Complexity of surface temperature in the urban environment

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COMPLEXITY OF SURFACE TEMPERATURE IN THE URBAN ENVIRONMENT

Directional anisotropy and emissivity

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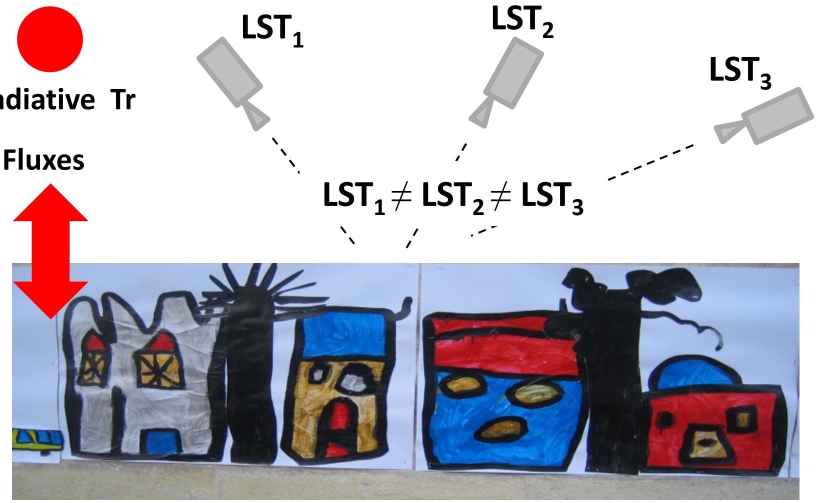
4th EarthTemp Network meeting, 8-10 June 2015, Reading

Introduction : TIR directional anisotropy and emissivity in urban context

PART 1

Coupling of energy and radiative transfer processes

TIR directional anisotropy (both daytime and nighttime)

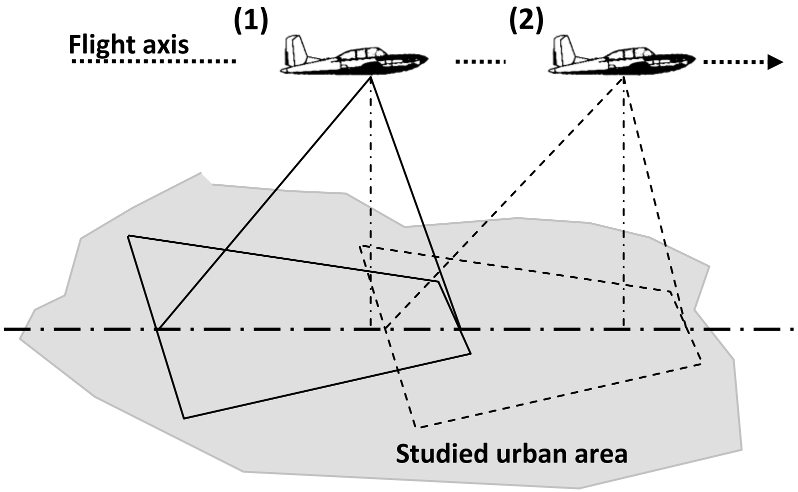


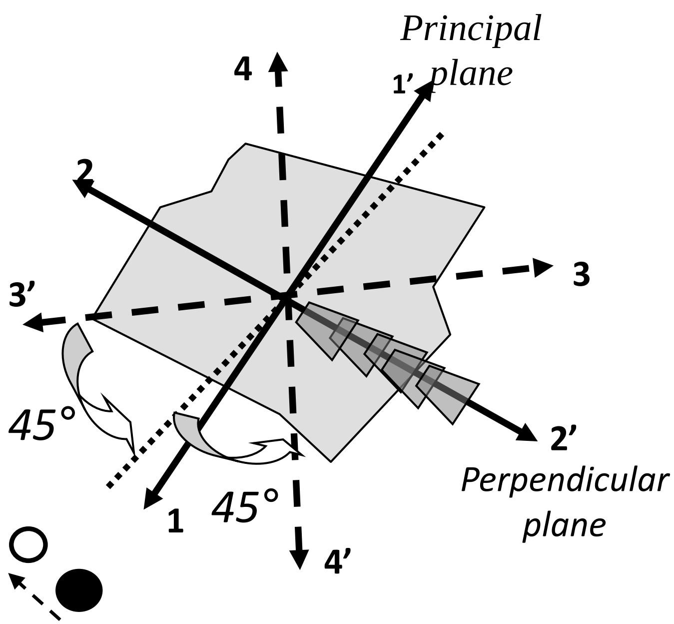
PART 2

Variety of artificial materials + vegetation

Variability of emissivity crucial for urban ST (compositing, directionality, temperature emissivity separation)

Experimental characterization of TIR directional anisotropy





Data acquisition

- Airborne TIR camera with wide-angle lenses inclined backward
- Flight pattern : 4 axis flown in oposite directions crossing at the center of the studied area
- allows a spatio-temporal integration of LST to be performed

Data processing

- Camera : calibration, distortion, etc…
- Atmospheric correction (MODTRAN)
- Assumption $\varepsilon = 1$ $\rightarrow$ retrieval of **brightness LST** from Brightness Temperature at sensor level

Lagouarde et al., (2000). *Remote Sens. Environ.* 72, 17-34
Lagouarde and Irvine M. (2008). *Meteor. Atmos. Phys.*, 102, 173-185

Experimental characterization of TIR directional anisotropy

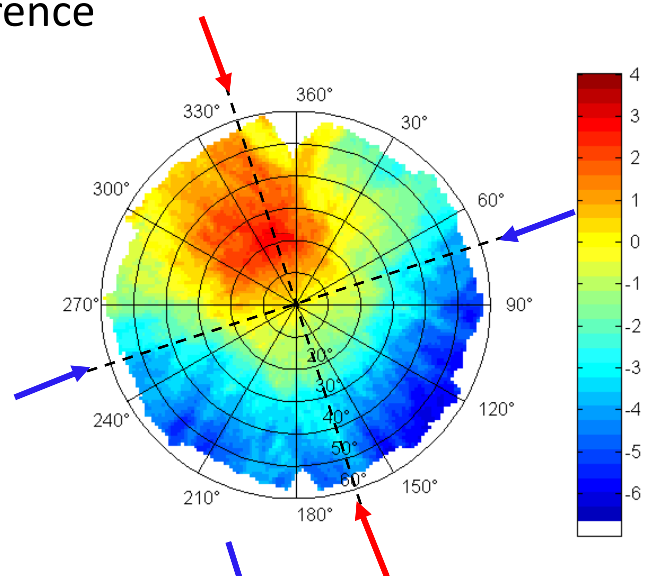
TIR directional anisotropy defined as the difference between oblique and nadir brightness LST :

DBTA = Tb(θ_v , φ_v) – Tb_{nadir}

zenith viewing angle θ_v : 0 → ~60°
azimuth viewing angle φ_v : 0 → 360°

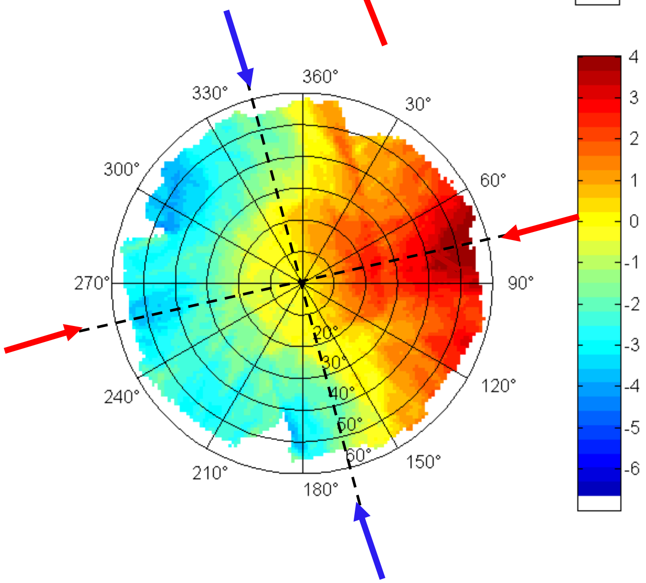
Examples of anisotropy over Marseille (ESCOMPTE experiment, 2001 :

- the hot spot position follows the Sun displacement
- maximum anisotropy variation with θ_v in the principal solar plane
- attention to be paid to possible 'smoothing effect' due to aircraft movements (attitude)



July 12th 2001

11 :04 - 11 :35 TU



June 26th 2001

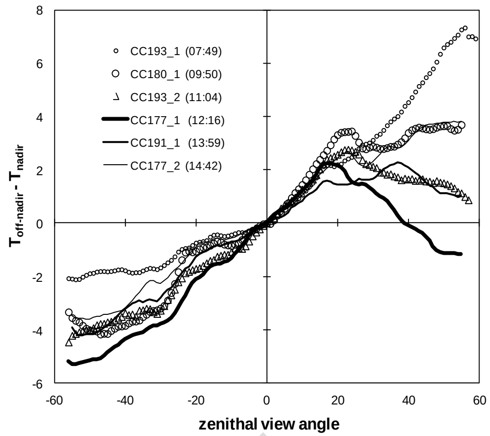
14 :42 - 15 :23 TU

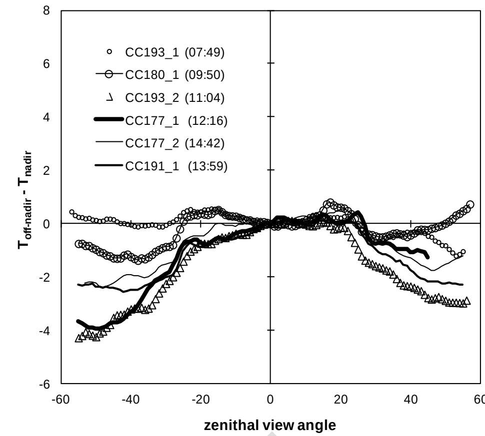
Principal solar plane
Perpendicular solar plane

Lagouarde et al. (2004). *Remote Sens. Environ.* 93, 443-462

Impact of the urban canopy structure and of vegetation (ESCOMPTE/Marseille, 2001)

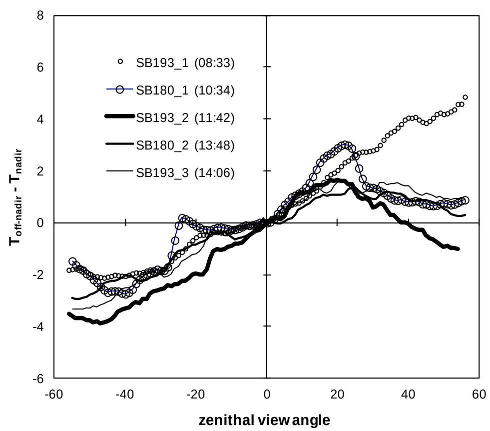
Densely built
(Marseille city center)

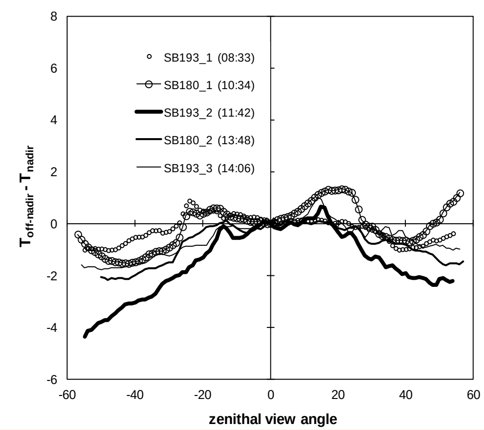




Principal solar plane **Perpendicular solar plane**

Individual houses with gardens
Saint Barnabé district

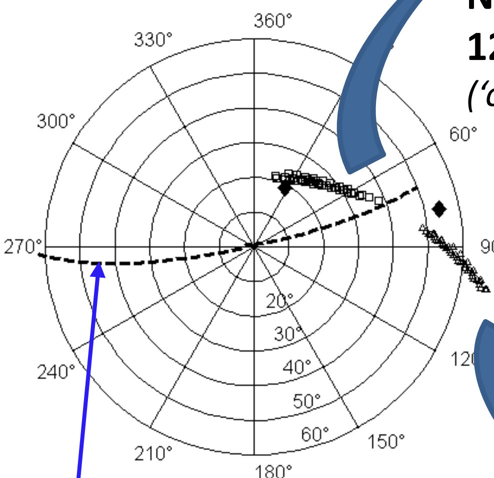




- **Attenuation of anisotropy with vegetation in the principal plane**
- **Less impact in perpendicular plane**

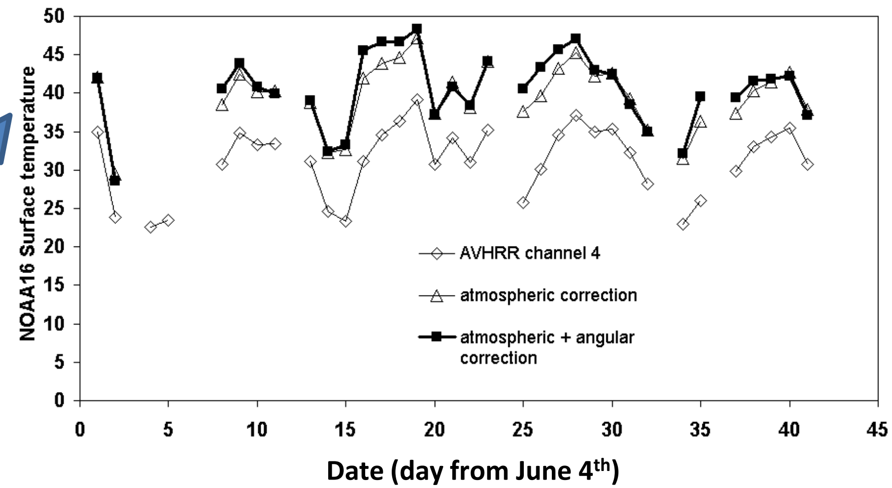
Lagouarde et al. (2004). *Remote Sens. Environ.* 93, 443-462

Impact of TIR directional anisotropy on satellite temporal series data (ESCOMPTE/Marseille)

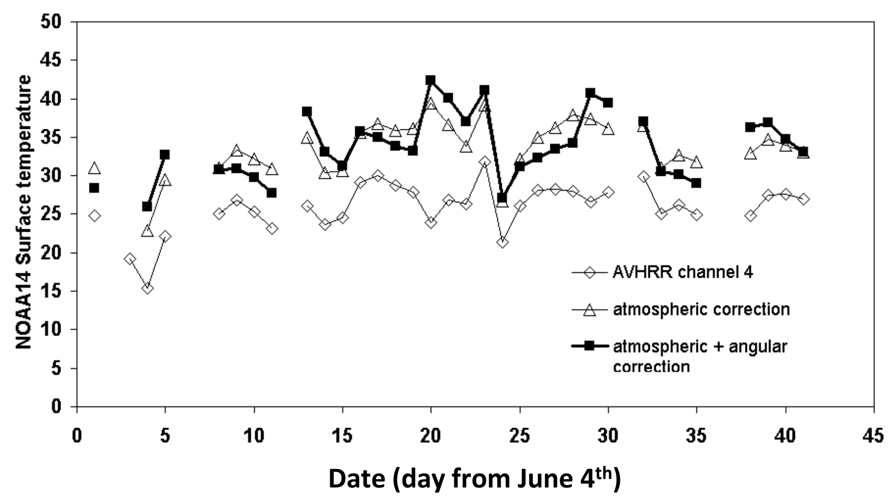


AVHRR viewing configuration over Marseille

NOAA 16
12:07– 14:12 UT
('closer' to perp. plane)



NOAA 14
15:19 - 17:03 UT
('closer' to perp. plane)



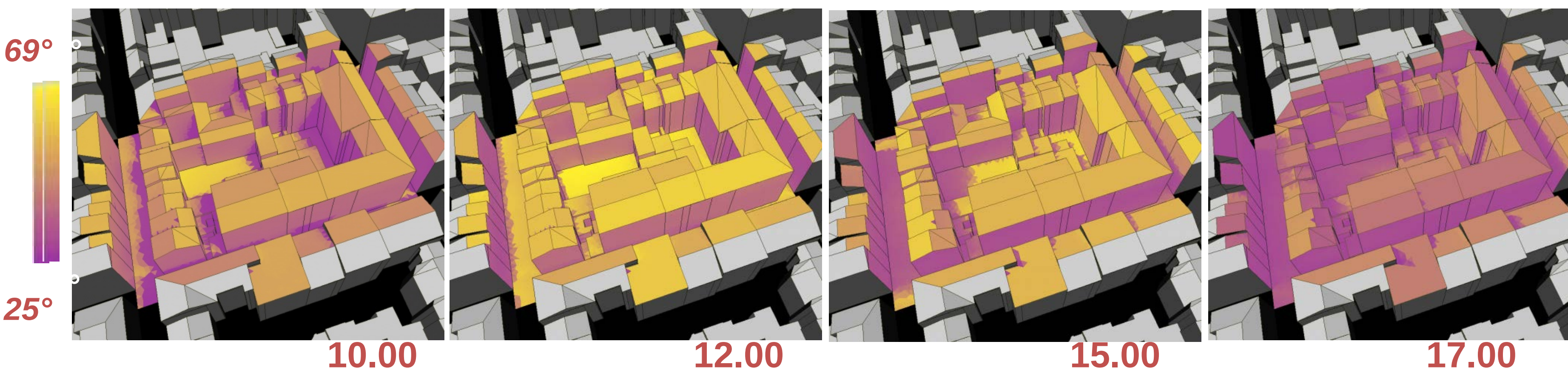
Lagouarde et al. (2004). *Remote Sens. Environ.* 93, 443-462

Modelling daytime directional anisotropy over the city center of Toulouse

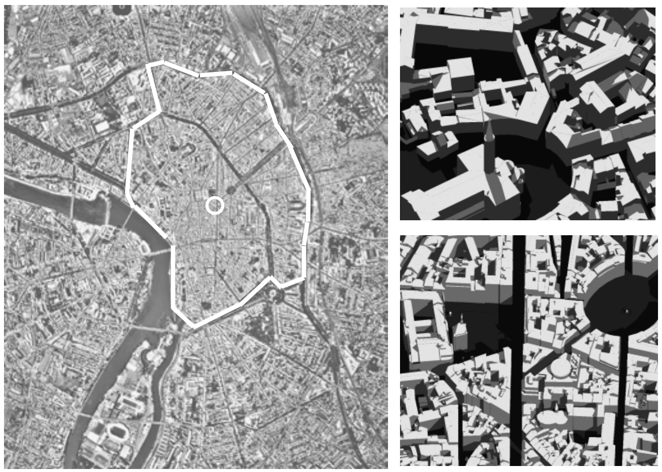
Based on the use of SOLENE (collab. with IRSTV, Nantes)

SOLENE : Software for simulating of sunshine, lighting and thermal radiation

CRENAU (Nantes)
http://cerma.archi.fr/



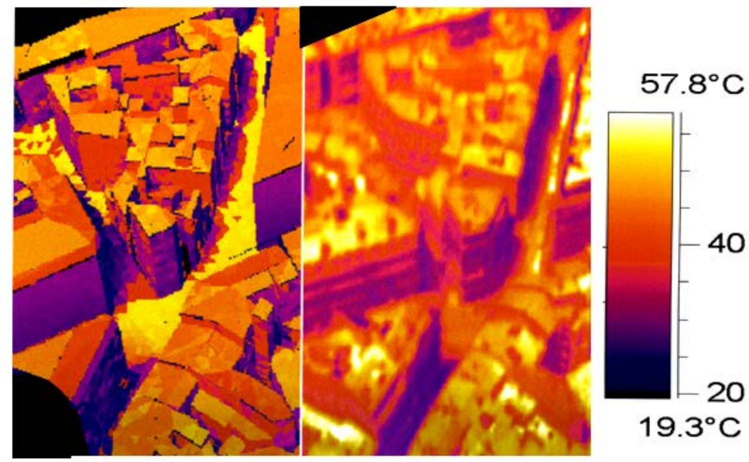
Modelling daytime directional anisotropy over the city center of Toulouse



Toulouse 3D model

SOLENE

Toulouse / CAPITOUL project



SOLENE model (Hénon, 2008)

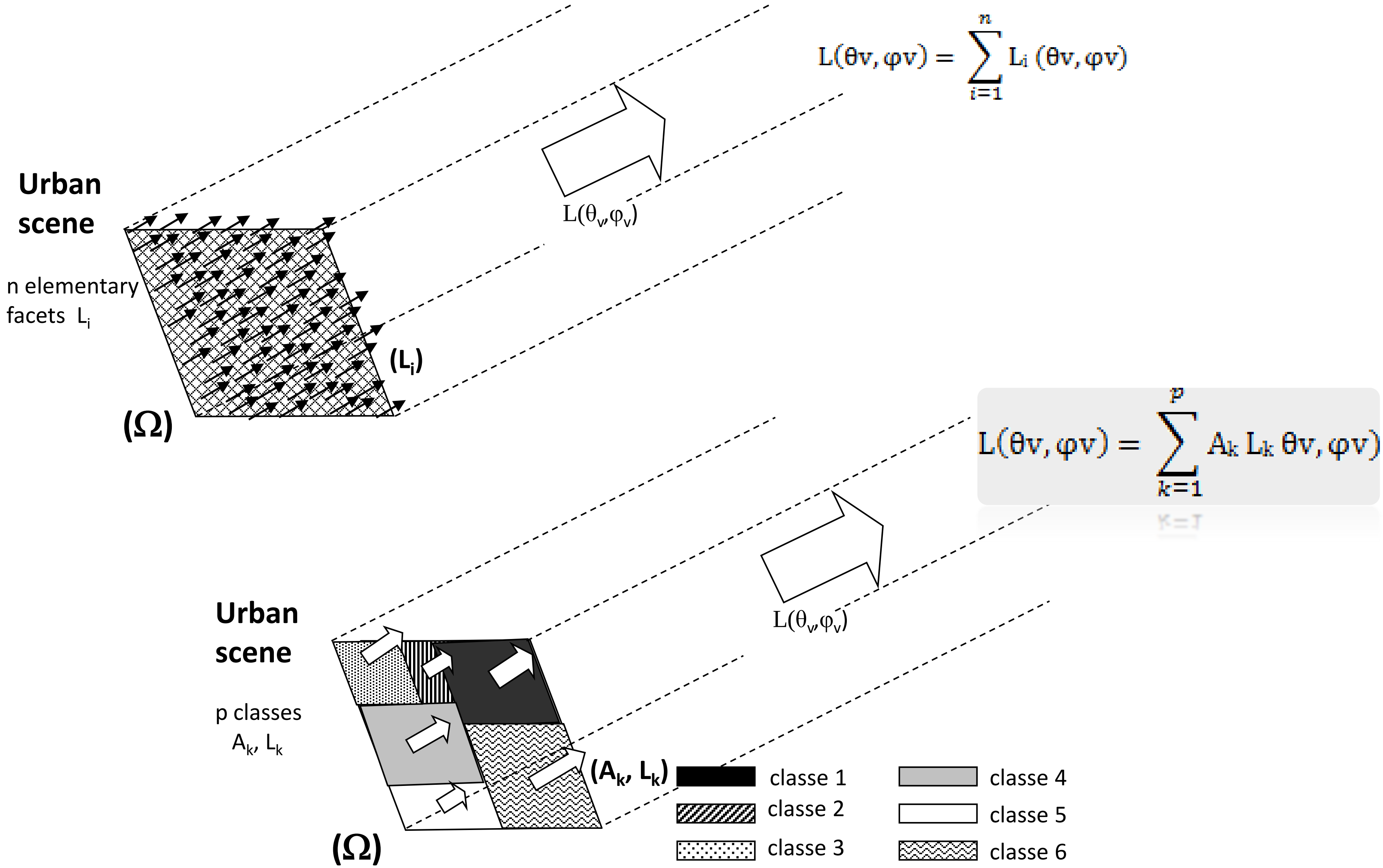
Airborne TIR image

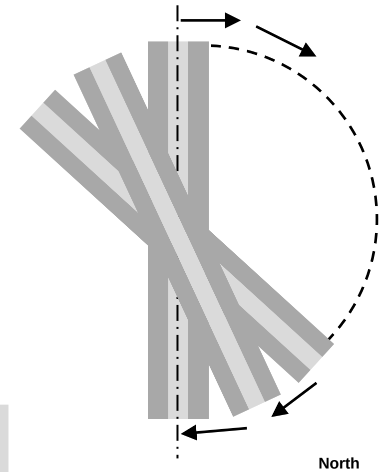
Possible direct approach to simulate directional LST using SOLENE simulations in [0 50°] and [1 360°] zenital θ_v and azimuthal φ_v angles too time and computer ressources consuming,

Development of a simplified methodology proposed

Hénon et al., (2012). Part 1: *Theor. Appl. Climatol.*, DOI 10.1007/s00704-012-0615-0.
Hénon et al. (2012). Part 2: *Theor. Appl. Climatol.*, DOI 10.1007/s00704-012-0616-z.

Modelling daytime directional anisotropy over the city center of Toulouse : methodology

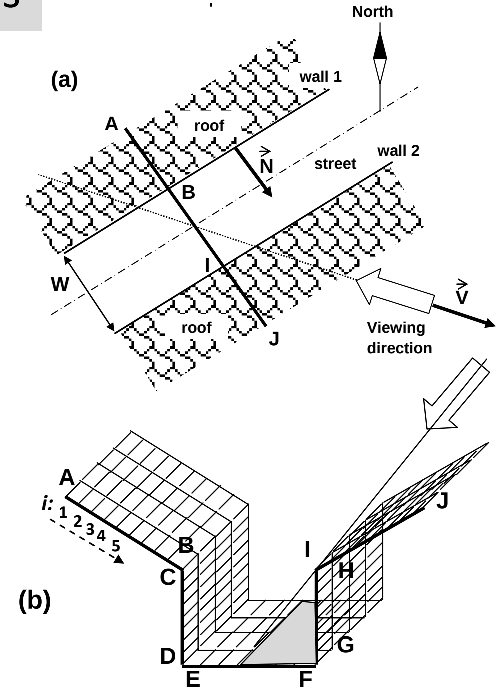




Simplified approach:

based on the aggregation in any viewing direction of 6 directional temperatures only (sunlit/shaded walls/streets/roofs) weighted by their corresponding surface ratios within the scene viewed.

The city is described by 18 canyon streets oriented in all directions



$$T_b(\theta_V,\varphi_V)=\left[\sum_{i,j} A_{ij}(\theta_V,\varphi_V)\left[T_{b\,ij}(\theta_V,\varphi_V)\right]^4\right]^{1/4}$$

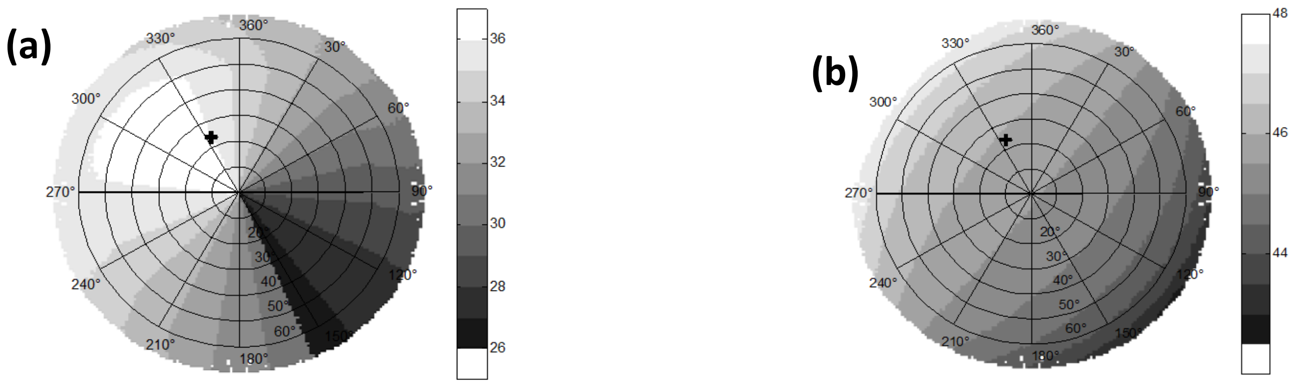
Actual surface ratios of each class computed from images generated with the POV-Ray software (http://www.povray.org/) and 3D model

Temperatures are determined by integrating SOLENE simulations SOLENE repeated for the 18 canyon streets

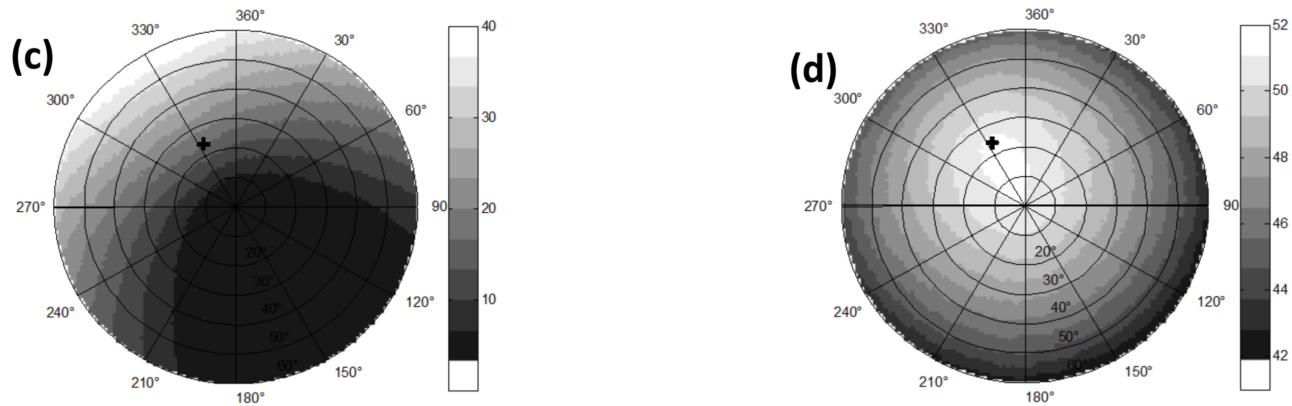
Lagouarde et al. (2010). *Remote Sens. Environ.* 114, 87-105

Example of temperature and ratio for 2 classes

Sunlit walls **Sunlit roofs**



Directional brightness temperatures (in °C) computed for sunlit walls (a) and sunlit roofs (b) with the 18 canyon street model. July 15th, 11:35 UT



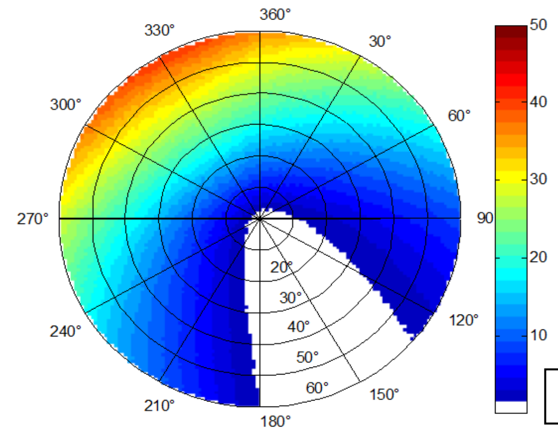
A_{ij} fractions (in percent) for sunlit walls (c) and sunlit roofs (d) The direction opposite to Sun (φ_{vSUN} = 334.1, θ_{vSUN} = 23.9) is referred to by a black cross

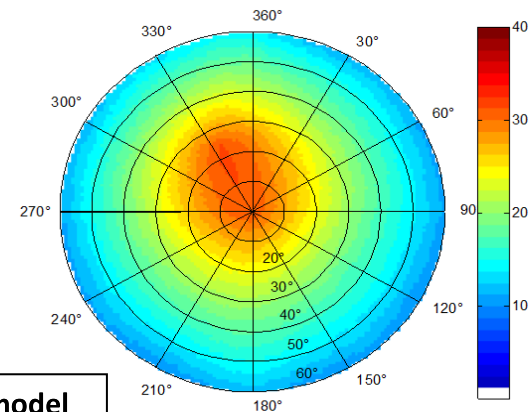
Modelling daytime directional anisotropy over Toulouse city center of Toulouse

Validation of the 18 canyon street approach against the actual 3D model of Toulouse

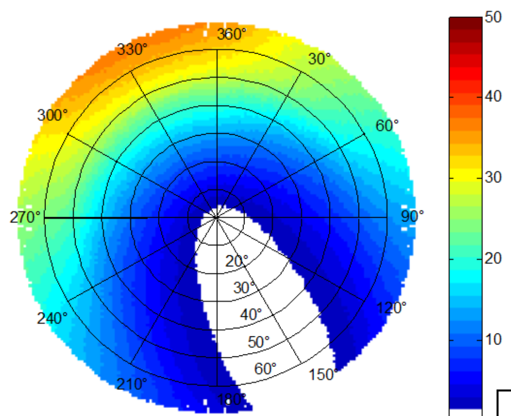
SUNLIT WALLS DIRECTIONAL RATIO

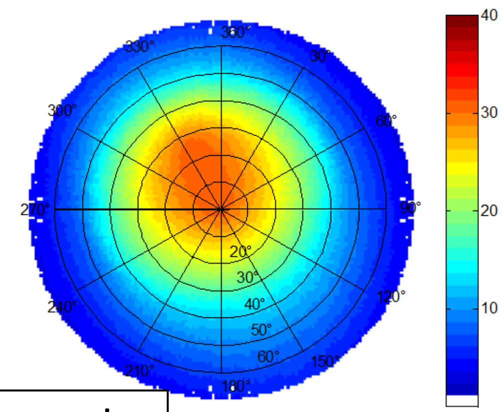
SUNLIT STREET DIRECTIONAL RATIO





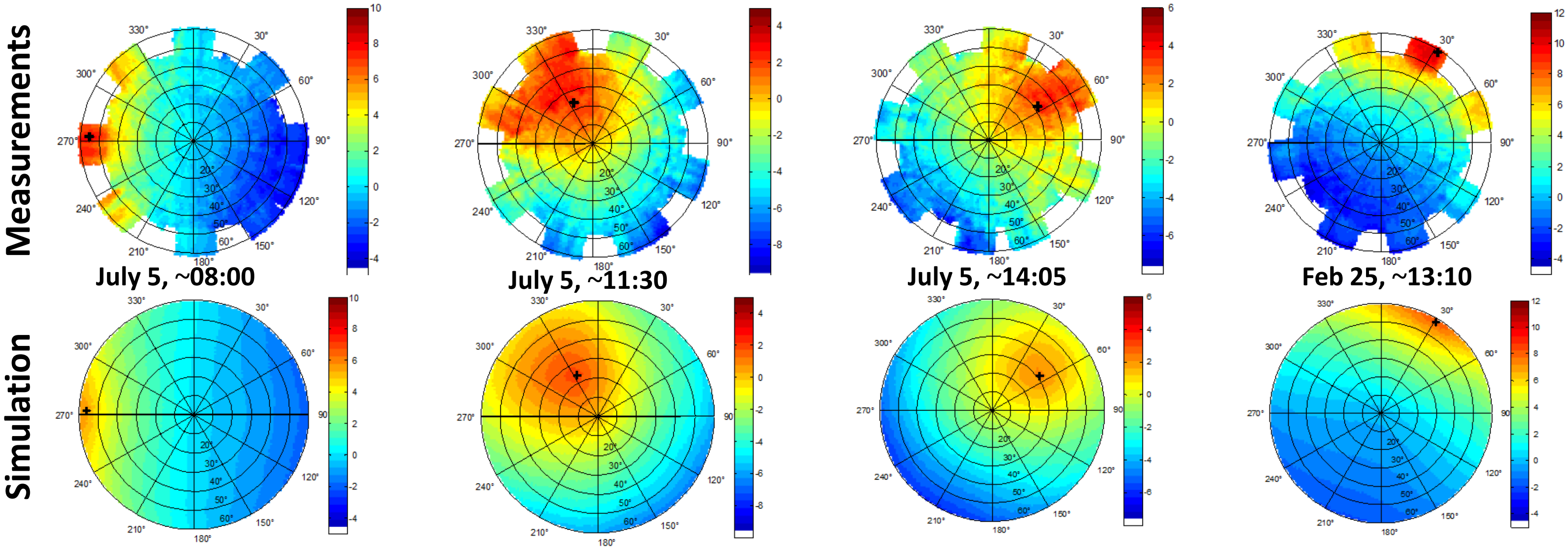
Toulouse 3D model

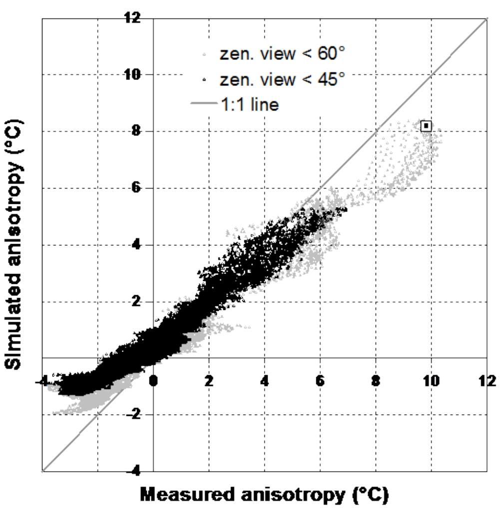




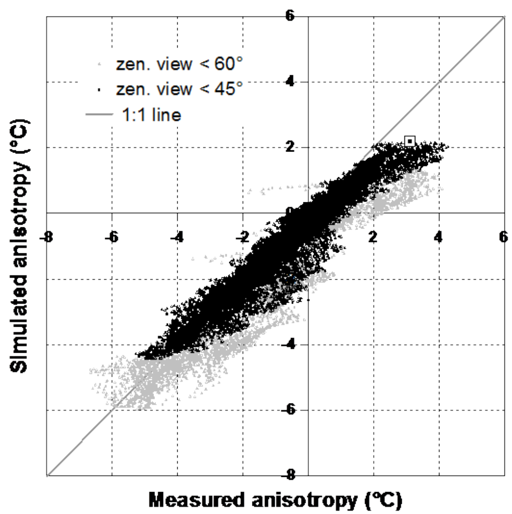
18 canyon street approach

Modelling daytime directional anisotropy over Toulouse city center of Toulouse : results





July 5, ~08:00



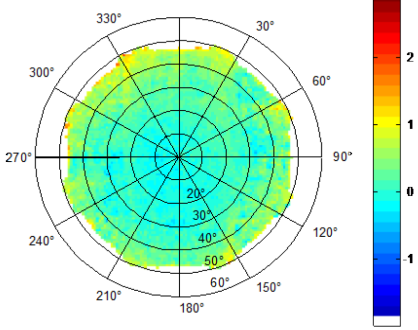
July 5, ~14:05

- **Satisfactory results**
- **Methodology to be tested over cities with preferential directions and/or ≠ canyon street shapes (aspect ratios)**
- **Underestimation possibly related to small scale built elements ?**

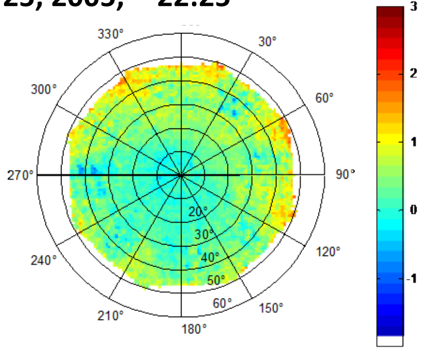
Lagouarde et al. (2010). *Remote Sens. Environ.* 114, 87-105

Characterization of nighttime directional anisotropy : experimental results

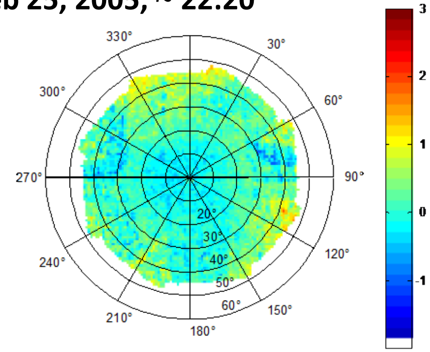
Oct 5, 2004, ~ 23:00



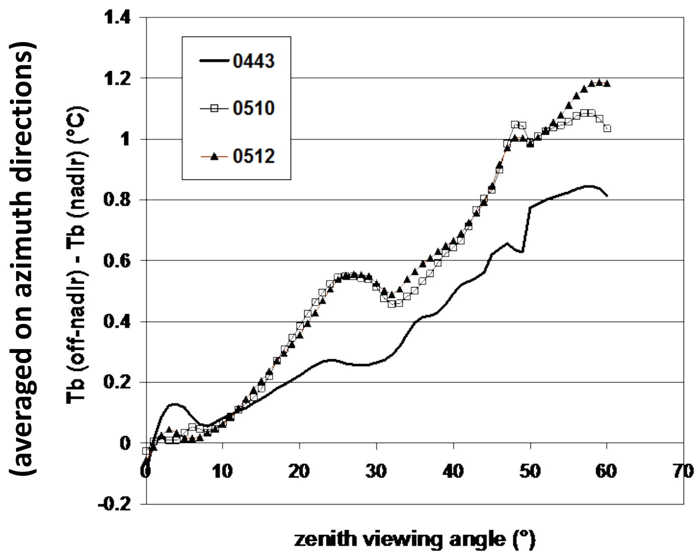
Feb 25, 2005, ~ 22:25



Feb 25, 2005, ~ 22:20

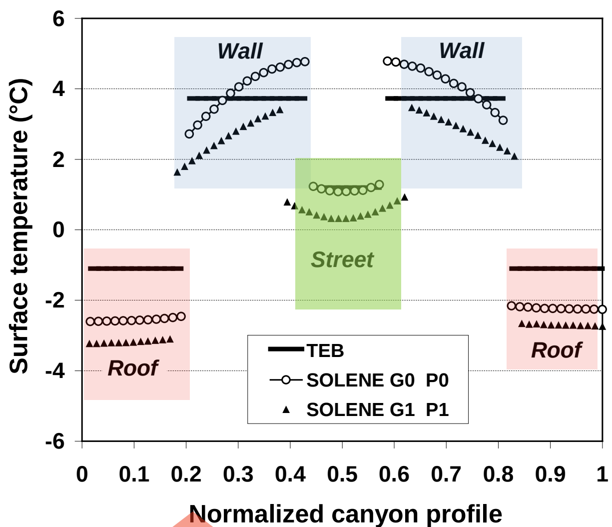


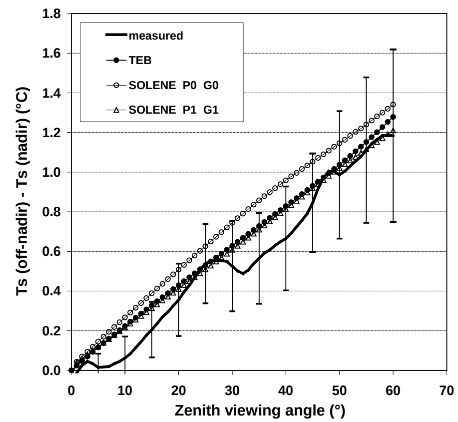
- ♦ Similar airborne protocol measurements as for daytime
- ♦ Similar results obtained on 3 autumn and winter nights
- ♦ Anisotropy remains small within the 0 - 50° range investigated with the M740 camera equipped with wide angle lenses)
- ♦ No effect of azimutal viewing direction

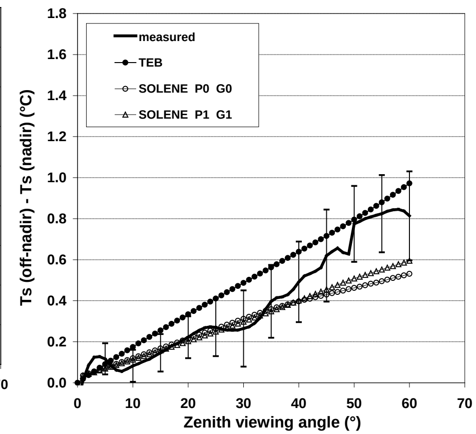


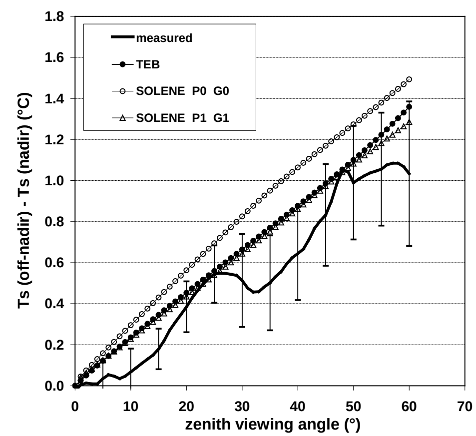
Modelling nighttime directional anisotropy : simulation

- ♦ Same methodology as for daytime modeling, but with 3 classes walls/roofs/street only
- ♦ 2 models used for computing facet surface temperatures :
  - SOLENE (with 2 geometries)
  - TEB (Meteo France)

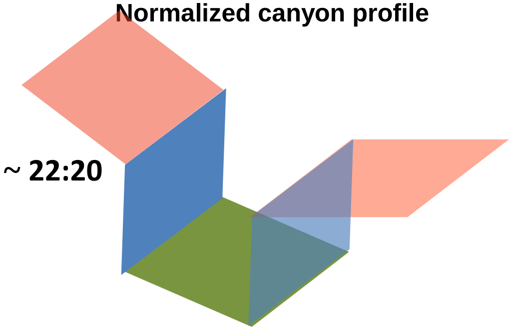








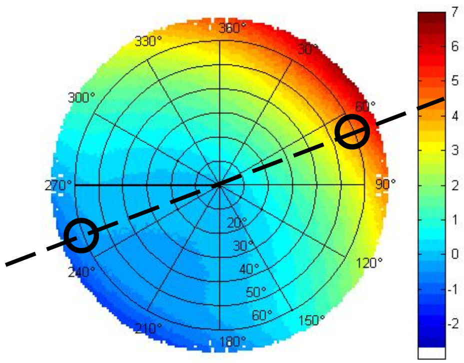
Feb 25, 2005, ~ 22:20



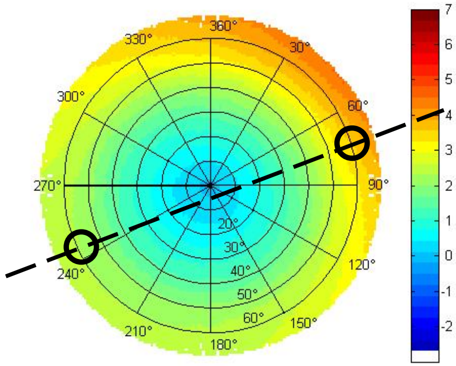
- **Good agreement model/measurements**
- **According to sensitivity tests to canopy geometry (not presented here), anisotropy remains lower than 1.5°C up to 60° zenih viewing angles**

Lagouarde et al. (2011). *Rem. Sens. Environ.,* 117, 19-33

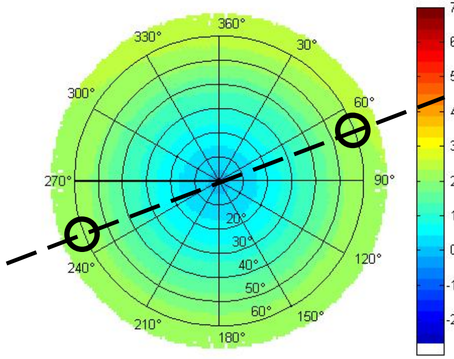
Modelling nighttime directional anisotropy : simulation/effect of thermal inertia



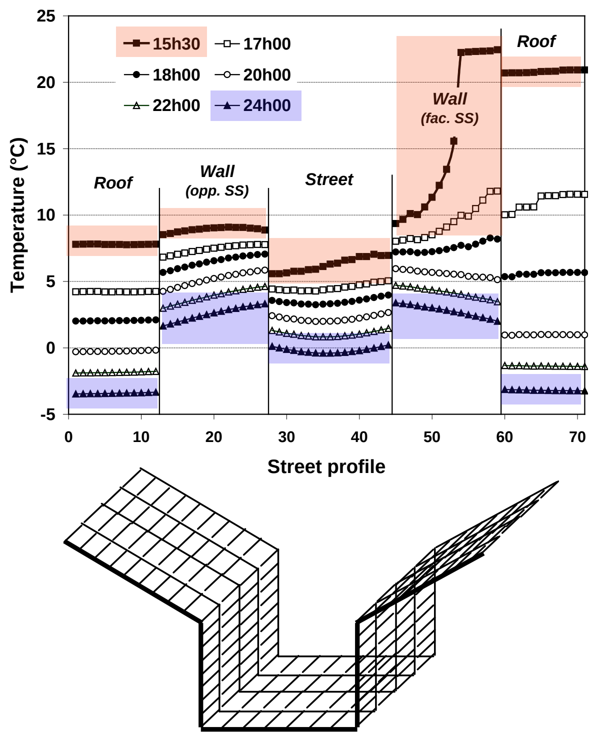
Simulated 15:30 UT

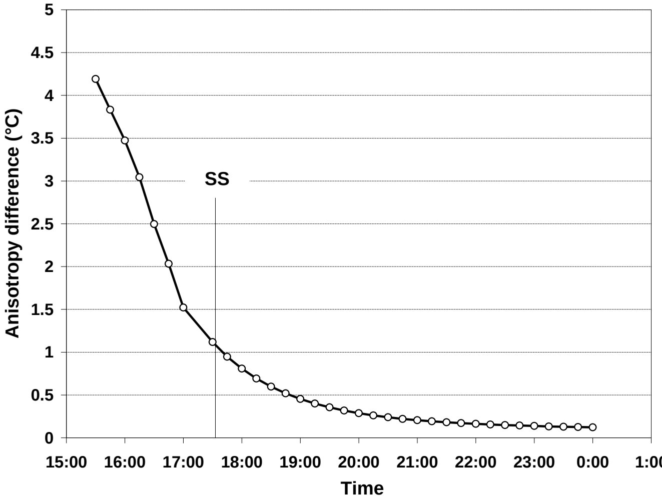


Simulated 17:30 UT



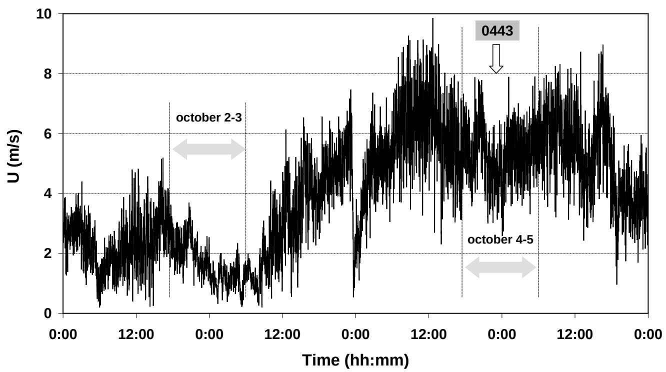
Simulated 24:00 UT

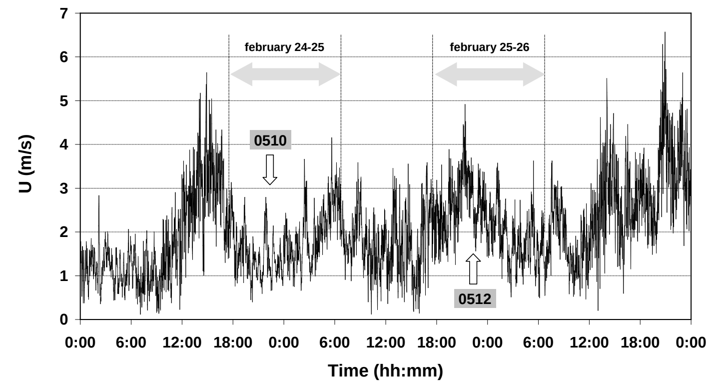


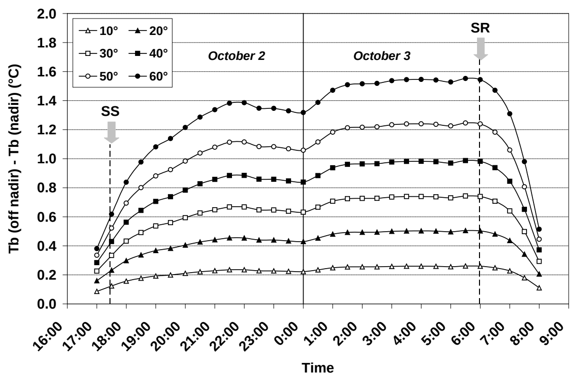


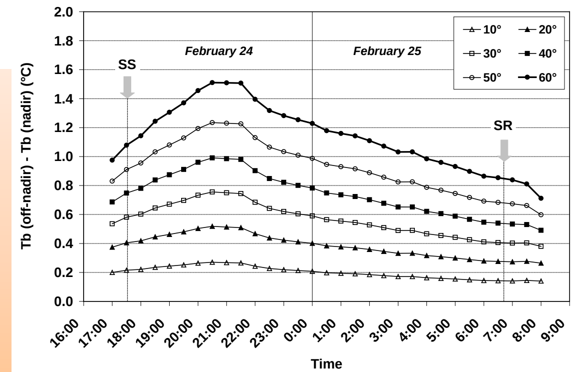
No more thermal inertia effect remaining about 4 hours after sunset

Modelling nighttime directional anisotropy : simulation/evolution throughout night

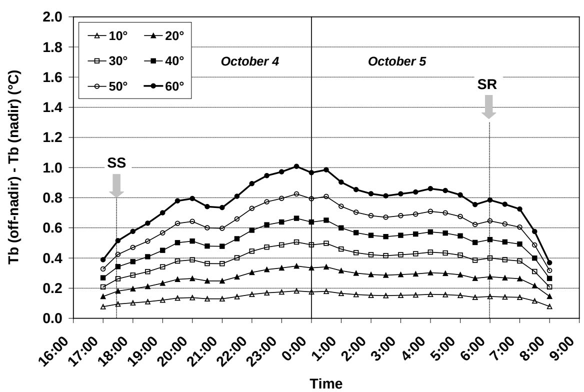


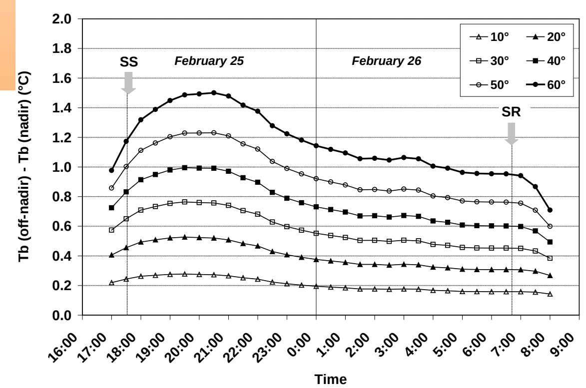






- ♦ Simulations of anisotropy throughout night based onTEB
- ♦ Anisotropy decreases with wind
- ♦ Night anisotropy < 2°C

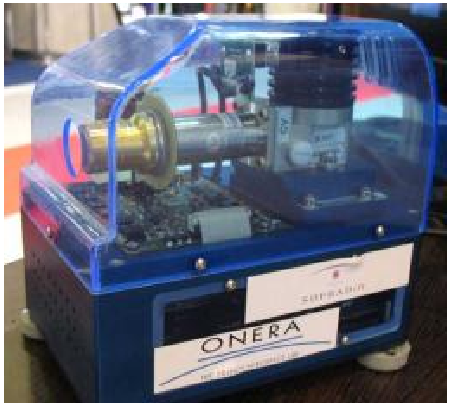




Introduction : emissivity of urban canopies

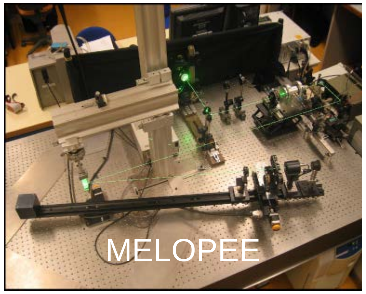
Objectives:

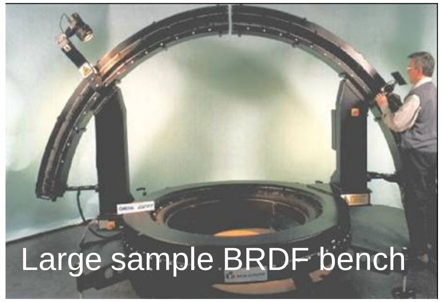
- **Emissivity facilities and examples in urban area**
- **Emissivity estimation from aircraft**
- **Error budget to retrieve emissivity and temperature**
- **Unmixing in the LWIR**

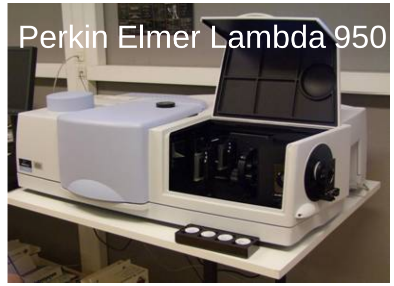


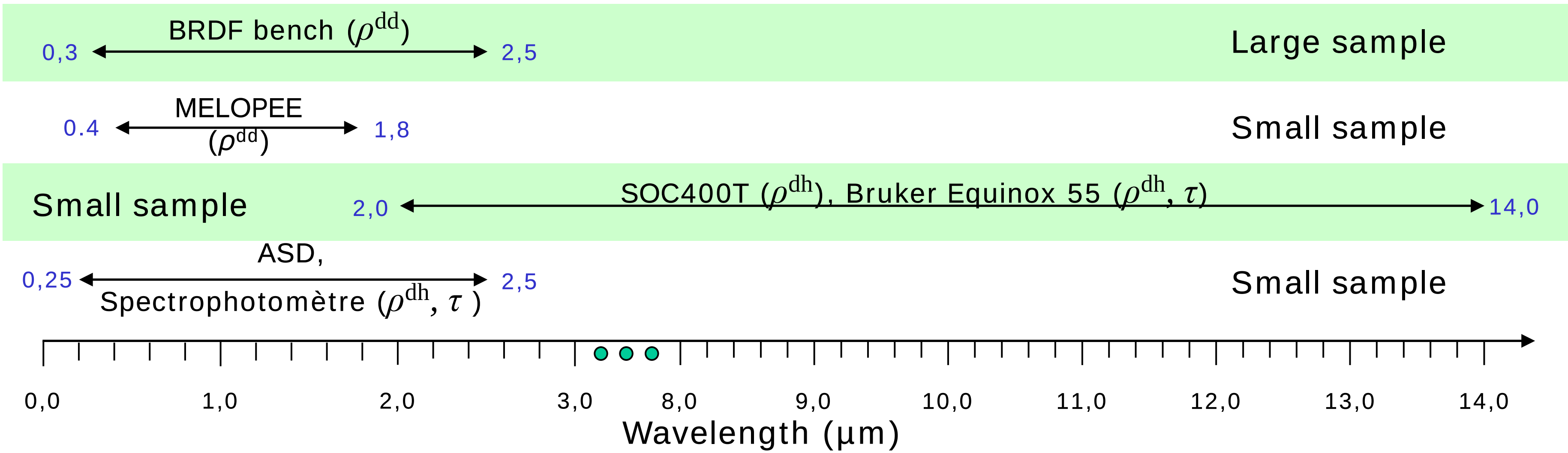
In-lab and ou-door facilities to measure the spectral emissivity

Quasi simultaneous measures on solar spectral reflectance and spectral emissivity

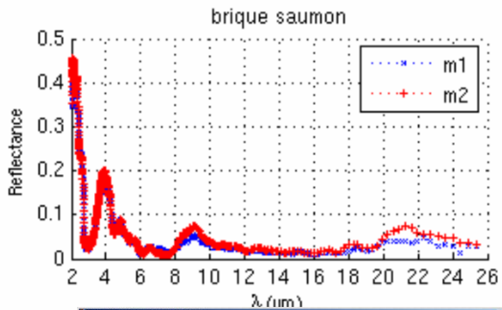




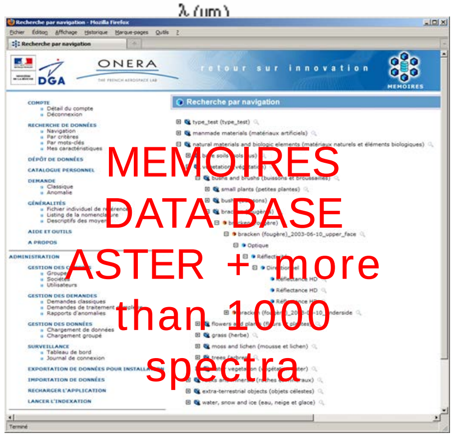




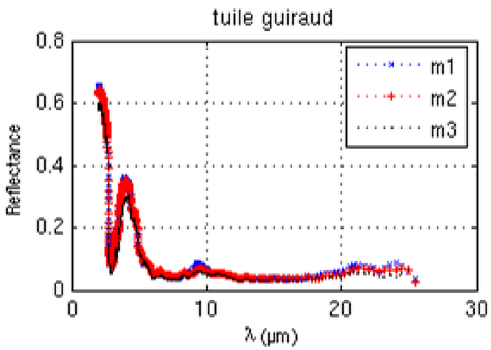
… Stored in ONERA MEMOIRES data base



Several types of brick, tile, asphalt (road, pavement), paint, rendered facade, marble, … in terms of color, use, age

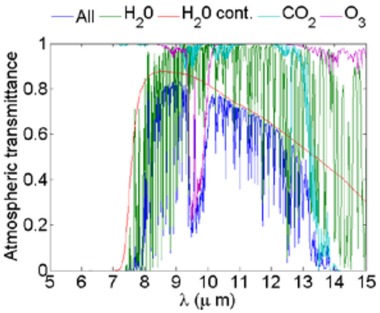


MEMOIRES DATA BASE
ASTER + more than 1000 spectra

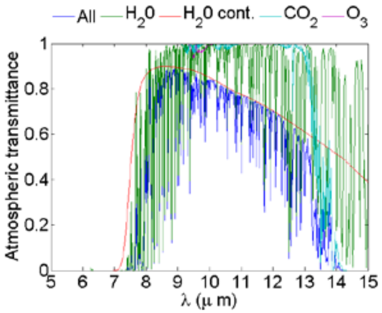


ONERA

Emissivity/temperature retrieval in urban area: methodology (Valence university, J. Sobrino, R. Oltra-Carrio)



All the atmosphere



Flight altitude (1860 m)

+ MODTRAN

$$L_i(T_i) = L_{g,i}\tau_i + L_i^{\uparrow}$$

$$L_{g,i} = \varepsilon_i B_i(T_s) + (1-\varepsilon_i)L_i^{\downarrow}$$

$$L_{g,i} = \frac{L_i(T_i) - L_i^{\uparrow}}{\tau_i}$$

LSE retrieval

NDVI[TM*]

Input: ρ_{red} ; ρ_{NIR}

* Sobrino, J. A., et al. 2008. IEEE TGRS, 46.

TES[**]

Input: $L_{g,TIR}$

AHS TIR channels: 72, 73, 75, 76, 77, 78, 79

Gillespie, A. et al. 1998. IEEE TGRS, 36(4)

TISI[***]

Input: $L_{g,MWIR}$; $L_{g,TIR}$ night and day

Becker, F. Li, Z.-L., 1990. RSE, 32.

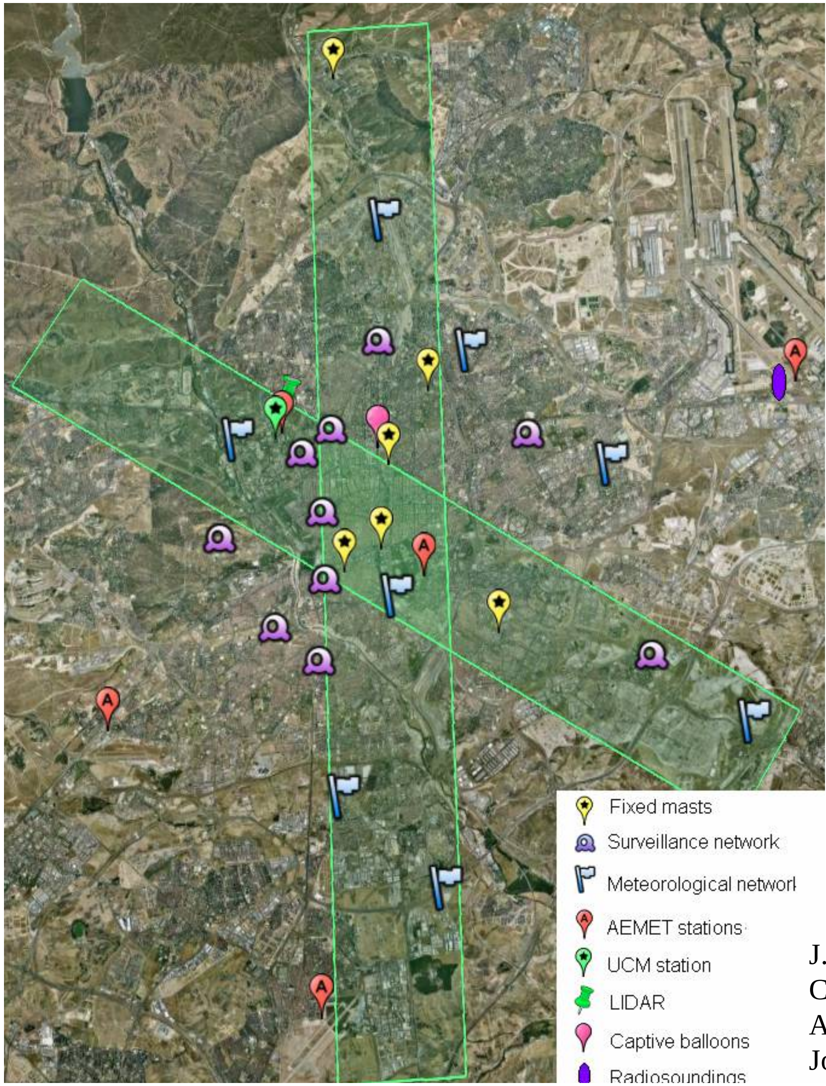
LST retrieval

Split Window

Input: w, LSE, T_{sensor}

i=AHS band 75, j=AHS band 79

Emissivity/temperature retrieval in urban area: DESIREX experiment (Valence university, J. Sobrino, R. Oltra-Carrio)



DESIREX 2008 field campaign:

- Founded by the ESA
- Coordinated by the Global Change Unit (GCU) from the University of Valencia (UVEG)
- Data acquisition in collaboration with different European teams

Data acquired:

- Airborne data with the AHS sensor covering two different patterns

- Spaceborne images:
ASTER/TERRA, MODIS/TERRA.

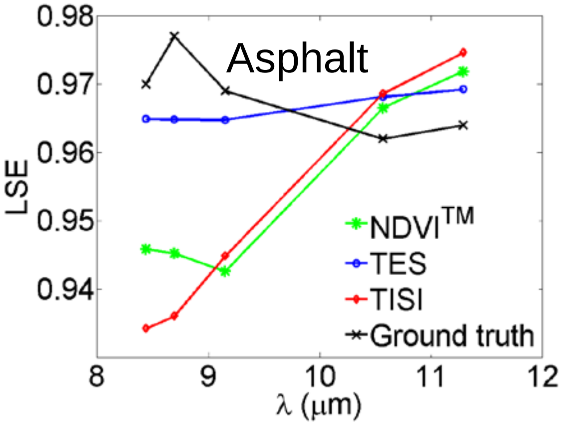
- Atmospheric and ground parameters:
air temperature, surface temperature, wind speed and direction, emissivity and reflectivity of urban and rural surfaces, radiation balance. (In situ measurements, fixed masts and car transects)

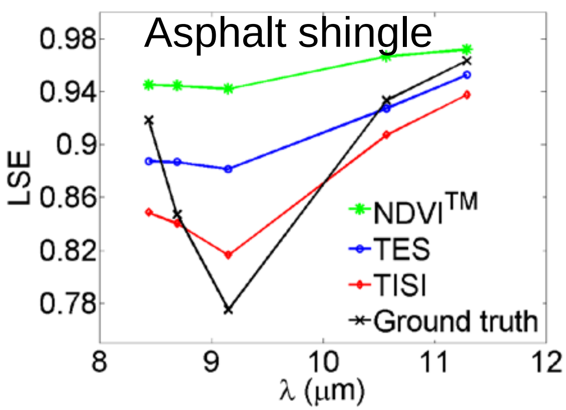
J.A. Sobrino, R. Oltra-Carrio, J.C. Jimenez-Mu~noz, Y. Julien, G. Soria, B. Franch, and C. Mattar. Emissivity mapping over urban areas using a classication-based approach: Application to the Dual-use European Security IR Experiment (DESIREX). International Journal of Applied Earth Observation and Geoinformation, 18:141{147, 2012.

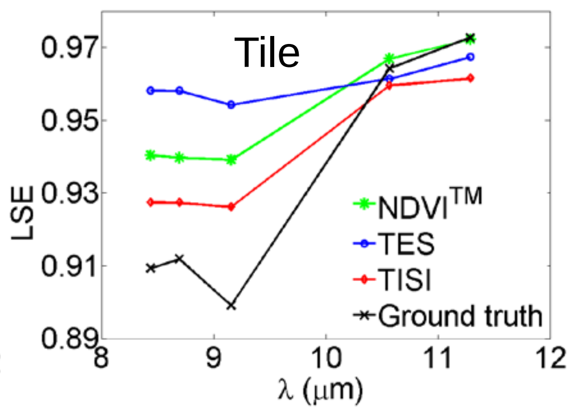
ONERA

Emissivity/temperature retrieval in urban area: Results (Valence university, J. Sobrino, R. Oltra-Carrio)

Results from AHS with ASTER configuration bands



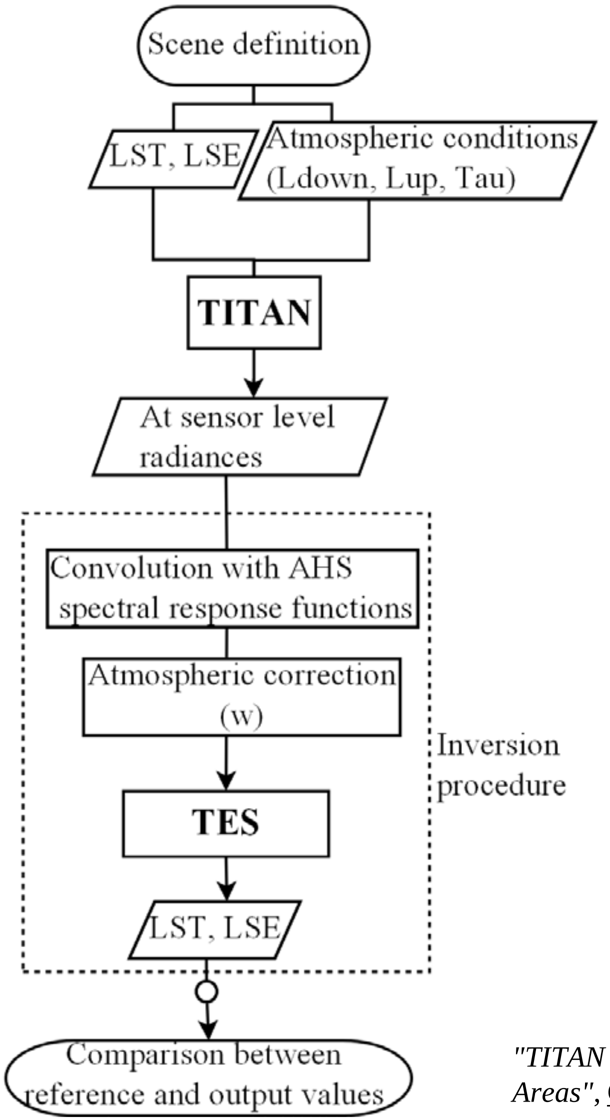


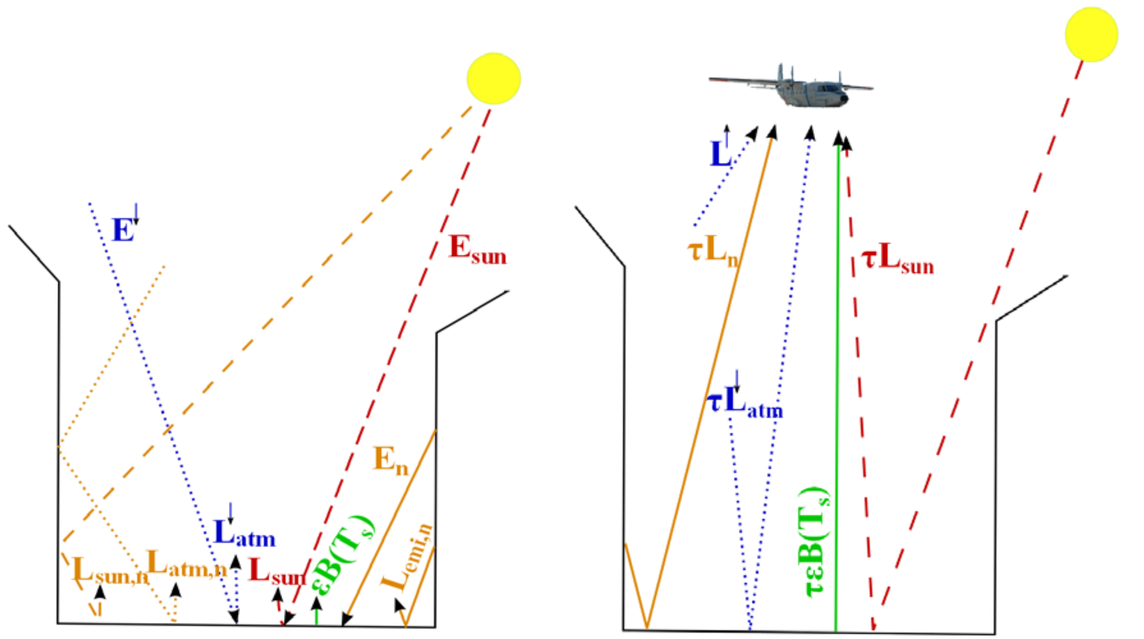


	← **NDVI**	**TES** →	**TISI** →
σ	0.051	0.036	0.029
Bias	0.024	0.015	-0.008
RMSE	0.056	0.039	0.030

- **Good performance for λ> 10 μm**
- **Better performance of algorithms TES and TISI**

Error budget: methodology (ONERA, Valence univ.)





- **TITAN 3D RT (Modtr**
analysis 3 Error sources:
  - TES algorithm
  - Atmospheric correction
  - 3D structure of the city

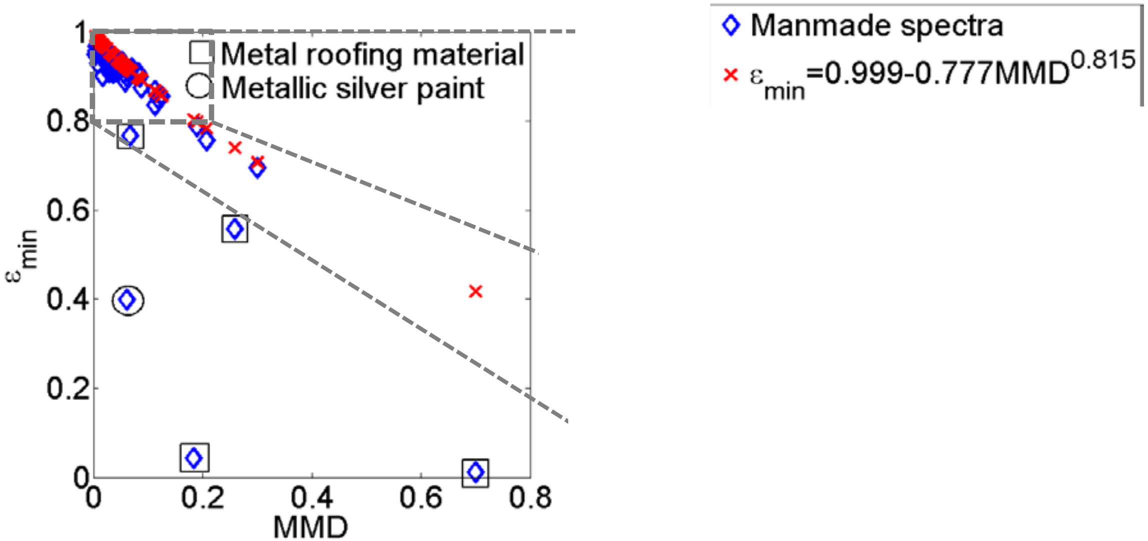
"TITAN : an Infrared Radiative Transfer Model for Heterogeneous 3-D Surface - Application over Urban Areas", G. Fontanilles, X. Briottet, T. Tremas, Applied Optics, Vol. 47, Issue 31, pp. 5799-5810

Error budget: TES algorithm (Gillespie, 1998)

ε_{min} and *MMD* relationship

$\varepsilon_{min}=0.999-0.777MMD^{0.815}$ (MMD = difference between max. and min. ε)

54 man-made spectra from the ASTER spectral library



- Metal surfaces badly modeled.

- Overestimation of the ε_{min} value, except for reddish asphalt, shingle roofing, terra cotta tile and brick.

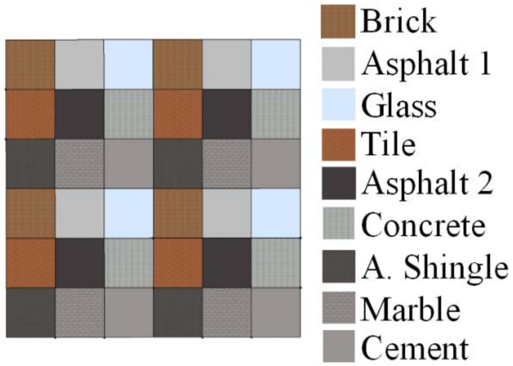
- ε_{min} recovered with an RMSE of 0.025

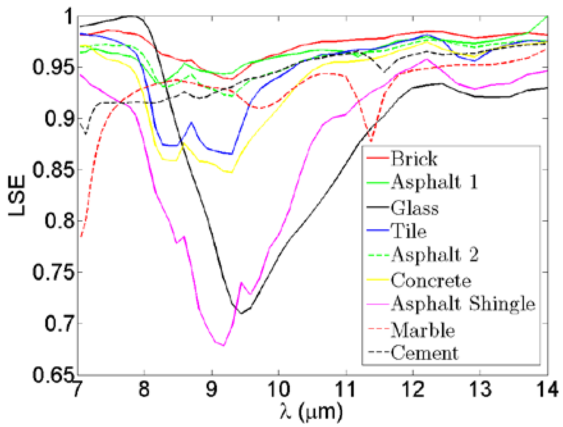
For most of the urban materials, our MMD relationship will lead to an overestimation of the LSE

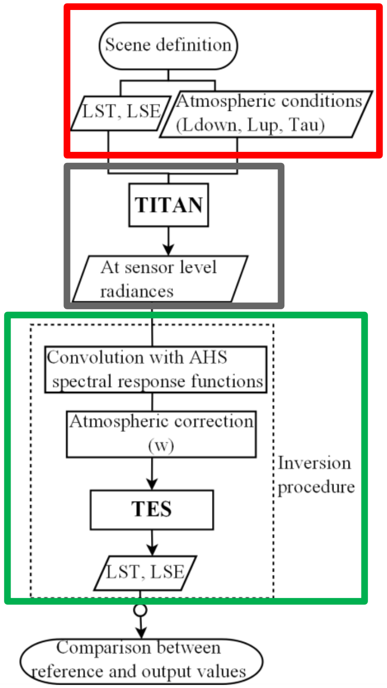
ONERA

Error budget: TES algorithm (Gillespie, 1998)

Scene definition





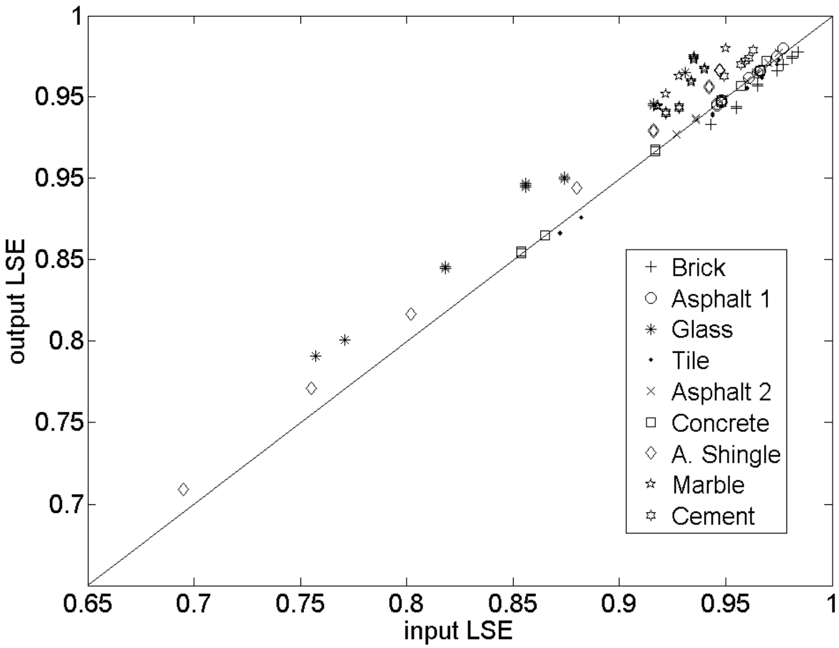


- LST: 295 K, 300 K, 305 K, 310 K
- 36 targets (9 materials at four LST)
- Atmospheric conditions: DESIREX atmospheric profile (w= 1.59 g/cm^2)
- illumination conditions: same as in DESIREX (θ_s=20.11°, φ_s=144.5°)
- Observation conditions: sensor altitude = 1866m; nadir viewing

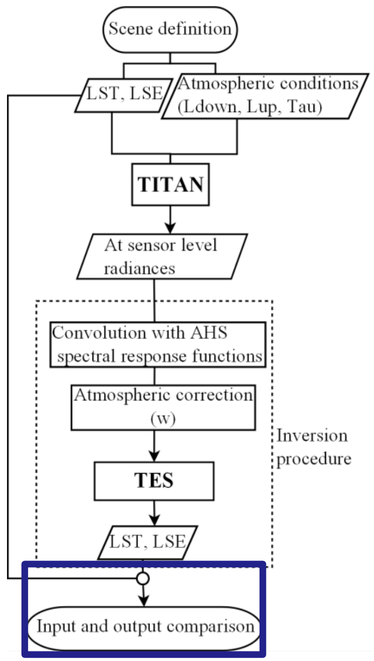
ONERA

Error budget: TES algorithm (Gillespie, 1998)

LSE analysis



Material	Bias	σ	RMSE
Brick	-0.008	0.002	0.008
Asphalt 1	0.001	0.001	0.001
Glass	0.032	0.004	0.032
Tile	-0.004	0.001	0.005
Asphalt 2	0.001	0.001	0.001
Concrete	0.001	0.001	0.001
Asphalt Shingle	0.015	0.002	0.016
Marble	0.030	0.005	0.031
Cement	0.015	0.002	0.015

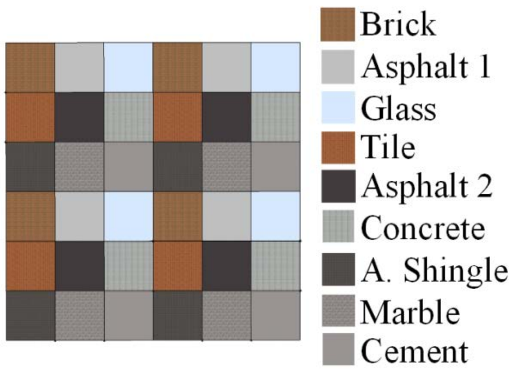


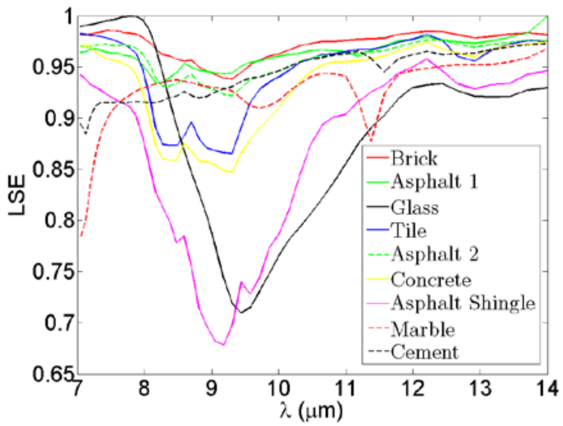
r^2	0.94
Bias	0.009
σ	0.014
RMSE	0.017

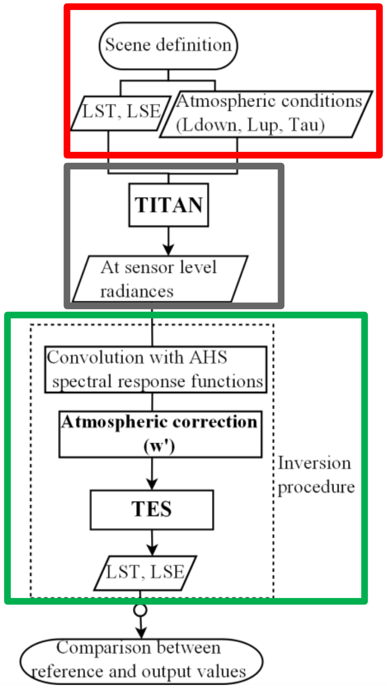
Overestimation of the emissivity.

Error budget: Atmospheric correction

Scene definition





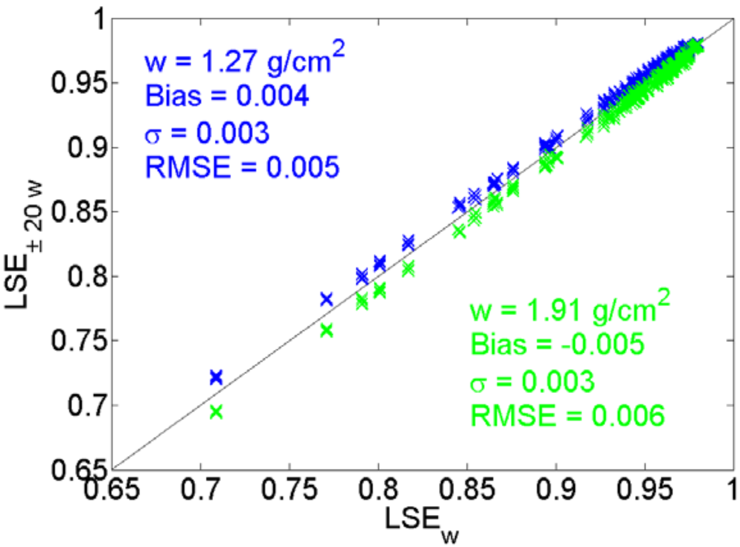


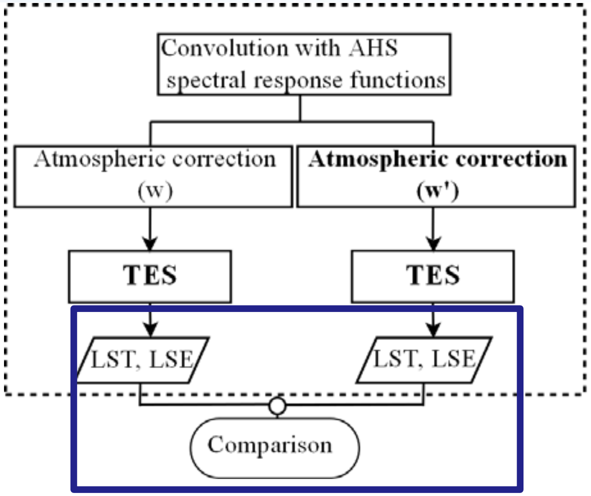
- LST: 295 K, 300 K, 305 K, 310 K
- 36 targets (9 materials at four LST)
- Atmospheric conditions: DESIREX atmospheric profile (w= 1.59 g/cm^2)
- illumination conditions: same as in DESIREX (θ_s=20.11º, φ_s=144.5º)
- Observation conditions: sensor altitude = 1866m; nadir viewing
- **Inversion procedure: new values of water vapour content;**
- **w' = ± 20%w (w'= 1.27 g/cm^2; 1.91 g/cm^2)**

ONERA

Error budget: Atmospheric correction

LSE analysis





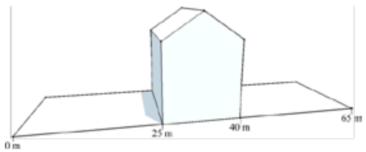
w	Material	r^2	Bias	σ	RMSE
$1.27 g/cm^2$	Brick	0.98	0.004	0.003	0.004
	Asphalt 1	0.95	0.003	0.003	0.004
	Glass	0.99	0.006	0.003	0.007
	Tile	0.99	0.004	0.003	0.005
	Asphalt 2	0.98	0.003	0.003	0.004
	Concrete	0.99	0.004	0.003	0.005
	Asphalt Shingle	0.99	0.007	0.004	0.008
	Marble	0.96	0.003	0.002	0.004
	Cement	0.97	0.003	0.002	0.004
$1.91 g/cm^2$	Brick	0.97	-0.004	0.003	0.005
	Asphalt 1	0.96	-0.004	0.003	0.005
	Glass	0.99	0.008	0.004	0.009
	Tile	0.99	-0.005	0.003	0.006
	Asphalt 2	0.98	-0.004	0.003	0.005
	Concrete	0.99	-0.005	0.003	0.006
	Asphalt Shingle	0.99	-0.008	0.004	0.009
	Marble	0.96	-0.004	0.003	0.005
	Cement	0.97	-0.004	0.003	0.005

+20%w → underestimation of the LSE
-20%w → overestimation of the LSE

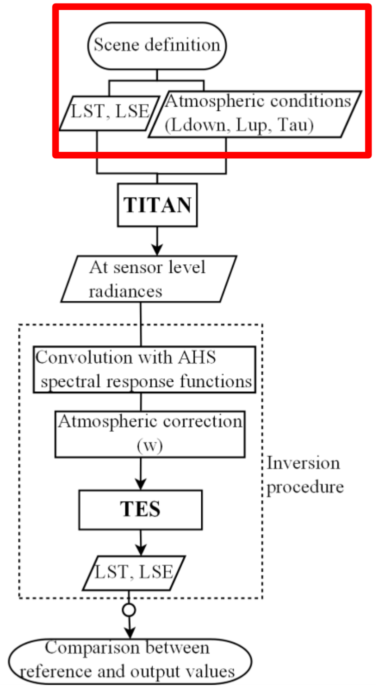
ONERA

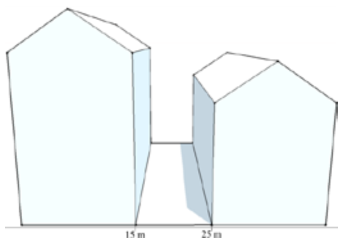
Error budget: 3D shape

Scene definition



- Building height : 15 m



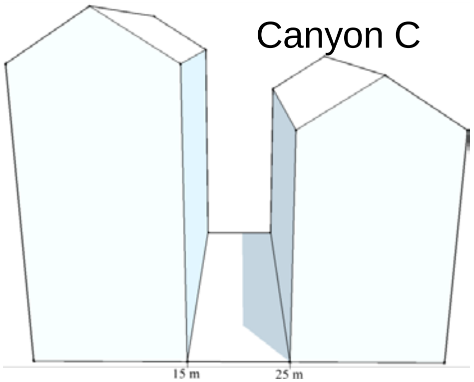


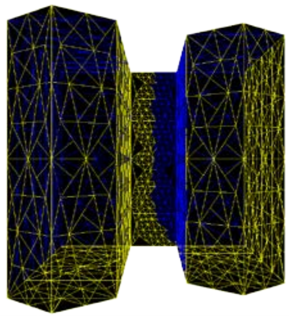
	Canyon A	Canyon B	Canyon C	Canyon D
Street width (m)	10	10	10	10
Buildings width (m)	15	15	15	15
Left building height (m)	15	22	30	50
Right building height (m)	12	16	24	44

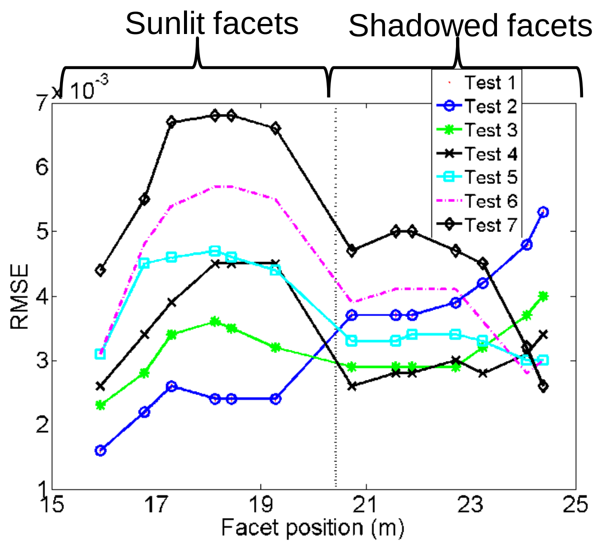
		Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Wall (Brick)	Sunlit LST (K)	296	301	306	311	316	321	326
	Shaded LST (K)	286	291	296	301	306	311	316
Street (Asphalt)	Sunlit LST (K)	316						
	Shaded LST (K)	301						
Roof (Tile)	Sunlit LST (K)	311						
AT (K)		300.8						

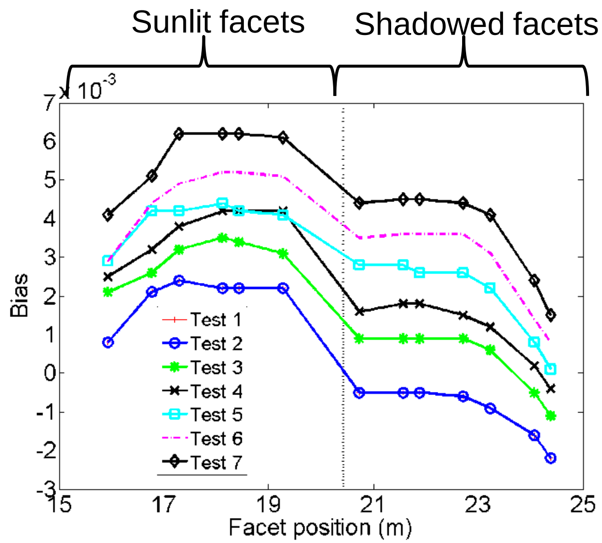
- Atmospheric conditions: DESIREX atmospheric profile (w= 1.59 g/cm^2)
- Illumination conditions: same as in DESIREX (θ_s=20.11°, φ_s=144.5°)
- Observation conditions: sensor altitude = 1866m; **nadir viewing**

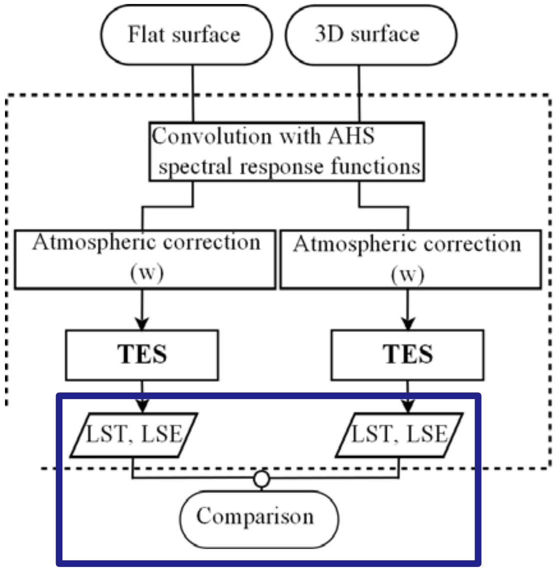
Error budget: 3D shape











- RMSE increases when the wall LST does. Except for the points closest to the shaded wall.
- When going from the sunlit to the shaded facets, the RMSE decreases.
- At the center of the canyon the RMSE increases with the canyons height.
- The bias decreases next to both walls.

Error budget: synthesis

Man-made materials (Flat assumption)

Error source	LSE RMSE	LST RMSE (K)
TES algorithm	0.017	0.9
Atmospheric correction	0.005	0.4
Root Sum Square	**0.018**	**1**

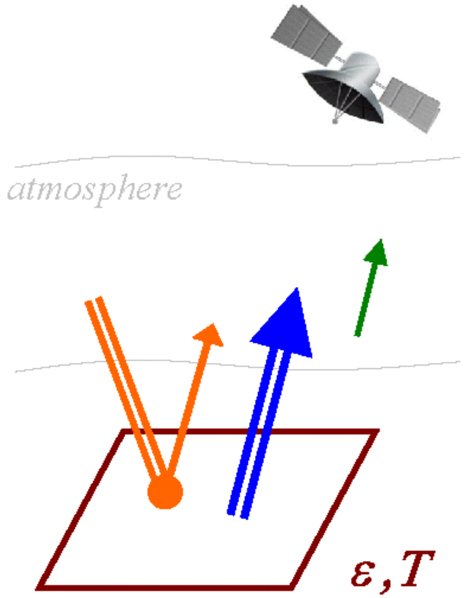
Asphalt (with 3D)

Error source	LSE RMSE	LST RMSE (K)
TES algorithm	0.001	0.1
Atmospheric correction	0.005	0.4
3D structure (Test 4)	0.005	0.2
Root Sum Square	**0.007**	**0.5**

R. Oltra-Carri´o, M. Cubero-Castan, X. Briottet & J. Sobrino, "Analysis of the performance of the TES algorithm over urban areas", IEEE Transactions on Geoscience and Remote Sensing, , vol.52, no.11, pp.6989-6998, Nov. 2014.

Unmixing: context

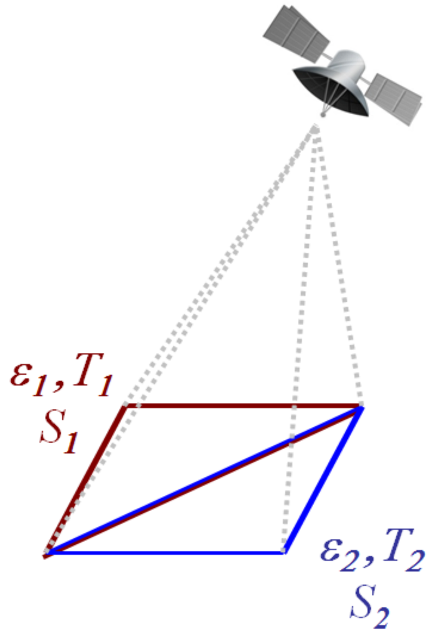
Pure pixel



Required steps:

- Atmospheric Compensation
- TES

Mixed pixel

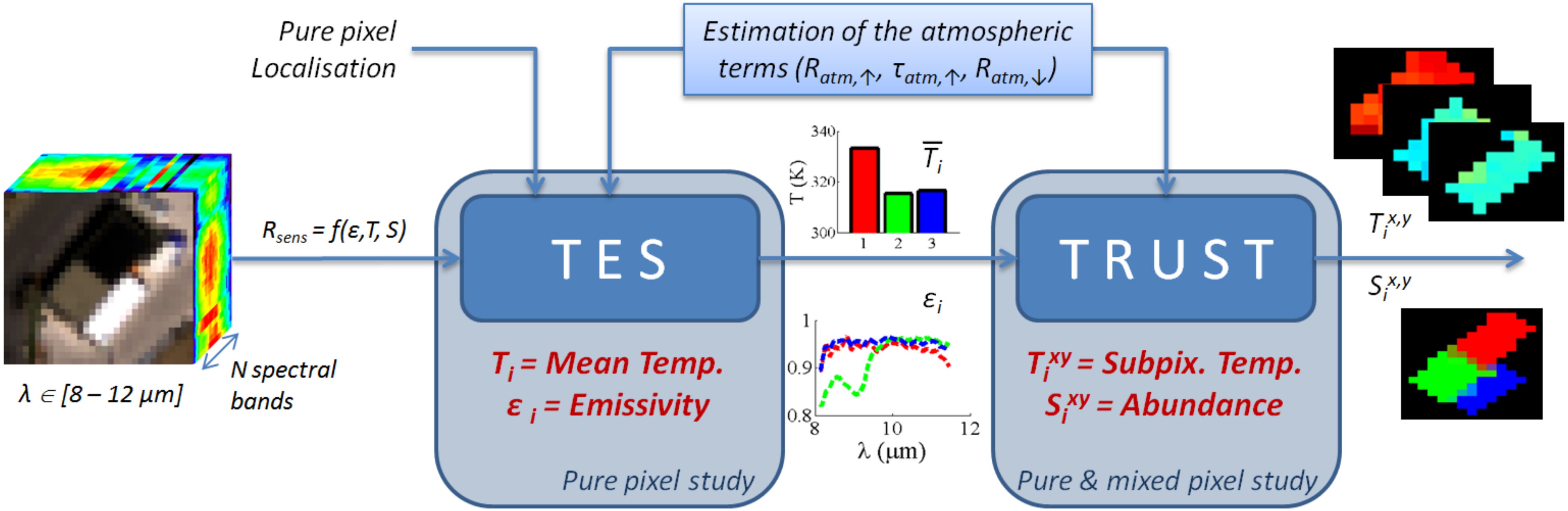


Three steps to retrieve:

- The number of **endmembers**,
- The **endmembers**: Ti, εi
- Their **abundances**.

"Aggregation process of optical properties and temperature over heterogeneous surfaces in the infrared domain", G. Fontanilles, X. Briottet, S. Fabre, S. Lefebvre and P.-F. Vandenhaute, Applied Optics, 20 Août 2010, Vol 49 N° 26, pp 4655-4669

Unmixing: TRUST methodology (ONERA, GIPSA-Lab)



A two-steps process:

- Estimation of the **mean temperature** and the **emissivity** on pure pixels, with a supervised or unsupervised localization.
- Estimation of the **subpixel temperature** and the **abundances** with TRUST method

Constraint: take into account the intraclass spatial variability of the temperature

Manuel Cubero-Castan, Jocelyn Chanussot, Véronique Achard, Xavier Briottet, Michal Shimoni. "A physics-based unmixing method to estimate subpixel temperatures on mixed pixels", Geoscience and Remote Sensing, IEEE Transactions on. Vol. 53, N. 4, 03/2015.

Unmixing: data set

Image: TASI sensor (32 bands, 8-12 *µm*) with 1m GSD.
DUCAS Experiment (EDA) at Zeebruges, Belgium (2011).

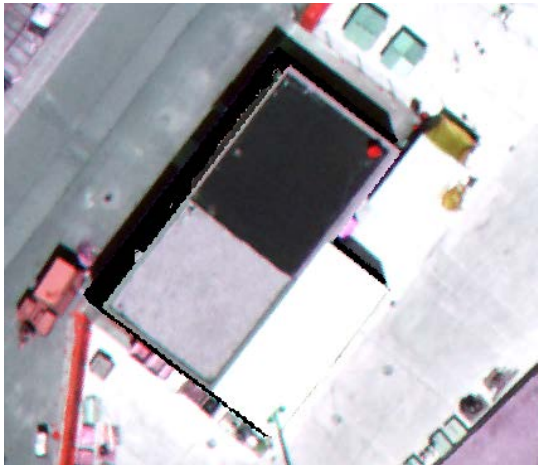
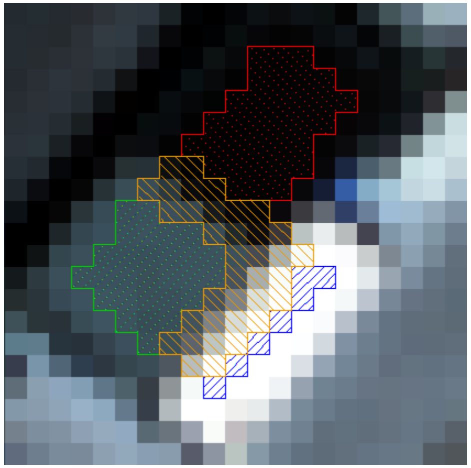
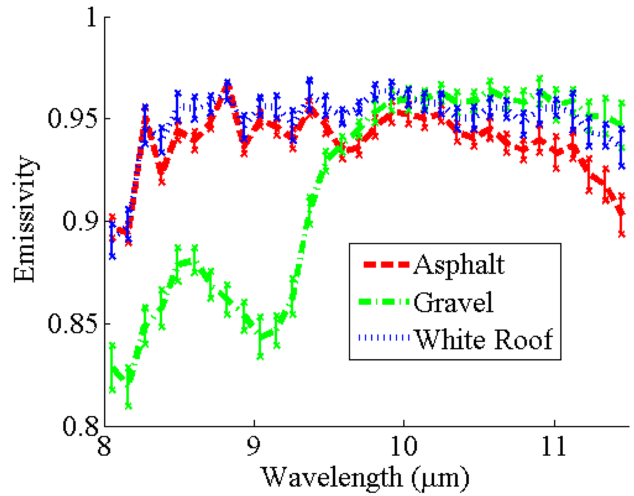


Image Pan - CANON/FOI - EDA DUCAS



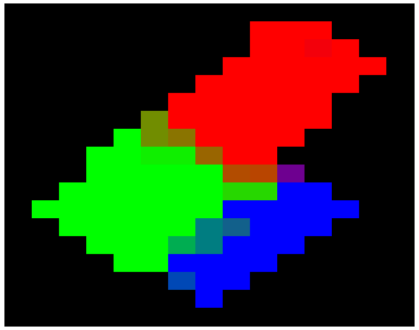
Pure and mixed pixels location - Image EAGLE/Fraunhofer IOSB - EDA DUCAS



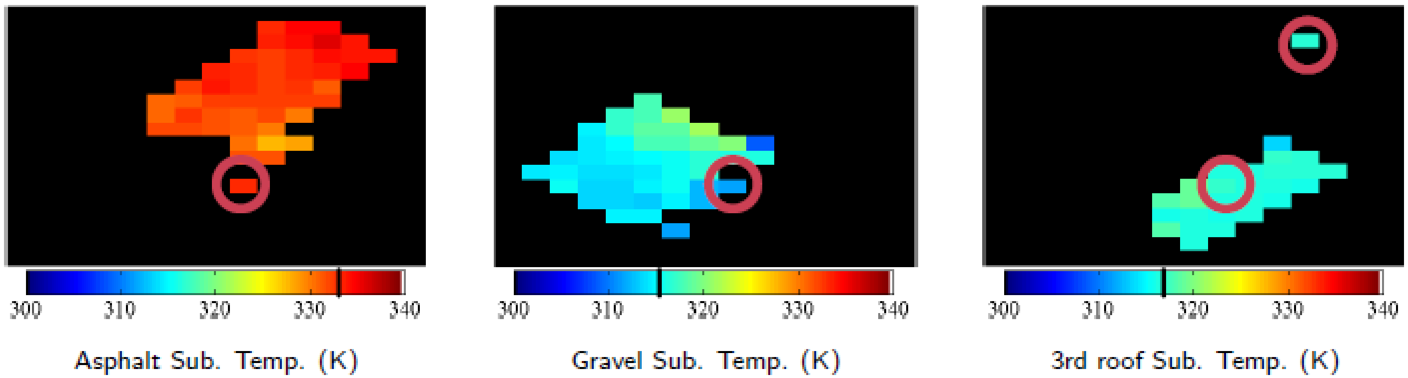
	Asph.	Grav.	3rd Roof
T_{mean}	333.2	315.3	316.6
T_{std}	1.3	1.4	0.4

Unmixing: results

Abundance map



Sub pixel temperature



- **Abundance: TRUST method favors the sparsity**
- **Coherent** estimation of subpixel temperatures when 2 endmembers
- Errors: mis-estimation of the abundance, 3 endmembers mixed pixel

General conclusion

PART 1
directional anisotropy

- ♦ **Experimental methodology for characterizing brightness temperature directional anisotropy efficient, but can be improved (a little)**
- ♦ **Simplified simulation methodology combining a transfer model and 3D information allows to simulate directional anisotropy.**
- ♦ **Impact of small scale heterogeinities on daytime anisotropy to be evaluated**
- ♦ **Nighttime anisotropy < 2K**

PART 2
emissivity

- ♦ **Documentation of spectral emissivity → MEMOIRES database**
- ♦ **Availability of a complete simulator LES, LST surface ↔ sensor (radiative transfer withTITAN + atmosphere + instrument)**
- ♦ **Adaptation of TES to urban surfaces**