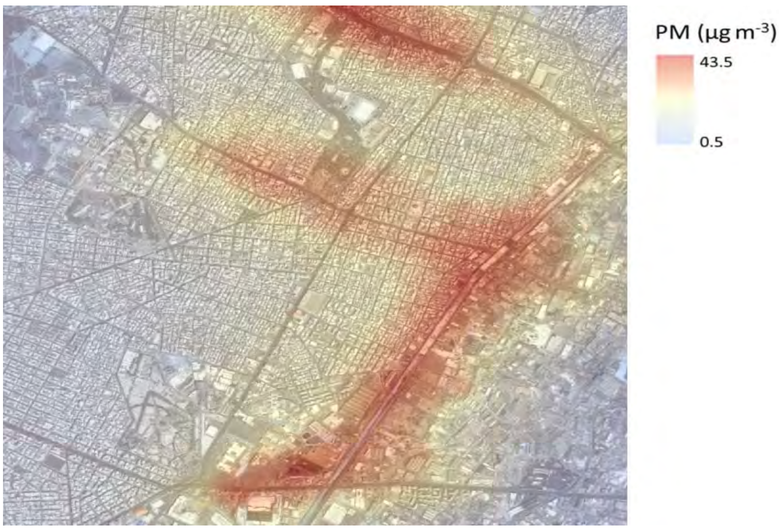
Urban Environmental Security

- The FLIRE **DSS** available at: *http://rslab.gr*



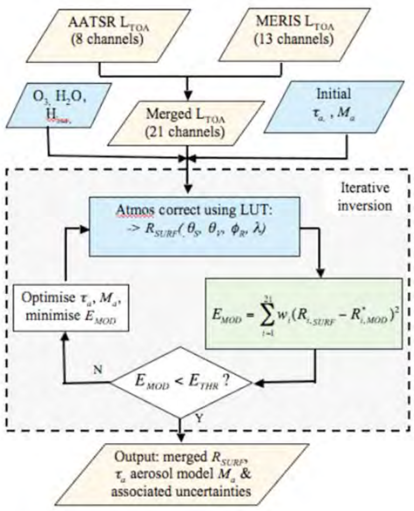
Urban Air Quality

- Air Quality Directive: PM10, PM2.5 thresholds.



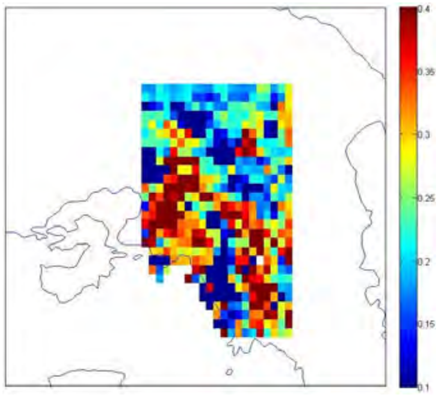
(Chrysoulakis et al. 2013)

Urban Air Quality



(North et al. 2009)

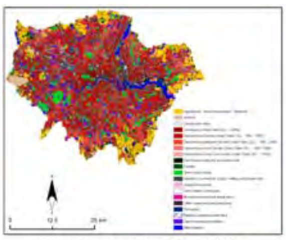
- Athens: mean AOT at 1 km x 1 km (2002 - 2012)



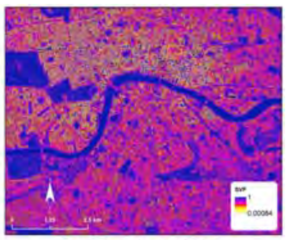
(Benas et al. 2012)

Urban Air Quality

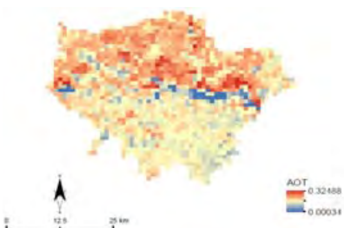
- Satellite Data Products
  - ✓ AOT – 1×1 km (MERIS/AATSR Synergy Algorithm)
  - ✓ Surface Temperature (STMP)
  - ✓ Surface Relative Humidity (RHUM)
  - ✓ K-Index (KIND)- estimator of atmospheric instability



Urban Atlas Land Use/Cover (LUC)



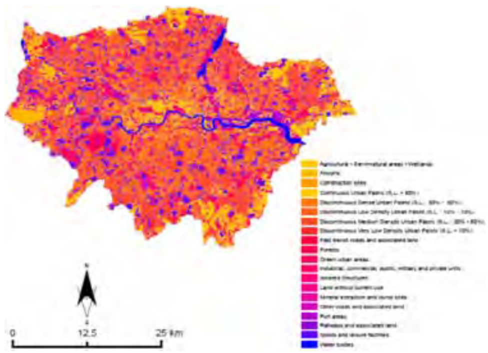
Sky View Factor (SVF)

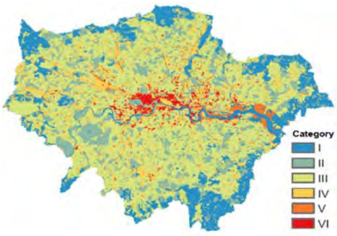


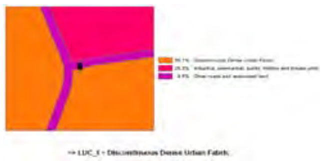
(Beloconi et al. 2016)

Urban Air Quality

Category	Land Cover Class
I	Agricultural - Semi-natural areas - Wetlands
	Forests
	Land without current use
	Water bodies
II	Sports and leisure facilities
	Discontinuous Very Low Density Urban Fabric (S.L. < 10%)
	Discontinuous Low Density Urban Fabric (S.L. : 10% - 30%)
	Green urban areas
III	Airports
	Discontinuous Medium Density Urban Fabric (S.L. : 30% - 50%)
	Discontinuous Dense Urban Fabric (S.L. : 50% - 80%)
IV	Construction sites
	Industrial, commercial, public, military and private units
	Isolated Structures
	Mineral extraction and dump sites
V	Fast transit roads and associated land
	Other roads and associated land
	Port areas
	Railways and associated land
VI	Continuous Urban Fabric (S.L. > 80%)

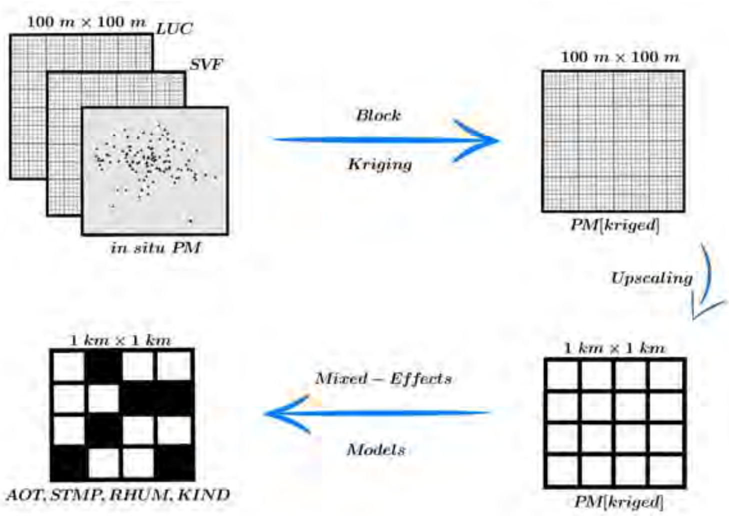






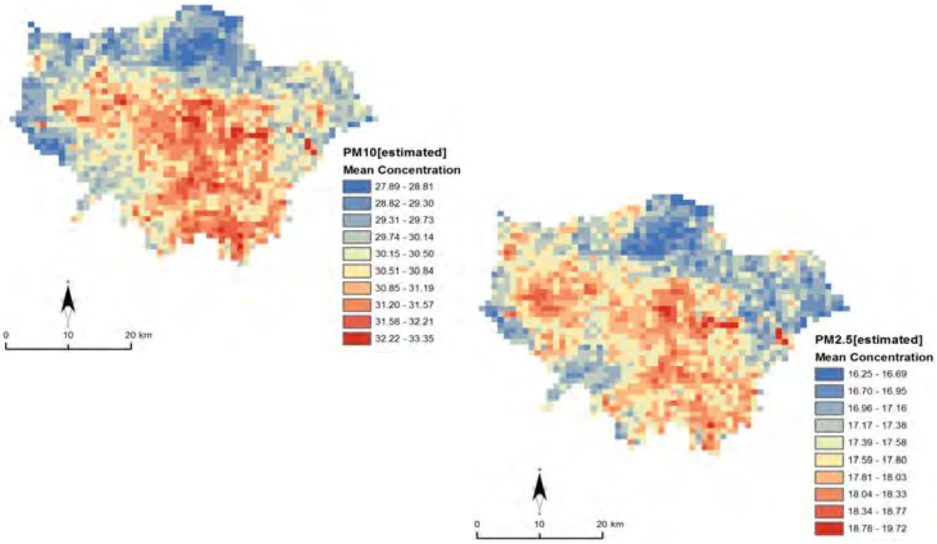
(Beloconi et al. 2016)

Urban Air Quality



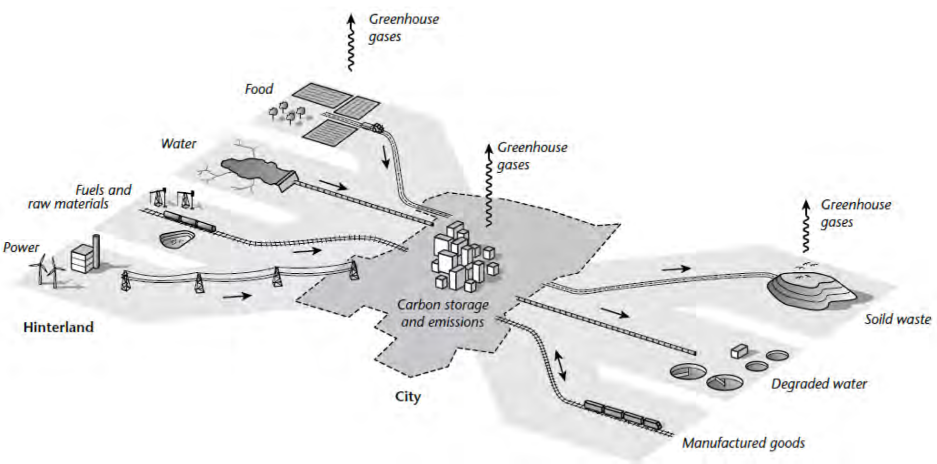
(Beloconi et al. 2016)

Urban Air Quality



(Beloconi et al. 2016)

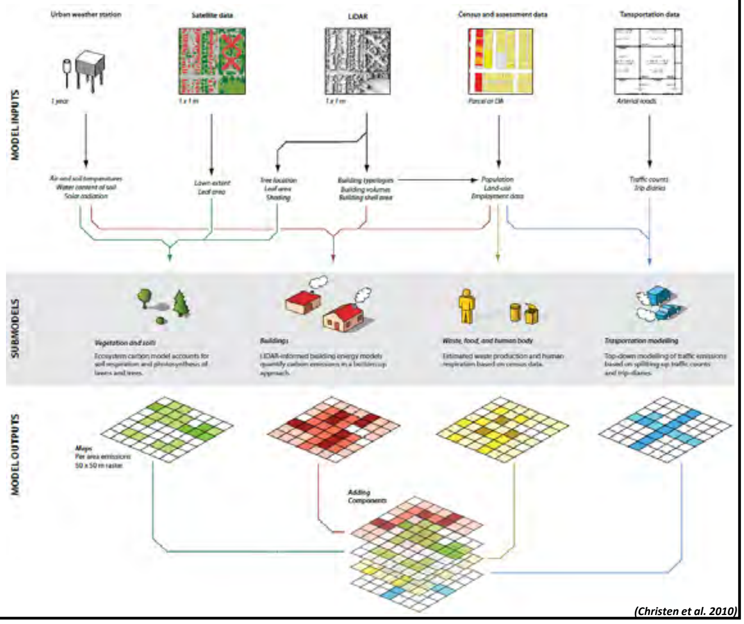
Urban metabolism



(Christen et al. 2010)

Urban metabolism

- Carbon emissions modelling



(Christen et al. 2010)

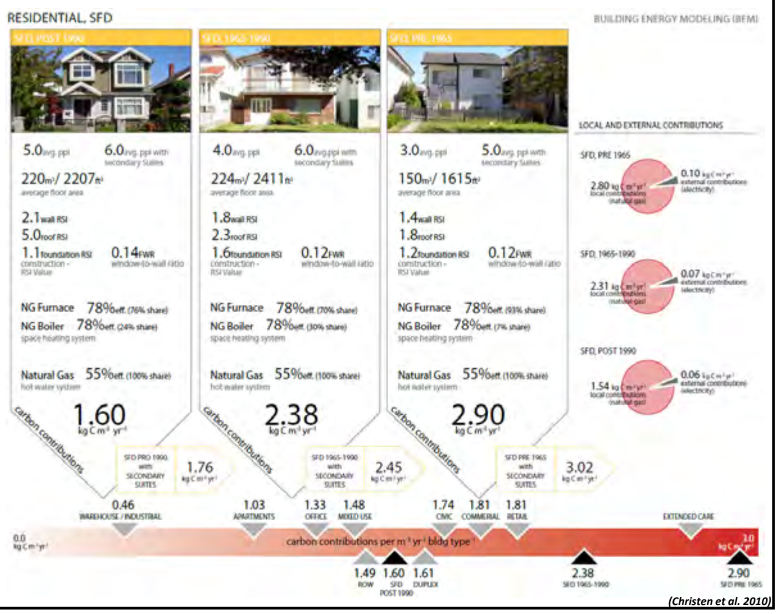
Urban metabolism

- Carbon emissions modelling

(Christen et al. 2010)

Urban metabolism

- Carbon emissions modelling

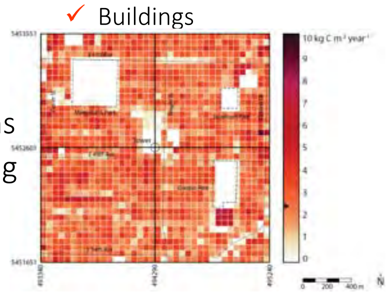


(Christen et al. 2010)

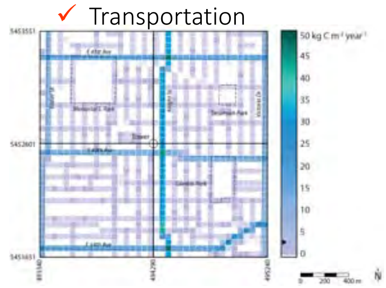
Urban metabolism

- Carbon emissions modelling

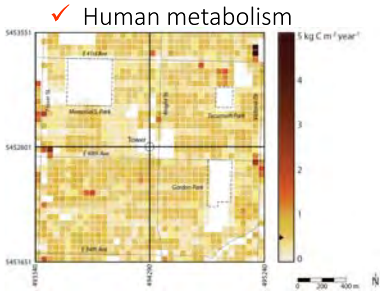
✓ Buildings



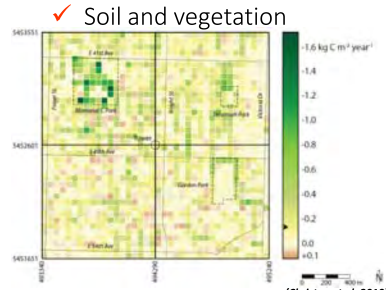
✓ Transportation



✓ Human metabolism



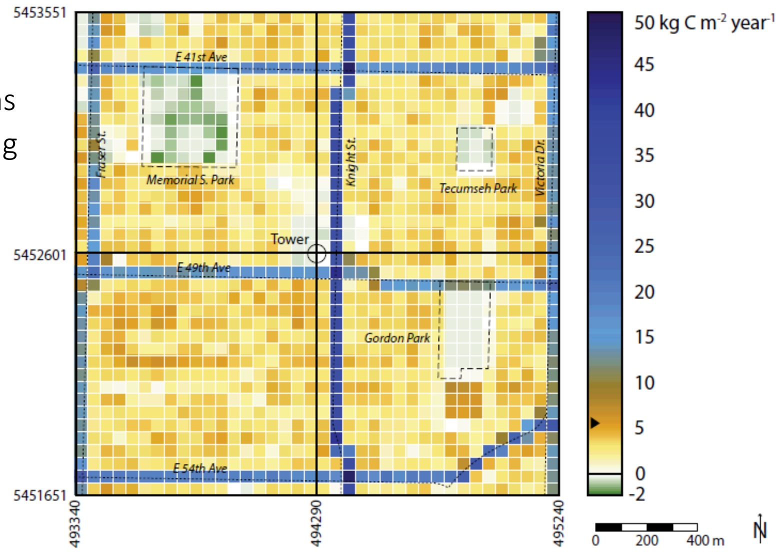
✓ Soil and vegetation



(Christen et al. 2010)

Urban metabolism

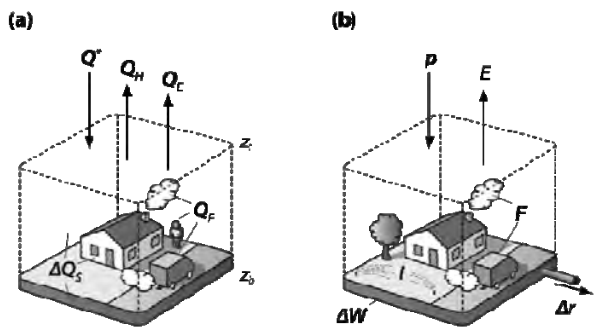
- Carbon emissions modelling



(Christen et al. 2010)

Urban metabolism

- The **BRIDGE** Project: *http://www.bridge-fp7.eu*



$Q^{*}+Q_F=Q_H+Q_E+\Delta Q_S$

$p+F+I=E+\Delta W+\Delta r$

$F_C+\Delta S=C+R_a-P$

(Chrysoulakis et al. 2013)

Urban metabolism

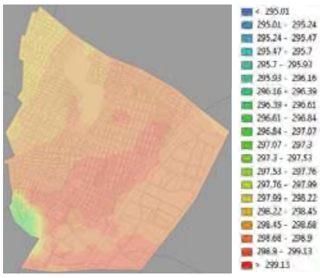
- The BRIDGE Project: Athens planning alternatives.

Apply cool materials on all buildings at Egaleo municipality and on roads	Change the land use of Eleonas from brownfield to built area	Change the land use of Eleonas from brownfield area to green space

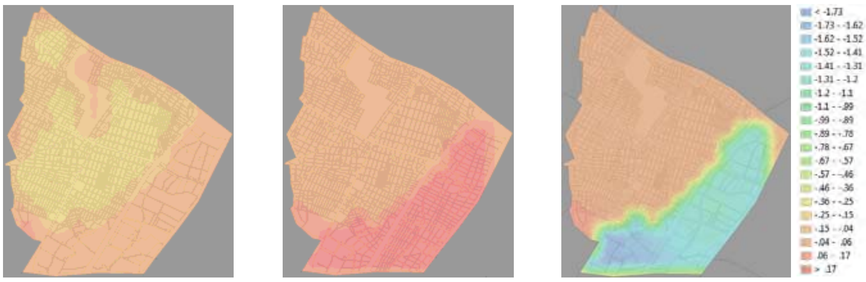
(Chrysoulakis et al. 2013)

Urban metabolism

Mean air temperature (K) 20:00 - 23:00 LST in Summer. Alternatives' maps present the difference from Base.



Base

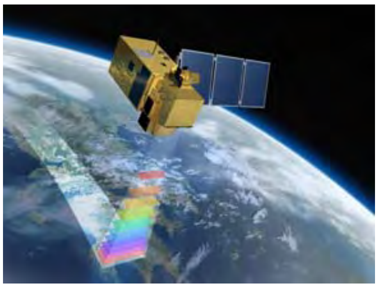


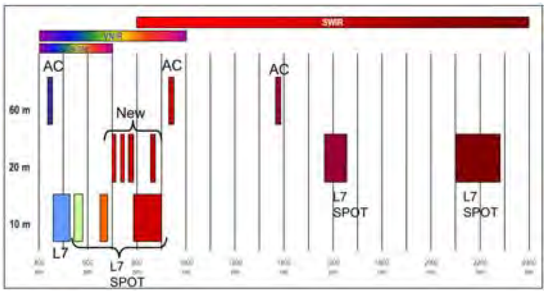
Alternative 1 | Alternative 2 | Alternative 3

(Chrysoulakis et al. 2013)

EO trends and synergies

		Expected launch	Spatial Resolution	Revisit time
Radar Missions	Santinel-1	2014	5 m	6 days (2 satellites)
	Radarsat	2018	1.3 m	1 day (3 satellites)
	TerraSAR-X2	2016	0.25 m	11 days
	ALOS-2	2013	1 m	14 days
Multispectral Missions	Santinel-2	2014	10 m	5 days (2 satellites)
	ALOS-3	2013	0.8 m	14 days
	Cartosat-3	2014	0.25 m	14 days
	World View-3	2014	0.3 m	1 day (off-nadir)
Hyperspectral Missions	HISUI	2015	30 m	14 days
	HyspIRI	2020	60 m	19 days
	EnMAP	2017	60 m	21 days

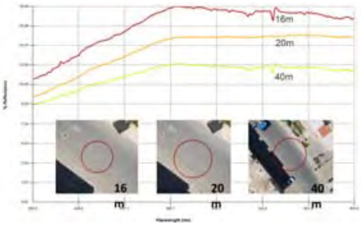




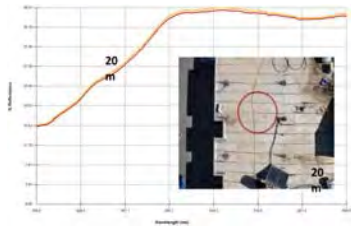
EO trends and synergies

EO trends and synergies

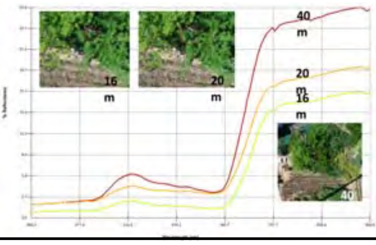
Spectral Signatures (asphalt)
SVC 1024 with 14°FOV



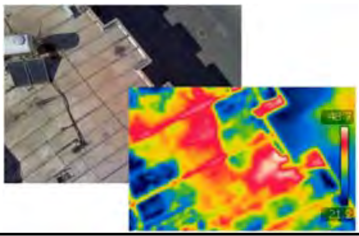
Spectral Signatures (Building Roof)
SVC 1024 with 14°FOV



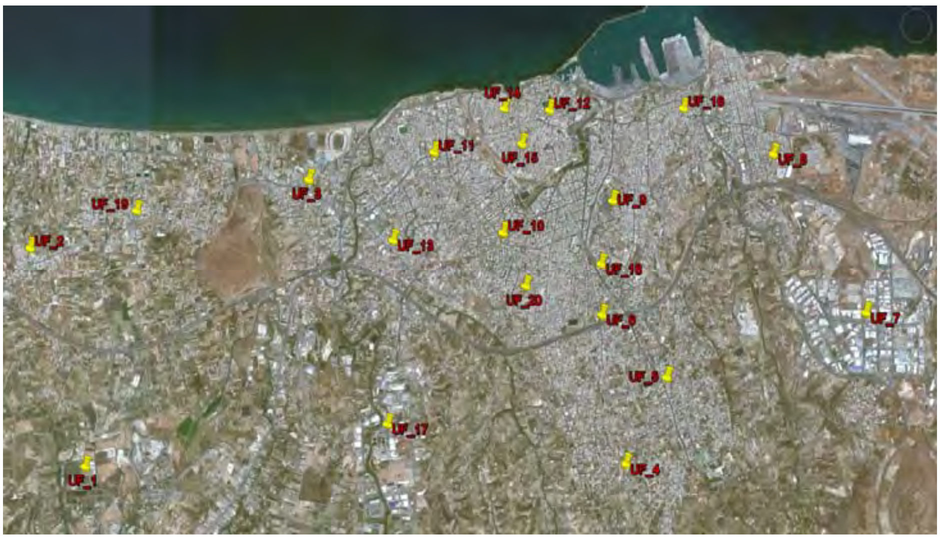
Spectral Signatures (Vegetation/Soil)
GER 1500 with 4°FOV



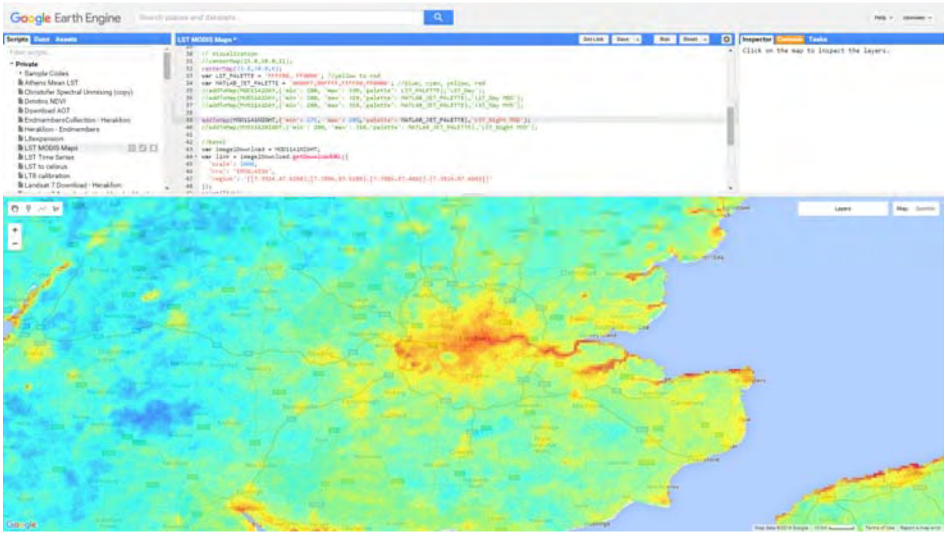
Thermal infrared (Building Roof Top)
FLIR B335



EO trends and synergies

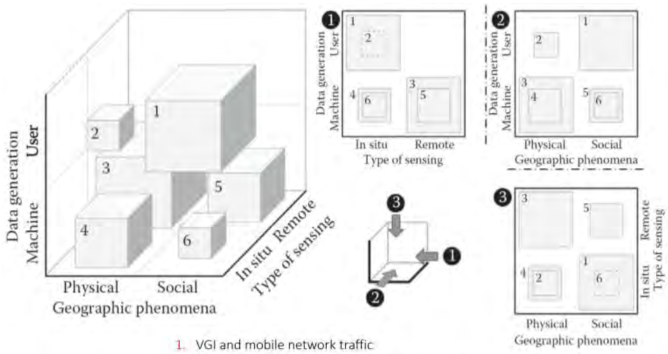


EO trends and synergies



EO trends and synergies

- Towards **integrated urban sensing**: blocks of sensor data assigned to the dimensions of sensing.

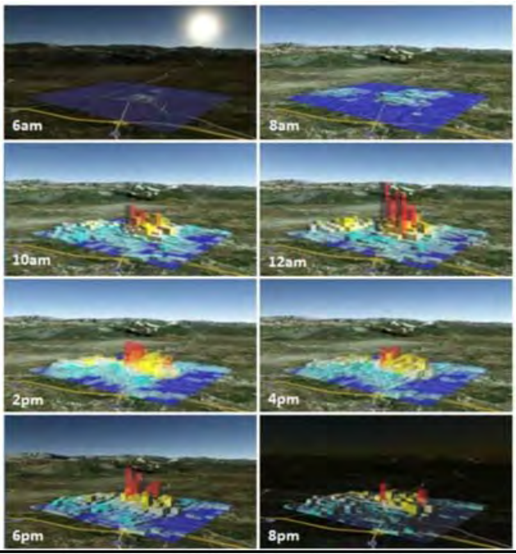


1. VGI and mobile network traffic
2. VGI in the context of environmental status updates
3. Satellite imagery
4. Measurements from sensors and sensor networks
5. Human settlements extracted from satellite imagery
6. Counter data at entrances and exits of shopping malls, public transport.

(Sagl and Blaschke 2014)

EO trends and synergies

- Towards integrated urban sensing.



(Sagl and Blaschke 2014)

Thank you!

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