

SEMINARIO:

AVANCES EN ESPECTRO-RADIOMETRÍA

3 y 4 de diciembre de 2009



Sensores Infrarrojos

Instrumentación, Protocolos de medidas y Aplicaciones

José A. Sobrino, Juan C. Jiménez, Guillem Sòria, Juan Cuenca, Belen Franch, Victoria Hidalgo, Rosa Oltra, Yves Julien, Cristian Mattar

Unidad de Cambio Global



VNIVERSITAT
ID VALÈNCIA



Image Processing Laboratory

CONTENIDOS

INTRODUCCIÓN

SENSORES INFRARROJOS

- de campo
- aerotransportados
- a bordo de satélite

MEDIDA DE LA TEMPERATURA Y LA EMISIVIDAD

- método de la caja
- algoritmo TES
- medidas angulares
- medidas de laboratorio

APLICACIONES

- actividades de calibración/validación
- flujos de energía y evapotranspiración
- efecto de isla térmica
- otras aplicaciones...

CONCLUSIONES

INTRODUCCIÓN

Teledetección térmica:

Menos utilizada en comparación con sensores Visible-Infrarrojo cercano

Necesaria para comprender y analizar los procesos que ocurren en la superficie terrestre y en la interfase superficie-atmósfera (**la mayoría de los flujos en esta interfase sólo pueden parametrizarse mediante datos térmicos**).

Principales variables a obtener:

TEMPERATURA DE LA SUPERFICIE TERRESTRE

EMISIVIDAD DE LA SUPERFICIE TERRESTRE (magnitud espectral)

Aplicaciones baja resolución:

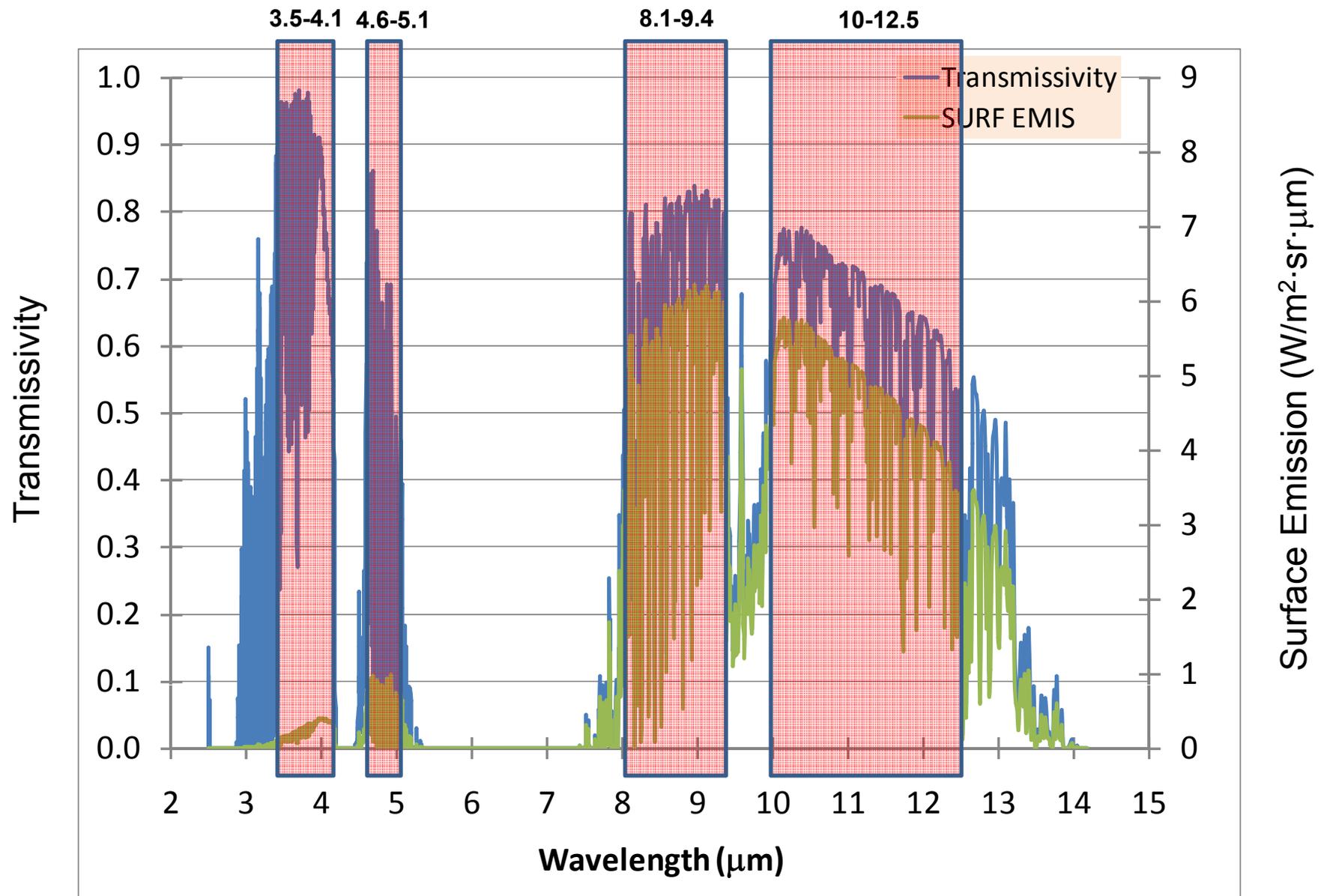
Temperatura: climatología, detección de cambios, oceanografía

Emisividad: Poco utilizada. “input” para algoritmos de temperatura.

Media/alta resolución:

Temperatura: balance de energía (flujos de calor => ET => gestión de recursos hídricos)

Emisividad: geología (identificación de minerales), cambios en la cobertura terrestre

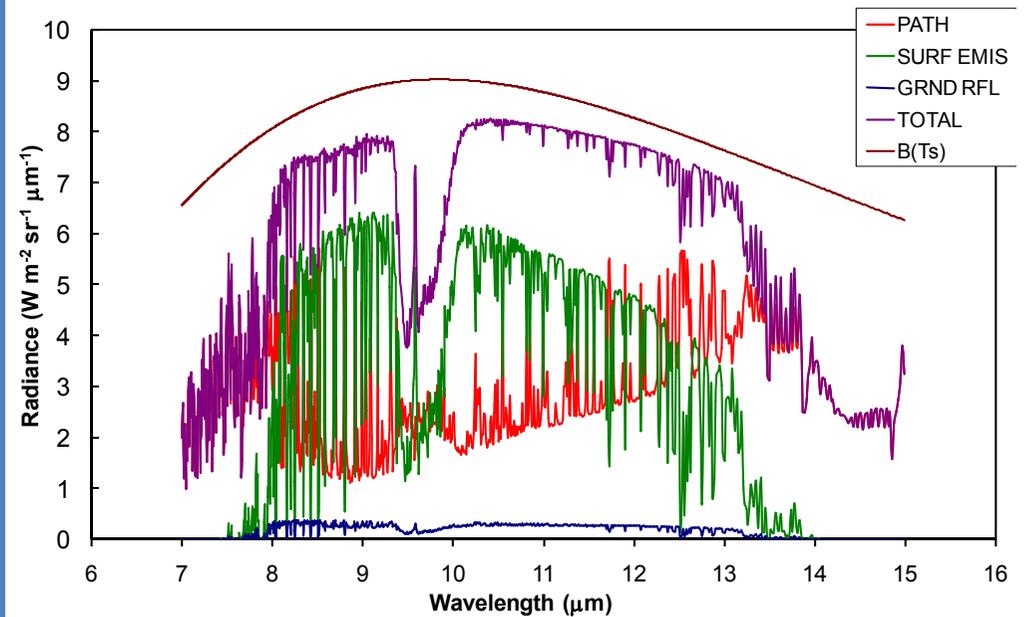
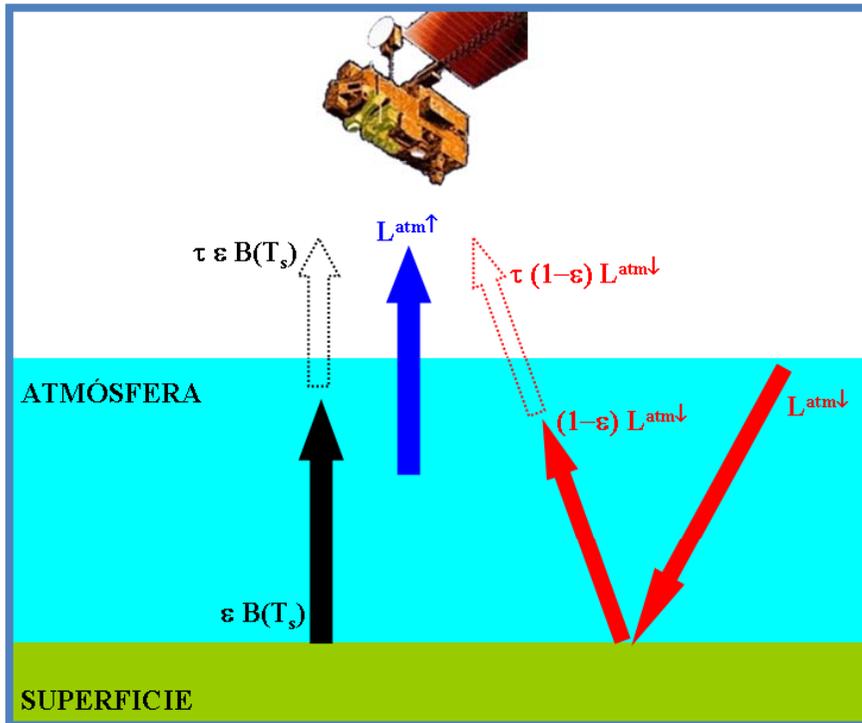


INTRODUCCIÓN

ECUACIÓN DE TRANSFERENCIA RADIATIVA EN EL TÉRMICO (8-14 μm)

$$L_{\lambda}^{sen} = \left[\varepsilon_{\lambda} B_{\lambda}(T_s) + (1 - \varepsilon_{\lambda}) L_{\lambda}^{atm\downarrow} \right] \tau_{\lambda} + L_{\lambda}^{atm\uparrow}$$

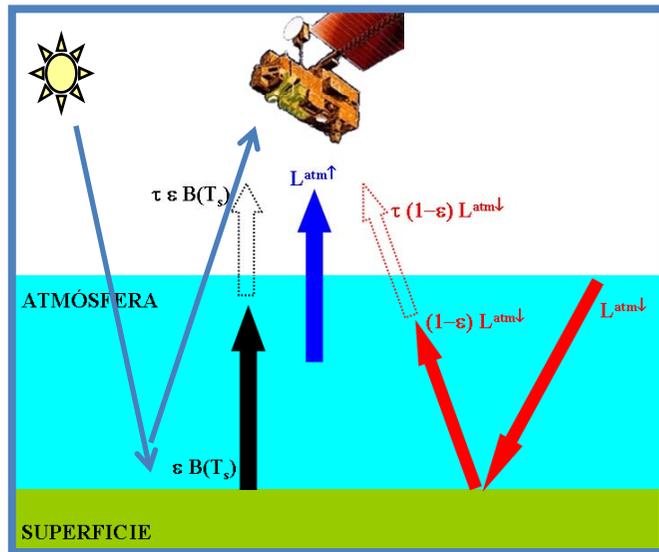
($\lambda \rightarrow i$)
 B: Planck's law
 Brightness temperature: $L^{sen} \equiv B(T^{sen})$
 LST: **Ts**



INTRODUCCIÓN

INFRARROJO DE ONDA MEDIA (3-5 μm)

$$L_{\lambda}^{sen} = \left[\varepsilon_{\lambda} B_{\lambda}(T_s) + (1 - \varepsilon_{\lambda}) L_{\lambda}^{atm\downarrow} + \frac{I_{sol,\lambda}^{TOA} \tau_{sol,\lambda} \rho_{\lambda}}{\pi} \right] \tau_{\lambda} + L_{\lambda}^{atm\uparrow}$$



Condiciones nocturnas:

$$L_{\lambda}^{sen} = \left[\varepsilon_{\lambda} B_{\lambda}(T_s) + (1 - \varepsilon_{\lambda}) L_{\lambda}^{atm\downarrow} \right] \tau_{\lambda} + L_{\lambda}^{atm\uparrow}$$

(igual que en el térmico)

Emisividad: permite una mejor caracterización de las superficies
Temperatura: su estimación es menos sensible a errores en la emis.

INTRODUCCIÓN

Problemas a resolver para la estimación de Temperatura y Emisividad:

- Acoplamientos Temp./Emis.
- Acoplamiento Emis. y L_{\downarrow}

ACOMPLAMIENTO ENTRE TEMPERATURA Y EMISIVIDAD:

Siempre tenemos una incógnita más que ecuaciones.

Para un sensor con N bandas:

$$\begin{aligned} L_1^{sen} &= \left[\varepsilon_1 B_1(T_s) + (1 - \varepsilon_1) L_1^{atm\downarrow} \right] \tau_1 + L_1^{atm\uparrow} \\ L_2^{sen} &= \left[\varepsilon_2 B_2(T_s) + (1 - \varepsilon_2) L_2^{atm\downarrow} \right] \tau_2 + L_2^{atm\uparrow} \\ &\dots \\ L_N^{sen} &= \left[\varepsilon_N B_N(T_s) + (1 - \varepsilon_N) L_N^{atm\downarrow} \right] \tau_N + L_N^{atm\uparrow} \end{aligned}$$

N Ecuaciones
(N+1) Incógnitas: (N emisividades + T_s)

(problema indeterminado)

SENSORES INFRARROJOS: campo

THERMAL RADIOMETERS



CALIBRATION SOURCES



DIFFUSE PLATE



GONIOMETER



BOX FOR EMISSIVITY MEASUREMENTS



THERMAL CAMERAS



SENSORES INFRARROJOS: campo

Radiómetros de banda ancha (8-14 μm)



RAYTEK ST8

-30 to 100 °C
 ± 0.5 °C
FOV: 8°



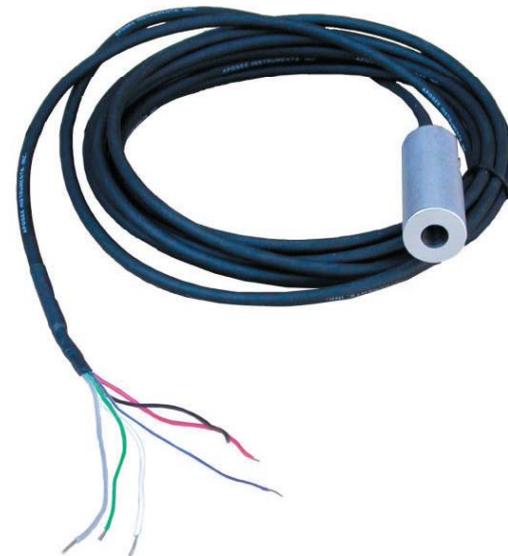
RAYTEK MID

-40 to 600 °C
 ± 0.5 °C
FOV: 20°



EVEREST 3000

-40 to 100 °C
 ± 0.5 °C
FOV: 4°



**Apogee
IR-120 (Campbell)**

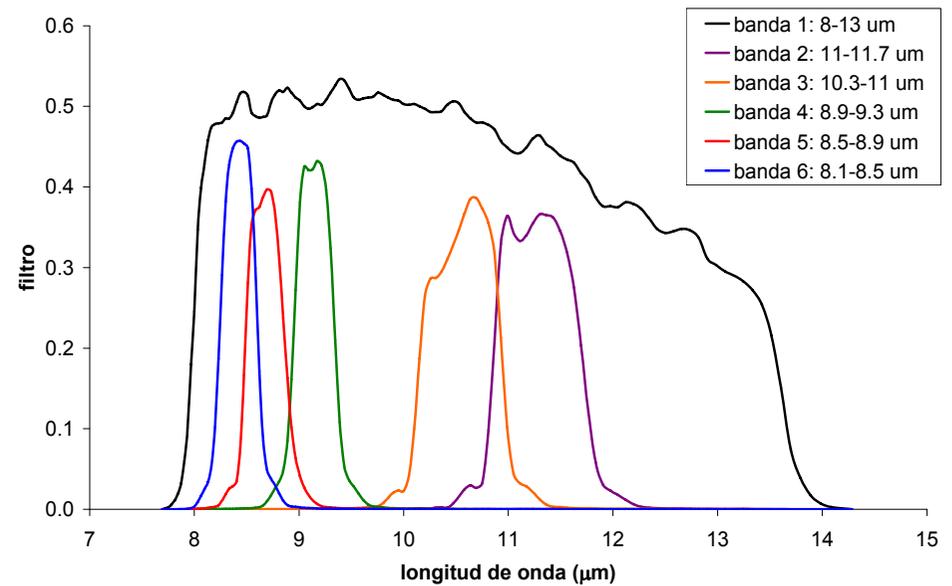
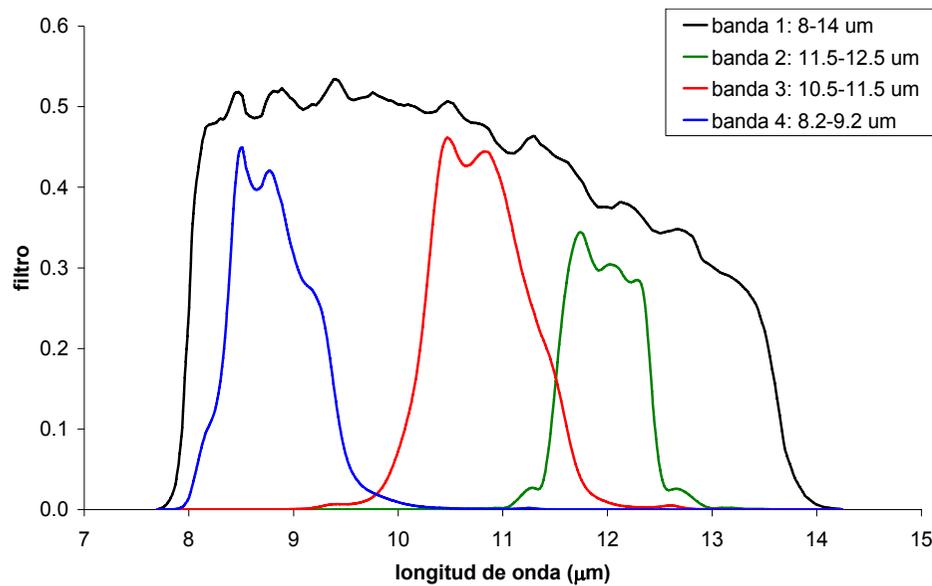
-25 to 60 °C
 ± 0.2 °C
FOV: 20°

SENSORES INFRARROJOS: campo

Radiómetros multibanda:
CIMEL



MODELO	BANDAS	RANGO	PRECISIÓN	VISIÓN
CIMEL 312-1	8-13 μm 8.2-9.2 μm 10.3-11.3 μm 11.5-12.5 μm	-80 a 60 $^{\circ}\text{C}$	0.1 $^{\circ}\text{C}$	10 $^{\circ}$
CIMEL 312-2	8-13 μm 11-11.7 μm 10.3-11 μm 8.9-9.3 μm 8.5-8.9 μm 8.1-8.5 μm	-80 a 60 $^{\circ}\text{C}$	0.1 $^{\circ}\text{C}$	10 $^{\circ}$



SENSORES INFRARROJOS: campo

The Micro Fourier Transform Interferometer (μ FTIR)—A New Field Spectrometer for Acquisition of Infrared Data of Natural Surfaces

Simon J. Hook and Anne B. Kahle**

*Jet Propulsion Laboratory, California Institute of Technology, Pasadena

Address correspondence Simon J. Hook, JPL, MS 183-501, 4800 Oak Grove Dr., Pasadena, CA 91109.

Received 5 April 1995; revised 4 October 1995.

REMOTE SENS. ENVIRON. 56:172-181 (1996)

Peso: 16 kg

Medidas de 2 a 14 μm

intervalo espectral de 6 cm^{-1}

(0.002-0.015 μm entre 2 y 5 μm)

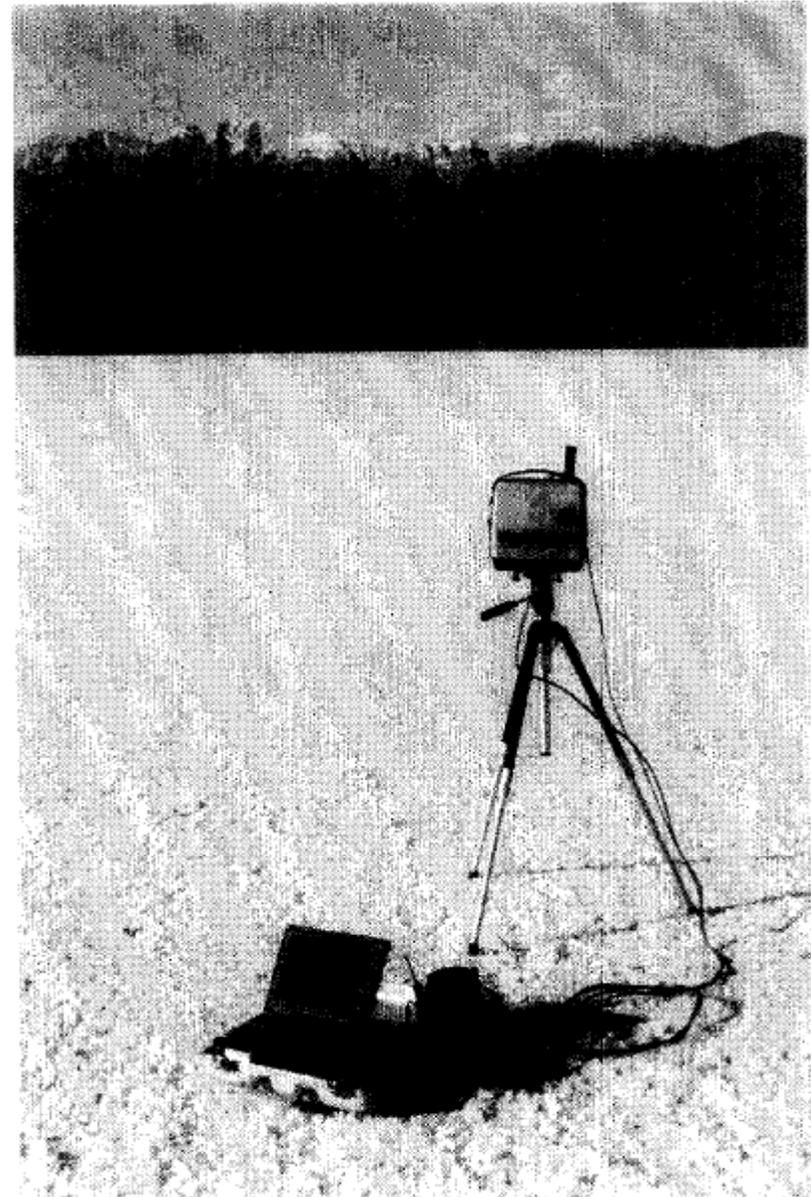
(0.015-0.117 μm entre 5 y 14 μm)

Detectores:

2-5 μm : Indio-Antimonio (InSb)

5-14 μm : Mercurio-Cadmio-Telurio (HgCdTe)

Enfriados con nitrógeno líquido



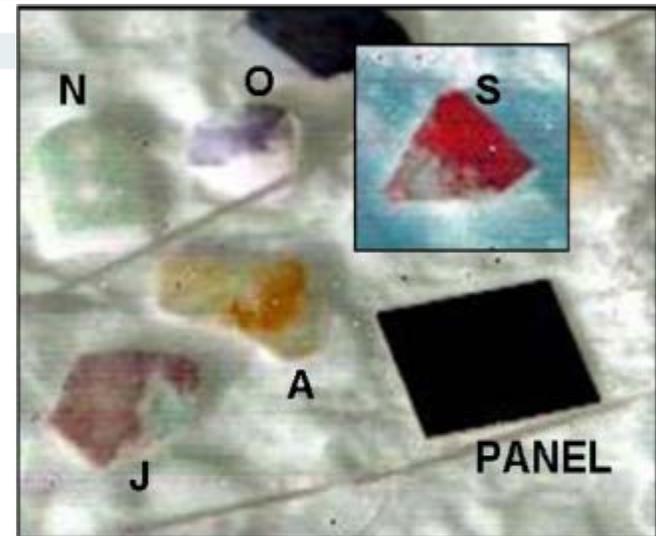
SENSORES INFRARROJOS: campo

IEEE GEOSCIENCE AND REMOTE SENSING LETTERS, VOL. 6, NO. 1, JANUARY 2009

Longwave Thermal Infrared Spectral Variability in Individual Rocks

Lee Balick, Alan Gillespie, Andrew French, Iryna Danilina, Jean-Pierre Allard, and Amit Mushkin

	Unit	HYPERCAM	
		LW	MW
Spectral Band	μm	8 - 11	3 - 5
Number of Pixels	-	320 x 256	
Spectral Resolution	cm^{-1}	0.25 - 150	
IFOV	mrad	0.35	
Communication	-	Ethernet	
Data Transfer	-	Cameralink	
Acquisition Software	-	FT Pro	
Detector Cooling	-	Closed Cycle	
Power Source	-	28 V (DC) or 120 V (AC)	
Weight	lbs	< 60	



(135 bandas)



SENSORES INFRARROJOS: aerotransportados



Digital Airborne Imaging Spectrometer (DAIS)

1998, 1999, 2000

79 spectral bands

32 VNIR
8+32 SWIR
1 MIR?
6 TIR

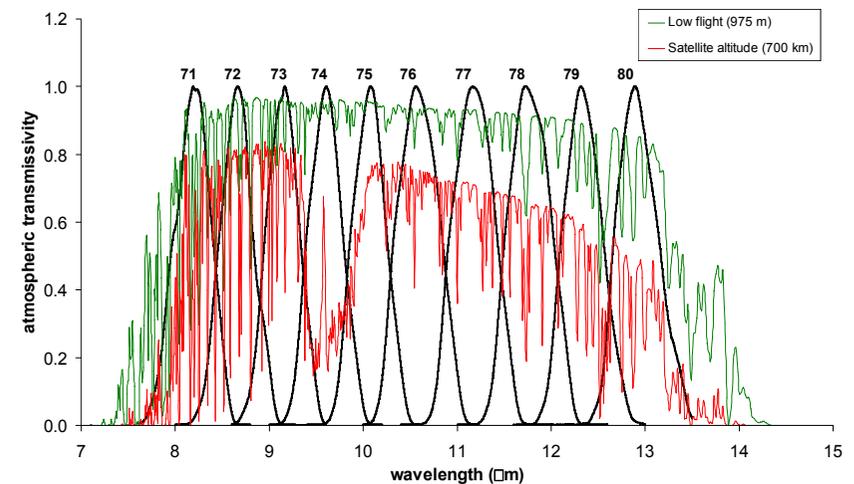
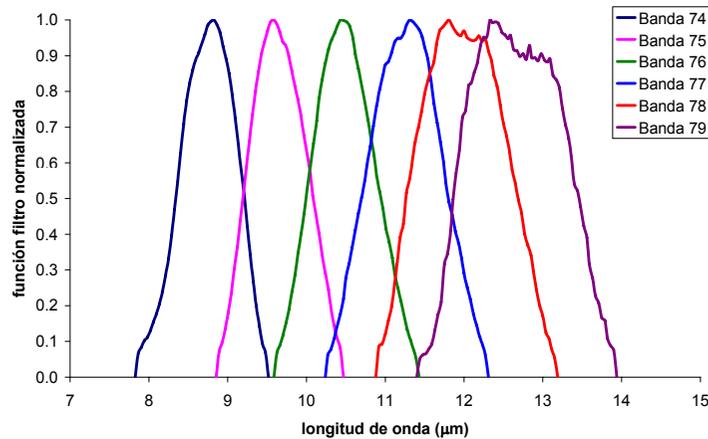
Airborne Hyperspectral Scanner (AHS)

From 2004 to present

80 spectral bands



20 VNIR
1+42 SWIR
7 MIR
10 TIR



SENSORES INFRARROJOS: aerotransportados



Remote Sensing of Environment 76 (2001) 93–102

Remote Sensing
of
Environment

www.elsevier.com/locate/rse

The MODIS/ASTER airborne simulator (MASTER) — a new instrument for earth science studies

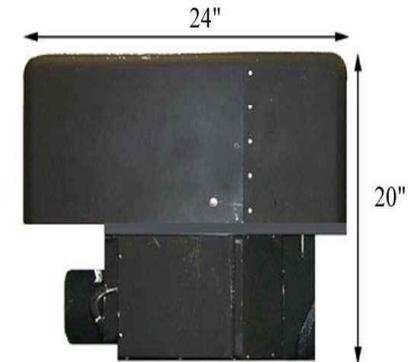
Simon J. Hook^{a,*}, Jeffrey J. Myers^b, Kurtis J. Thome^c, Michael Fitzgerald^b, Anne B. Kahle^a

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^bSAIC, NASA Ames Research Center, Moffett Field, CA 94035, USA

^cOptical Sciences Center, University of Arizona, Tucson, AZ 85721, USA

Received 25 October 1999; accepted 23 July 2000



Summary characteristics of the MASTER instrument

Wavelength range	0.4–13 μm
Number of channels	50
Number of pixels	716
Instantaneous field of view	2.5 mrad
Total field of view	85.92°
Platforms	DOE King Air Beachcraft B200, NASA ER-2, and NASA DC-8
Pixel size DC-8	10–30 m
Pixel size ER-2	50 m
Pixel size B200	5–25 m
ER-2 range (without refueling)	3700 statute miles
B200 range (without refueling)	700 statute miles
DC-8 range (without refueling)	5403 statute miles
Scan speeds	6.25/12.5/25 rps
Products	Radiance at sensor (Level 1B)
Calibration VIS-SWIR	Laboratory Integrating Sphere
Calibration MIR-TIR	2 on-board blackbodies
Data Format	Hierarchical Data Format (HDF)
Digitization	16-bit

SENSORES INFRARROJOS: aerotransportados

ELSEVIER

Remote Sensing of Environment 80 (2002) 447–459

www.elsevier.com/locate/rse

First use of an airborne thermal infrared hyperspectral scanner for
compositional mapping

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^cThe Aerospace Corporation, P.O. Box 92957, Los Angeles, CA 90009-2957, USA

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Received 26 January 2001; received in revised form 26 June 2001; accepted 22 September 2001

Spatially Enhanced Broadband
Array Spectrograph System (**SEBASS**)

Espectrómetro de prisma enfriado con helio líquido

Mide en dos rangos espectrales (128 bandas):

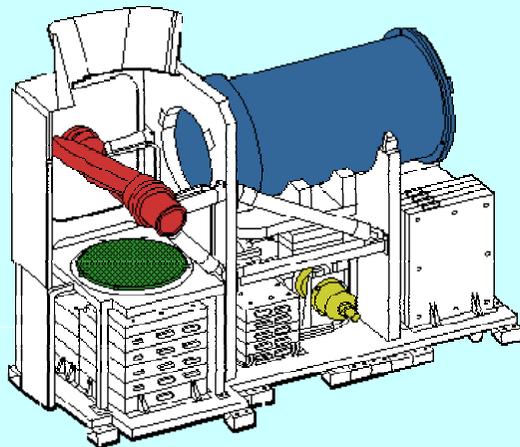
2.4–5.3 μm

7.5–13.5 μm

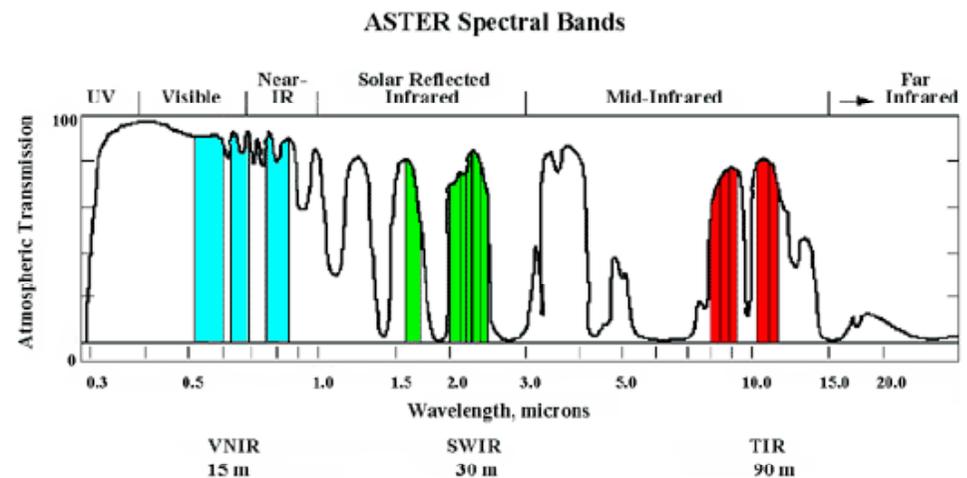
resolución espectral: 7 cm^{-1} (0.088 μm @11.25 μm)



SENSORES INFRARROJOS: satélites



ASTER: Advanced Spaceborne Thermal Emission and Reflection radiometer



Landsat, CEBERS, etc.: 1 banda térmica

baja resolución: AVHRR, MODIS, SEVIRI, AATSR, GOES, etc.

MEDIDAS DE T & ε : introducción

PROTOCOLOS DE MEDIDAS

Transectos

Puntos fijos (mástiles)

MEDIDA DE LA TEMPERATURA

Emisión (acoplamiento T/ ε)

MEDIDA DE LA EMISIVIDAD

Emisión (acoplamiento T/ ε)

Reflexión (ley Kirchhoff $\varepsilon = 1 - \rho$)

Protocolos de medida: http://lpvs.gsfc.nasa.gov/LST_background.html



NASA GODDARD SPACE FLIGHT CENTER | + NASA Homepage

CEOS WORKING GROUP ON CALIBRATION & VALIDATION
Committee on Earth Observation Satellites
Land Product Validation Subgroup

Home Landcover Biophysical Surface Rad LST/Emissivity Fire/Burn Soil Moisture

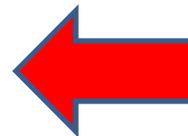
Within the newly created structure of the LPV subgroup, the Landcover focus area leads are

[Simon Hook](#) of the NASA Jet Propulsion Laboratory (JPL)
[Jose Sobrino](#) of the University of Valencia, Department of Earth Physics and Thermodynamics

Land Surface Temperature/Emissivity Focus Area Objectives

Land surface temperature and emissivity (LST&E) products are used in wide variety of applications and are available at multiple spatial resolutions from a few meters to many kilometers. The primary objective of this group is to help the community reconcile the differences between products to enable the products to be readily interchanged depending on product availability for any given location. In 2008 the scientific community engaged in generating LST&E products held an [LST workshop](#) at the NOAA offices in Asheville, North Carolina to bring the community together to start addressing what needs to be accomplished in order to meet their primary objective. Items that plan to be addressed in the near future include:

- Define protocols for the validation of remotely sensed LST&E
- Define protocols for the collection of *in situ* LST&E data
- Define the necessary metadata for LST&E remote sensing
- Define the necessary metadata for *in situ* LST&E data
- Identify existing sites where suitable LST&E data are acquired



MEDIDAS DE T & ε : introducción

MEDIDA POR EMISIÓN

Cuando se realizan medidas en superficie, se considera despreciable la capa atmosférica entre el sensor y la superficie

$$\tau_i \approx 1 \text{ y } L_i^\uparrow \approx 0$$

$$L_i^{at-sensor} = \left[\varepsilon_i B_i(Ts) + (1 - \varepsilon_i) L_i^\downarrow \right] \tau_i + L_i^\uparrow \quad \longrightarrow \quad L_i^{radiometer} = \varepsilon_i B_i(Ts) + (1 - \varepsilon_i) L_i^\downarrow$$

Una vez medida ε y L^\downarrow ,
podemos obtener la Ts:

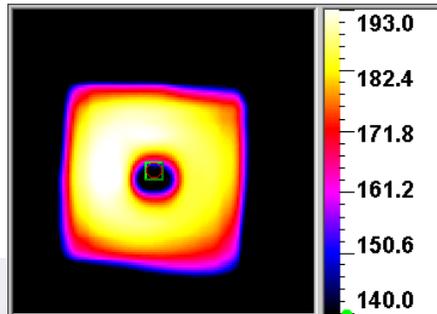
$$B_i(Ts) = \frac{L_i^{radiometer} - (1 - \varepsilon_i) L_i^\downarrow}{\varepsilon_i}$$

Una vez medida Ts y L^\downarrow ,
podemos obtener la ε :

$$\varepsilon_i = \frac{L_i^{radiometer} - L_i^\downarrow}{B_i(Ts) - L_i^\downarrow}$$

MEDIDAS DE T & ε: método de la caja

Caja con tapa fría y caliente



El método de la caja permite la medida independiente de emisividad y temperatura

$$\varepsilon_s = \frac{L_{t1} - L_s^1}{L_{t1} - L_s^2}$$
$$B(T_s) = L_s^1$$

L_{t1} : radiancia tapa caliente

L_s^1 : radiancia de la muestra con tapa fría

L_s^2 : radiancia de la muestra con tapa caliente

La tapa caliente necesita alimentación eléctrica (necesidad de un grupo electrógeno para su uso en campo).

(Las medidas tapa fría/tapa caliente deberían de ser simultáneas, y se asume $\varepsilon=0$ para las paredes de la caja, y $\varepsilon=1$ para la tapa caliente)

MEDIDAS DE T & ε: algoritmo TES

Gillespie et al. (1998), IEEE Trans. Geosci. Rem. Sens., 36(4), 1113-1126
Compuesto por 3 módulos: NEM, RATIO, MMD

NEM (Normalized Emissivity Method) Module

$$B_i(T'_s) = \frac{L_{\text{sup},i} - (1 - \varepsilon_{in})L_i^{\text{atm}\downarrow}}{\varepsilon_{in}}$$

$$T_s = \max(T'_s)$$

→ **Temperature**

$$\varepsilon_i = \frac{L_{\text{sup},i} - L_i^{\text{atm}\downarrow}}{B_i(T_s) - L_i^{\text{atm}\downarrow}}$$

→ **Band emissivities**

Iterative Procedure. Maximum number of iterations: 12

MEDIDAS DE T & ε : algoritmo TES

RATIO Module

The beta spectrum is obtained by normalizing the band emissivities

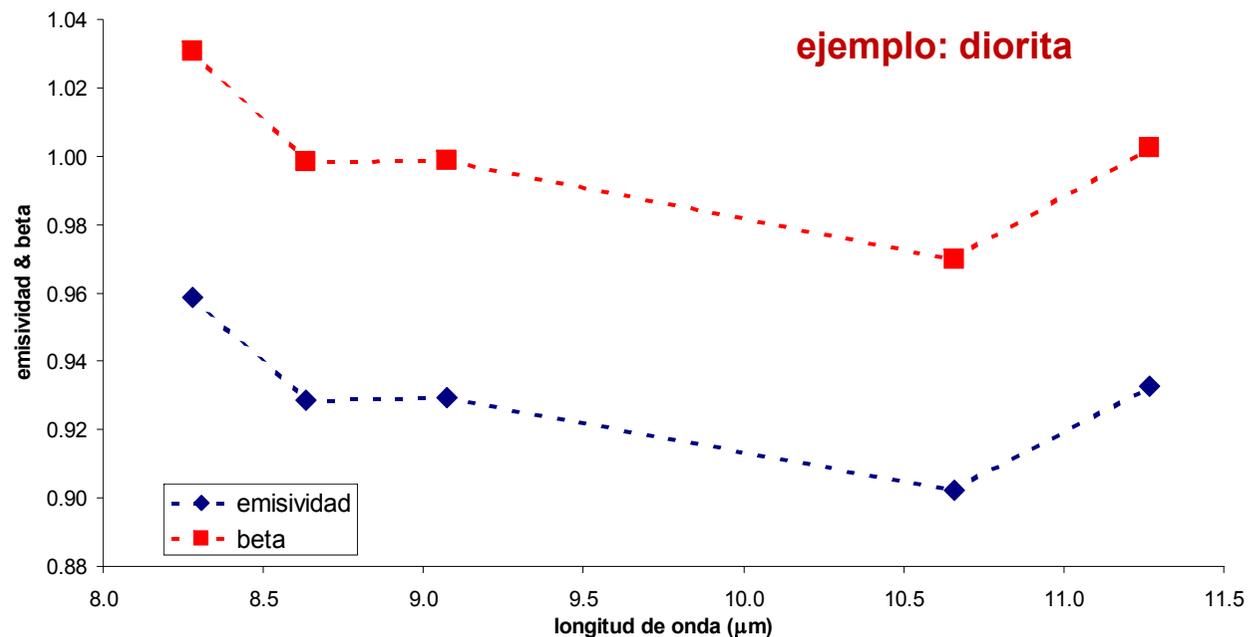
The beta spectrum preserves the shape, but not the values

The beta spectrum is less sensitive to uncertainties on temperature

β -spectrum

$$\beta_i = \frac{\varepsilon_i}{\bar{\varepsilon}}$$

$$\bar{\varepsilon} = \frac{\sum_{i=1}^N \varepsilon_i}{N}$$



MEDIDAS DE T & ε : algoritmo TES

MMD (Maximum Minimum Difference) Module

Land Surface Emissivity is obtained from an empirical relationship between minimum emissivity and MMD

Spectral Contrast (MMD)

$$\text{MMD} = \max(\beta_i) - \min(\beta_i)$$

**Relation between minimum ε
and spectral contrast**

$$\varepsilon_{\min} = 0.994 - 0.687 \text{MMD}^{0.737}$$

Expression used for ASTER

Band emissivity recovery

$$\varepsilon_i = \beta_i \left(\frac{\varepsilon_{\min}}{\min(\beta_i)} \right)$$

Land Surface Temperature

$$T = \frac{c_2}{\lambda_i^*} \left[\ln \left(\frac{c_1 \varepsilon_i^*}{R_i^* \lambda_i^{*5}} + 1 \right) \right]^{-1}$$

TES emissivities can be used again in the NEM module in order to apply again the RATIO and MMD modules.

MEDIDAS DE T & ε: laboratorio

Consideraciones acerca de las medidas en interiores (laboratorio)

$$L_i(T_{rad}) = \varepsilon_i B_i(T_s) + (1 - \varepsilon_i) L_i^\downarrow$$

MEDIDA DIRECTA DEL RADIÓMETRO TÉRMINO EMISIÓN TÉRMINO REFLEXIÓN

MEDIDA ÓPTIMA: TÉRMINO EMISIÓN >> TÉRMINO REFLEXIÓN

1) Medida en exteriores (cielo despejado): $B(T_s) \gg L^\downarrow$

2) Medida en interiores (laboratorio): $B(T_s) \sim L^\downarrow \rightarrow$ para conseguir las condiciones del caso 1 es necesario calentar la muestra

MEDIDAS DE T & ε : laboratorio

Como en el laboratorio el término de reflexión (radiancia que proviene de los alrededores y es reflejada por la superficie) tiene una contribución importante a la radiancia medida por el sensor, es necesario calentar la muestra para conseguir que $B(T_s) \gg L \downarrow$

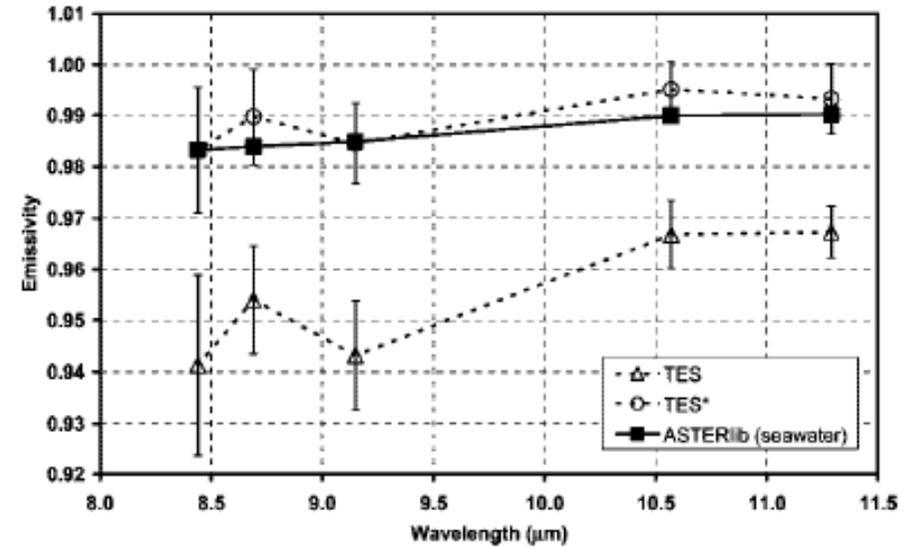
Ejemplo: Estufa calefactora situada debajo de una plancha de cobre.

Otra opción: uso combinado del método de la caja y el algoritmo TES

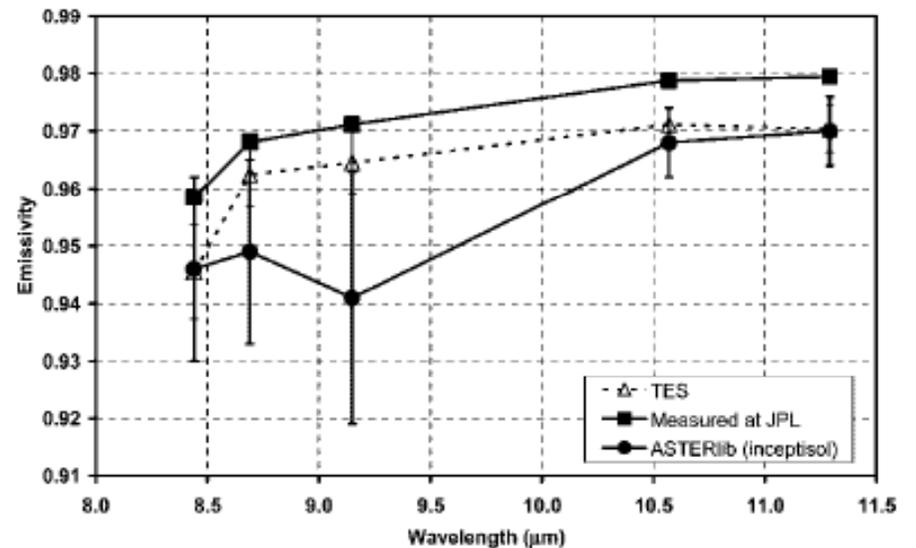


MEDIDAS DE T & ϵ : algunos resultados

AGUA

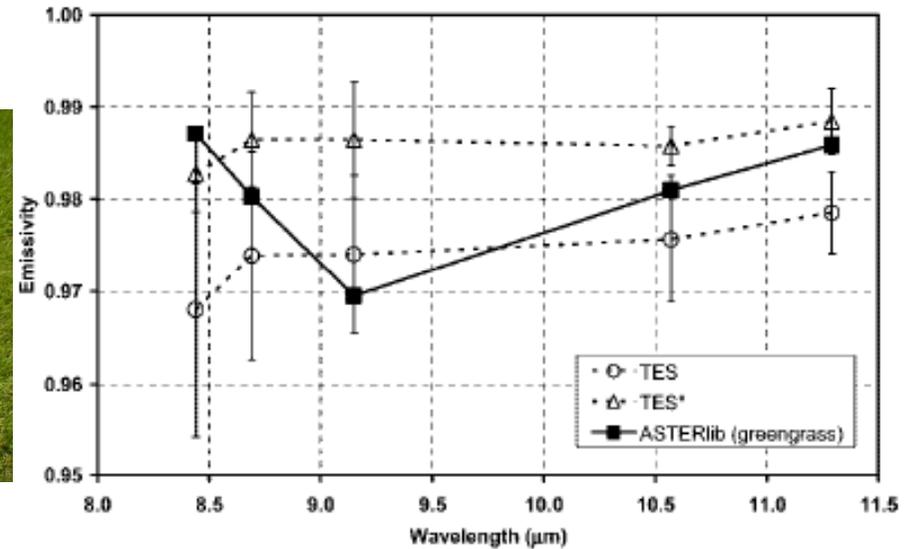


SUELO DESNUDO

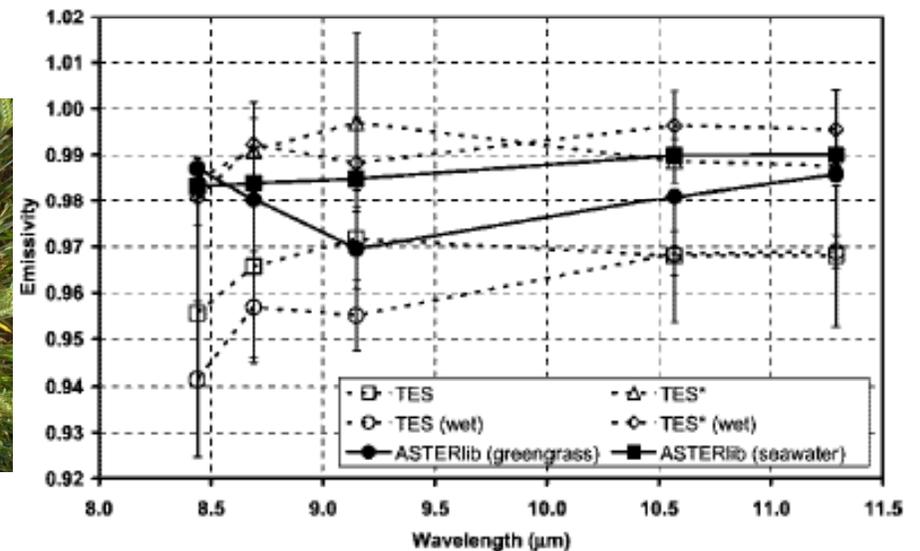


MEDIDAS DE T & ϵ : algunos resultados

HIERBA VERDE



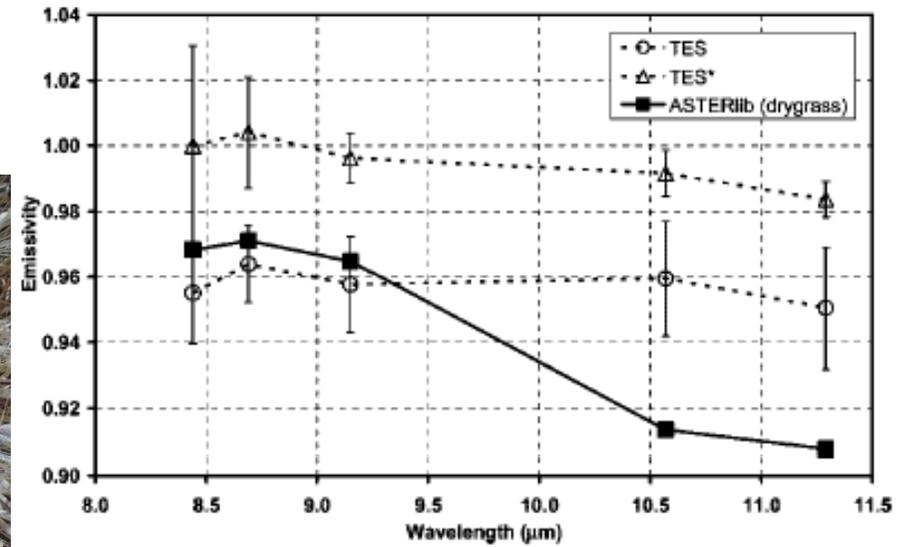
TRIGO VERDE



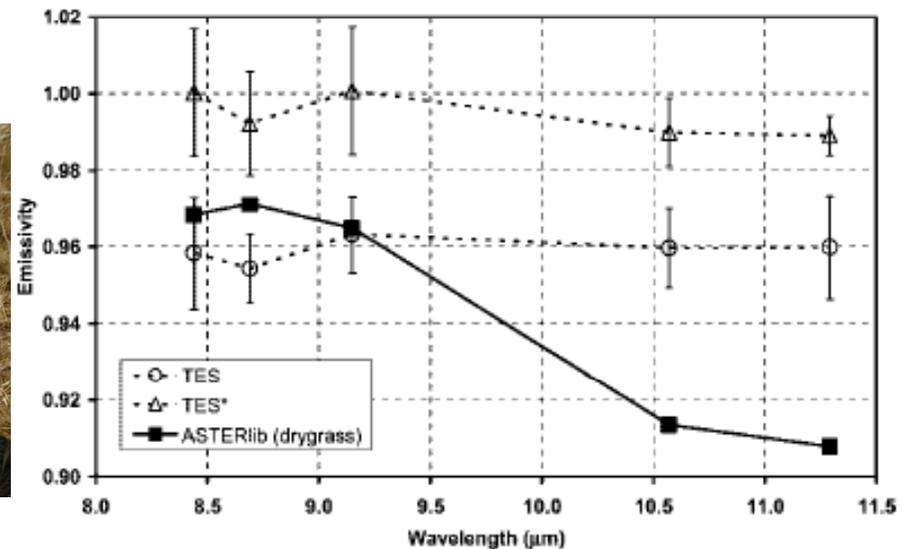
MEDIDAS DE T & ε: algunos resultados

VEGETACIÓN SENESCENTE

TRIGO



ZONA DE REFORESTACIÓN

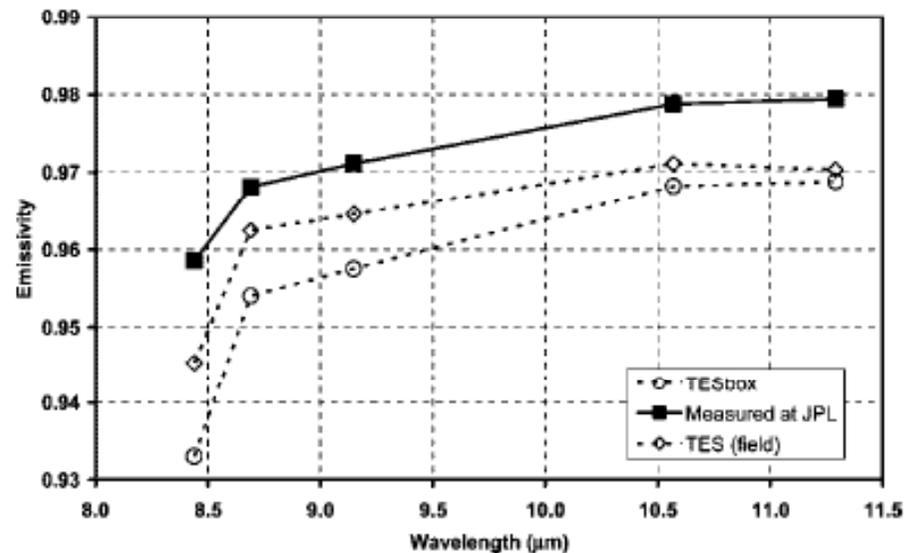
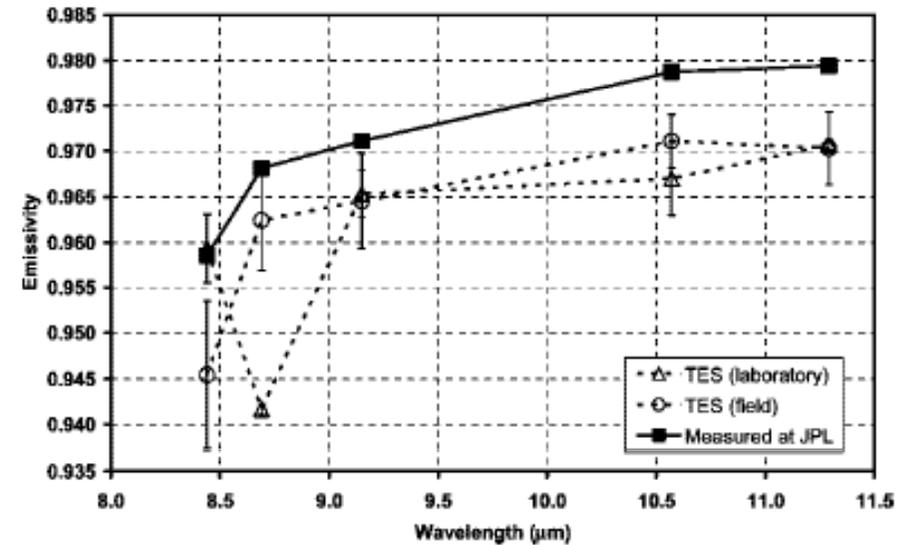


MEDIDAS DE T & ϵ : algunos resultados

MEDIDA EN LABORATORIO DE SUELO DESNUDO, CALENTANDO LA MUESTRA



MEDIDA EN LABORATORIO DE SUELO DESNUDO, UTILIZANDO UN USO COMBINADO DEL MÉTODO DE LA CAJA Y EL ALGORITMO TES



MEDIDAS DE T & ε : variación angular

Muchos sensores aerotransportados o a bordo de satélite realizan medidas bajo ciertos ángulos de observación, que pueden diferir significativamente de la visión nadir (0°), por lo que resulta necesario estudiar las variaciones angulares que sufren tanto la temperatura como la emisividad.

Ejemplos: AHS (45°), AVHRR (60°), (A)ATSR (55°), etc.

Las medidas angulares se realizan con sistemas goniométricos.



MEDIDAS DE T & ε: variación angular

J. A. Sobrino, and J. Cuenca, 1999
 Applied Optics, 38, No. 18, 3931-3936.

The observed radiance coming from the channel i and under an observation angle θ is written as:

$$B_i(T_{i\theta}) = \epsilon_{i\theta} B_i(T_s) + (1 - \epsilon_{i\theta}) L_{atm}$$

where

$$L_{atm} = (1 - \tau_{i53}) B_i(T_{atm})$$

Solving the previous equation for $\epsilon_{i\theta}$, we get:

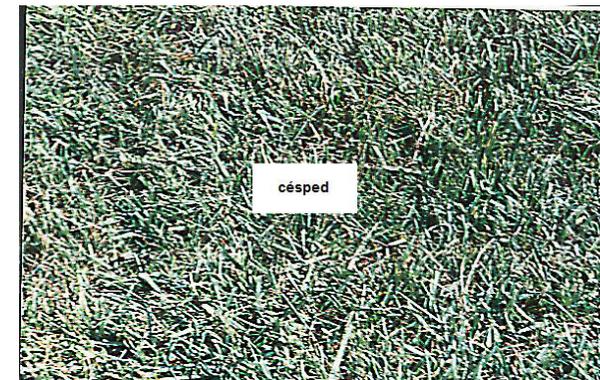
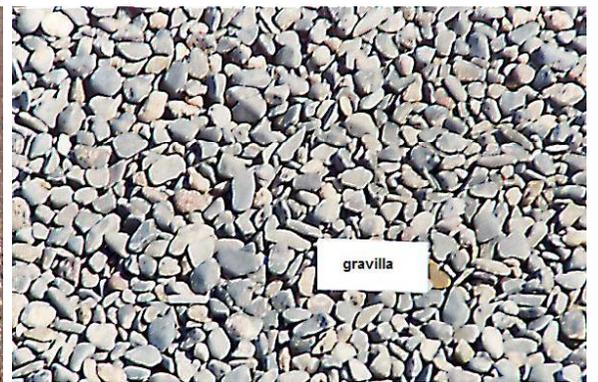
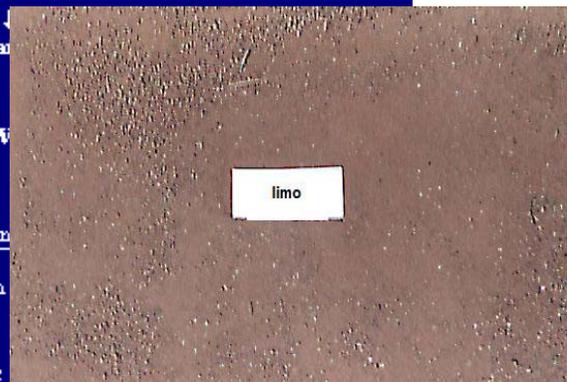
$$\epsilon_{i\theta} = \frac{B_i(T_{i\theta}) - L_{atm}}{B_i(T_s) - L_{atm}}$$

The operative expression for the emissivity is:

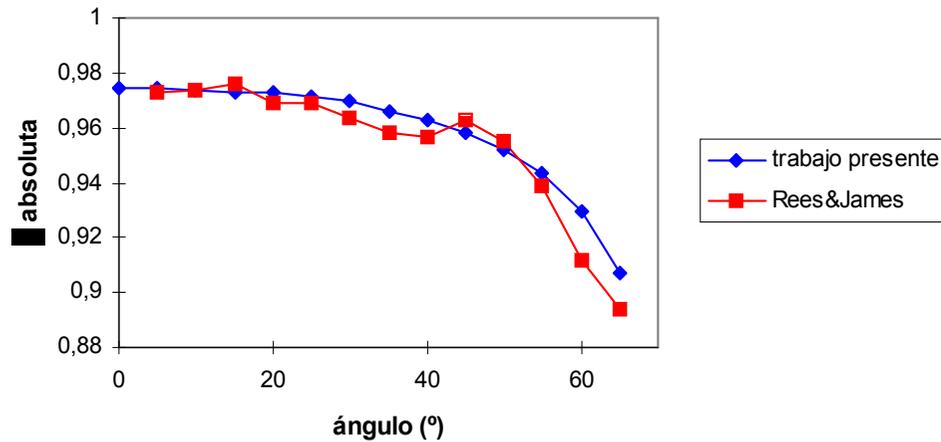
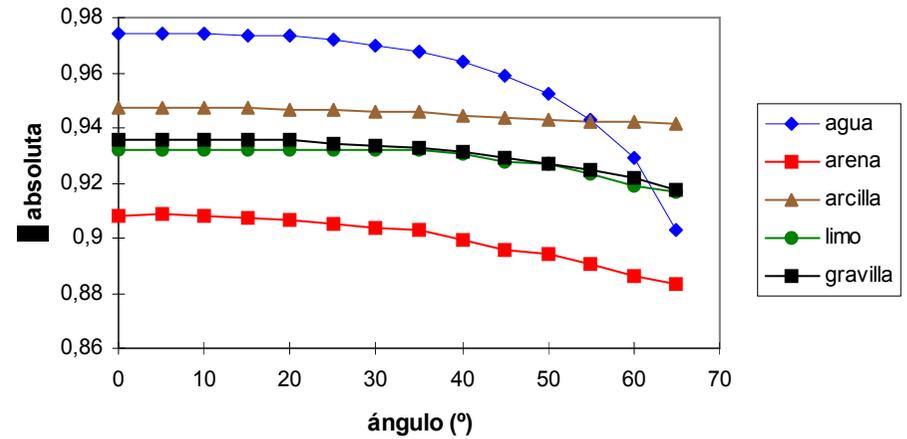
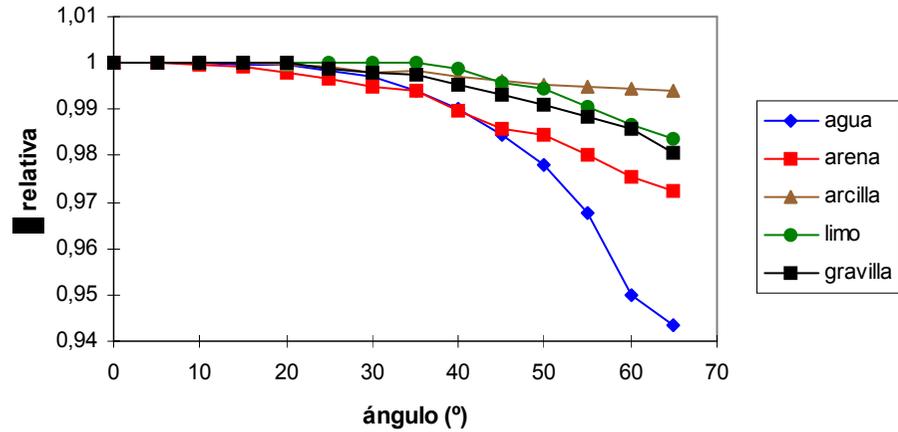
$$\epsilon_{\theta} = \frac{\exp(-\alpha/T_{rad}) - 1,3 \exp(-\alpha/T_{atm0})}{\exp(-\alpha/T_s) - 1,3 \exp(-\alpha/T_{atm0})}$$

The operative expression for the directional relative emissivity is:

$$\epsilon_{r,\theta} = \frac{\exp(-\alpha/T_{rad}) - 1,3 \exp(-\alpha/T_{atm0})}{\exp(-\alpha/T_{rad0}) - 1,3 \exp(-\alpha/T_{atm0})}$$



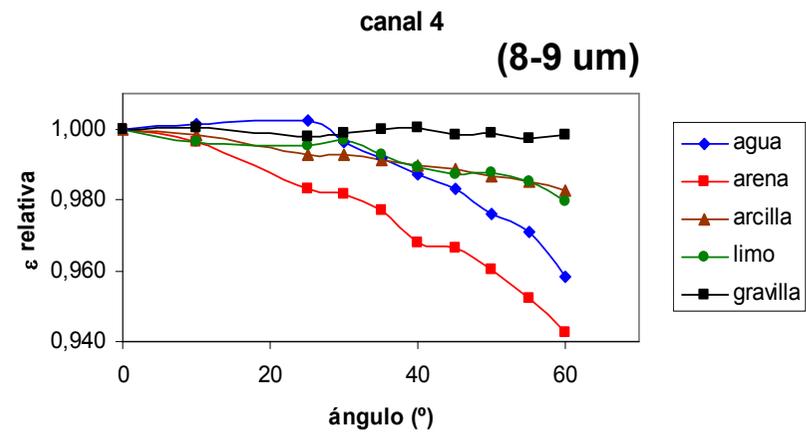
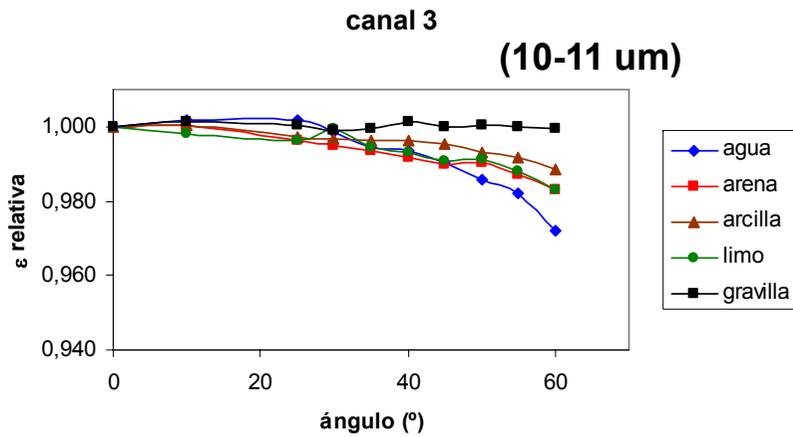
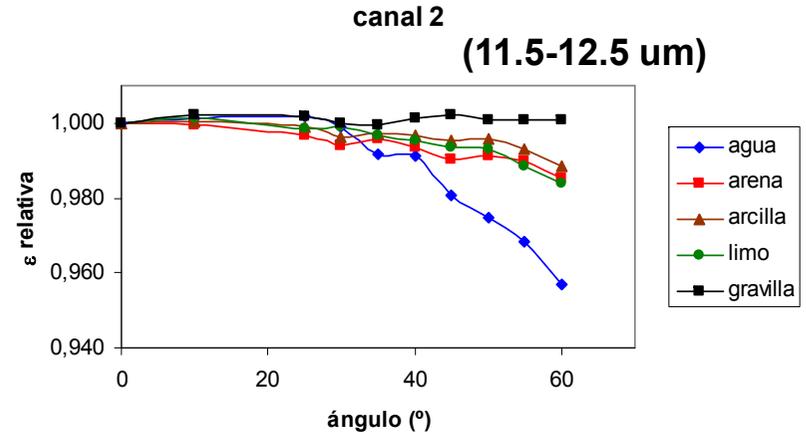
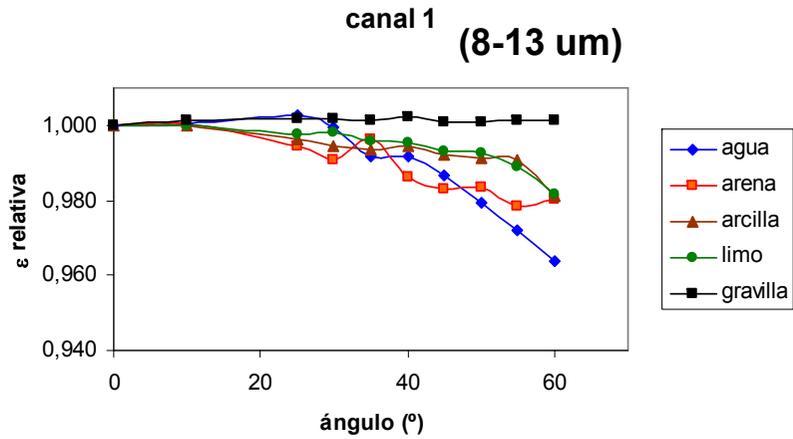
HOMOGENEOUS SAMPLES (8-14 μm)



Variación entre 0 y 55°

sample	Decrease in relative emissivity (%)	Decrease in absolute emissivity(%)
water	3,3	3,3
sand	2,0	1,9
clay	0,5	0,5
slime	0,9	0,9
gravel	1,2	1,2
grass	0	0

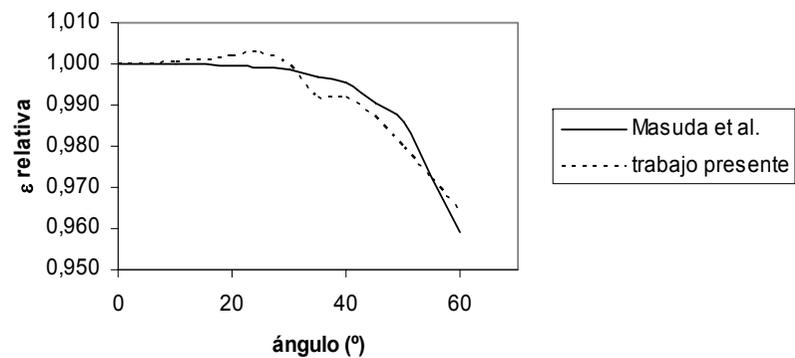
HOMOGENEOUS SAMPLES (CUATRO BANDAS CIMEL)



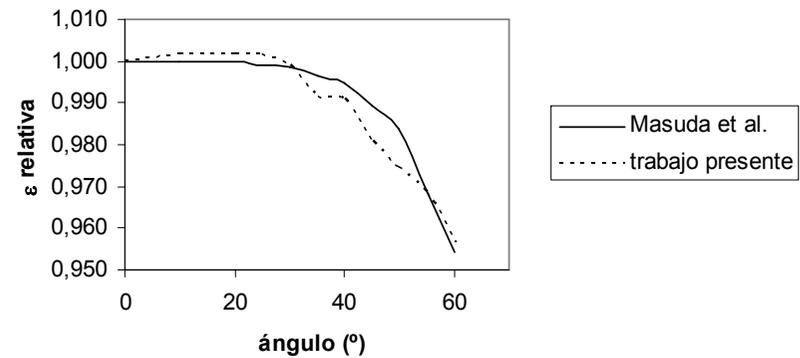
(Cuenca & Sobrino, 2004, Applied Optics)

RESULTADOS PARA UNA MUESTRA DE AGUA

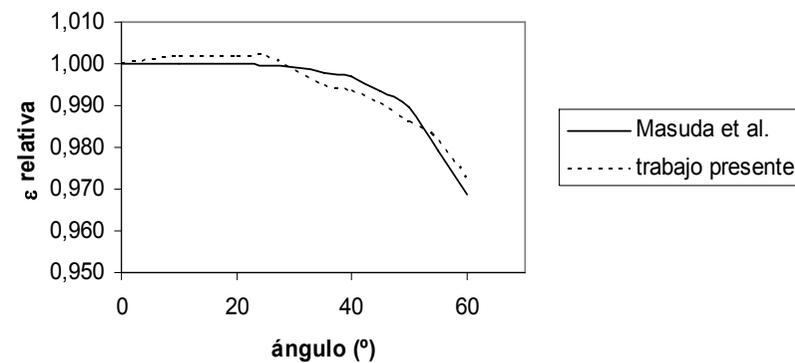
agua: canal 1



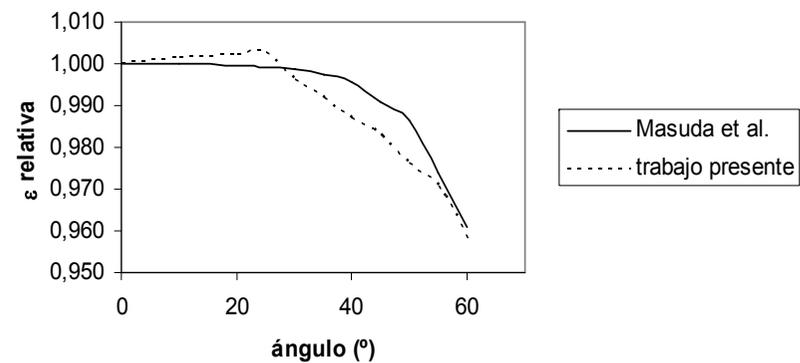
agua: canal 2



agua: canal 3



agua: canal 4



MEDIDAS DE T & ε: variación angular de la temp.

Angular variation of the Land Surface Brightness Temperature (LSBT) has been analyzed. Measurements were carried out at angles of 0-60° (15° increments) in the solar and perpendicular plane of the difference Δ LSBT (Land Surface Brightness Temperature Difference) as:

$$\Delta LSBT(\theta_i) = LSBT(\theta_i) - \frac{1}{n} \sum_{i=1}^n LSBT(\theta_i)$$



Bare soil 1



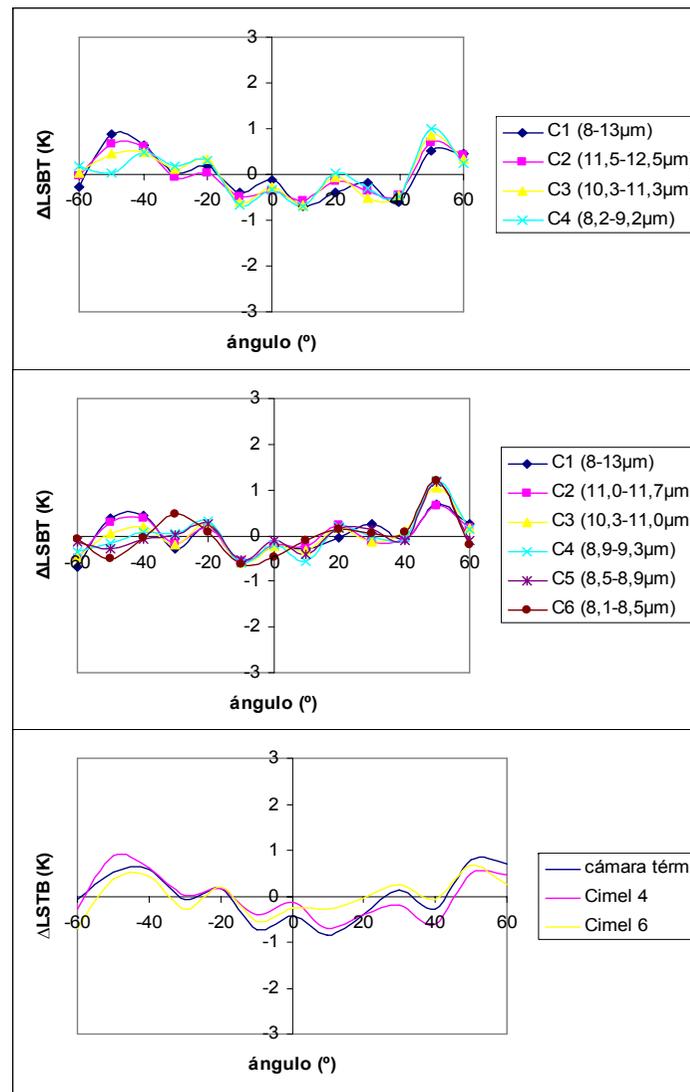
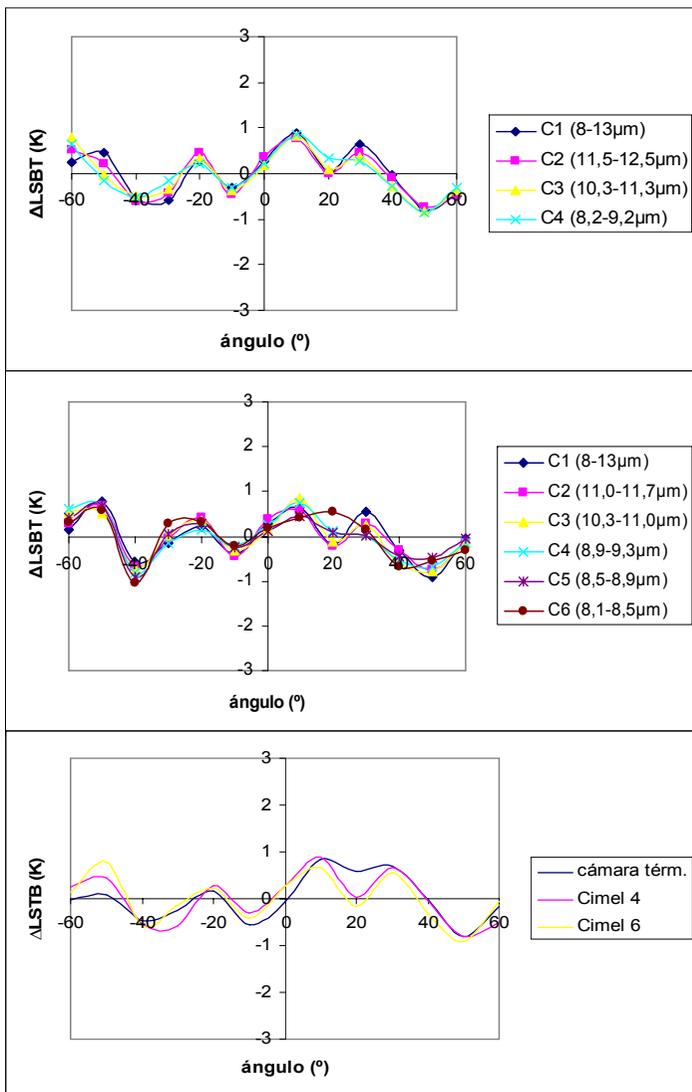
Lisimeter grass



Wheat 1

EAGLE-SPARC 2004 *IN SITU* DAY MEASUREMENTS

parallel
plane

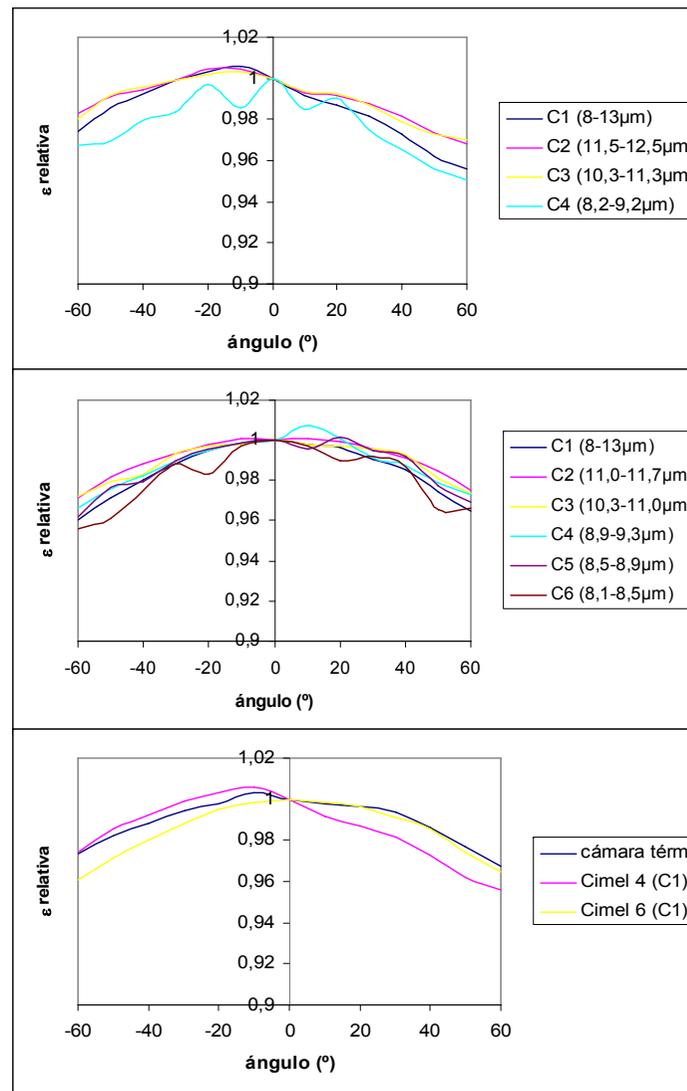
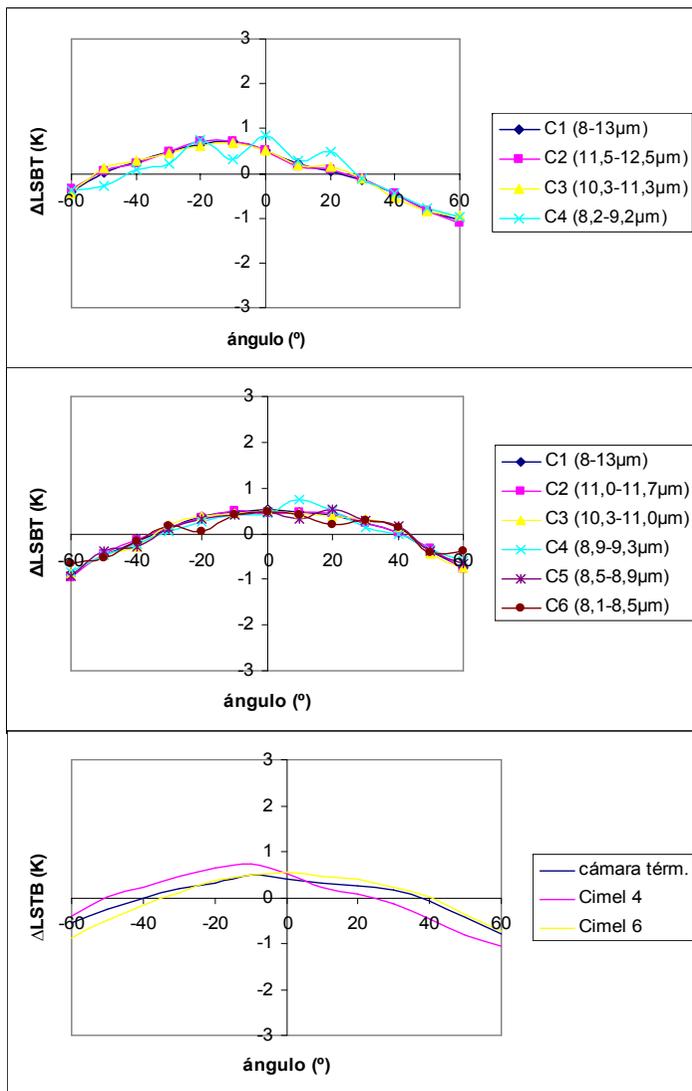


perpendicular
plane

grass

EAGLE-SPARC 2004 *IN SITU* NIGHT MEASUREMENTS

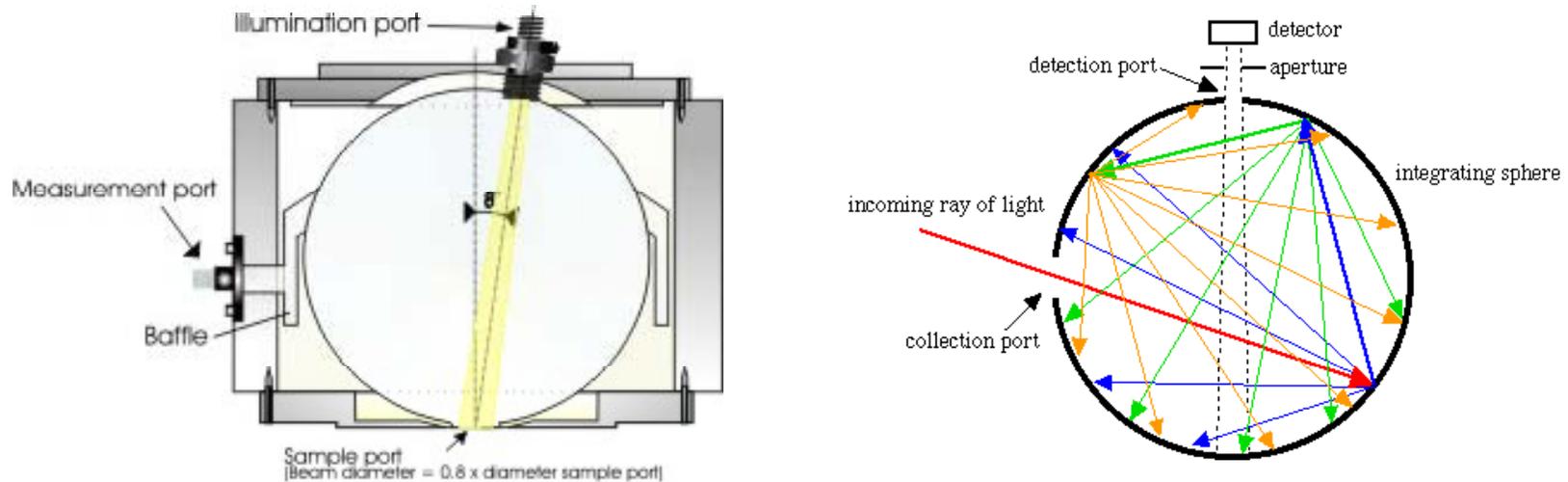
Δ LSBT



ϵ

ESPECTROSCOPIA FTIR

Las medidas realizadas con un espectrómetro FTIR (Fourier Transform Infra-Red) junto con una esfera integradora permiten obtener espectros continuos (intervalo espectral 4cm^{-1}) de emisividad para un amplio rango espectral ($2\text{-}14\ \mu\text{m}$).



Medidas de reflectividad direccional hemisférica.

Ley de Kirchhoff:

$$\varepsilon = 1 - \rho$$

ESPECTROSCOPIA FTIR

UTILIDAD

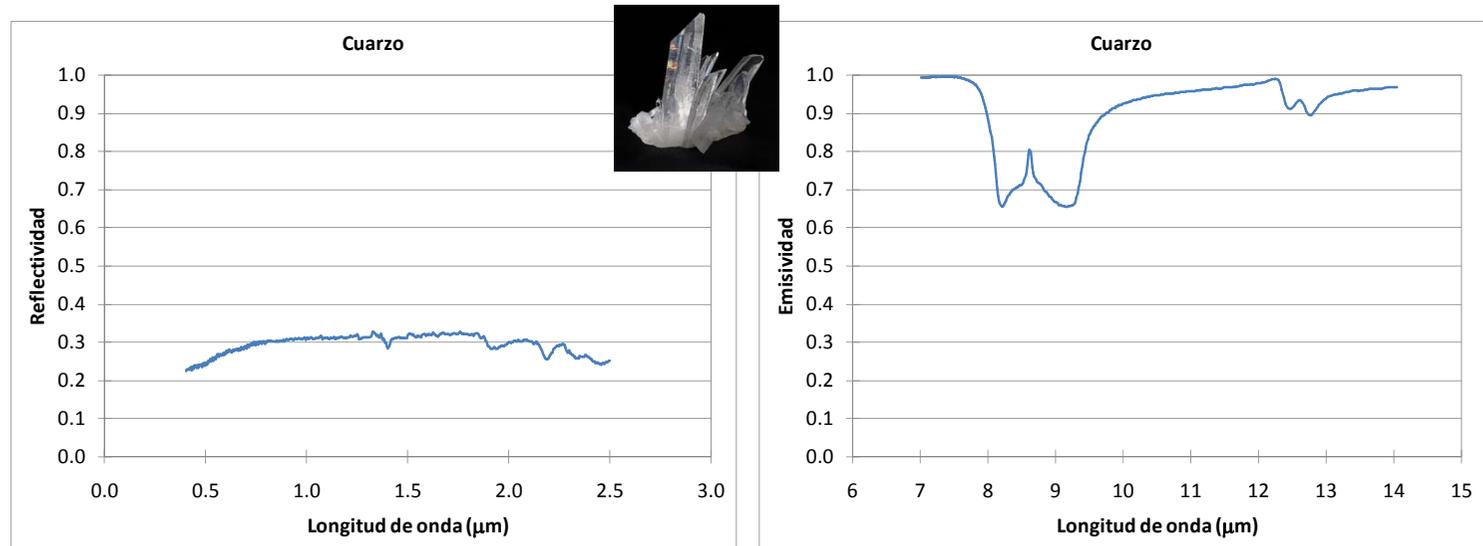
La emisión de energía en forma de calor está relacionada con la vibración y rotación de átomos y/o moléculas a ciertas frecuencias, que dependen de la composición y estructura de la muestra.

El espectro de emisividad permite observar aquellas frecuencias (long. de onda) en las cuales la energía ha sido absorbida en el proceso de activación de las vibraciones/rotaciones moleculares.

Bandas de resonancia: su posición (long. de onda), anchura y profundidad permiten caracterizar la composición y estructura molecular de la muestra.

Reflectividad vs Emisividad

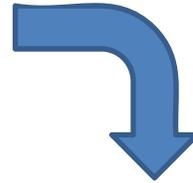
Algunos minerales presentan un espectro de reflectividad casi plano, mientras que en el espectro de emisividad se observan bandas características



Universidad de Burgos
(similar al del JPL)

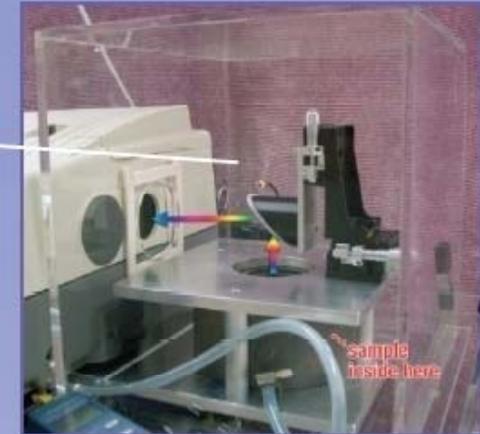


Universidad de Hawai



Reflectance side

Emission side



- Thermo Electron Nexus 470 FTIR
- Cesium iodide (CsI) beamsplitter
- Internal, TE-cooled deuterated triglycine sulfate (DTGS) detector
- Ports on left and right sides for external attachments
 - right - emission
 - left - reflectance



ESPECTROSCOPÍA FTIR: resultados

Muestras de suelos recogidas durante distintas campañas de campo fueron enviadas al JPL para realizar medidas del espectro de emisividad.

Las muestras fueron analizadas mediante difracción de Rayos X para obtener las fases cristalinas predominantes.

Se realizó también un análisis de fluorescencia a las muestras para determinar las concentraciones de los compuestos.

J. A. Sobrino, C. Mattar, P. Pardo, J. C. Jiménez-Muñoz, S. J. Hook, A. Baldrige & R. Ibañez, 2009, Applied Optics, 48(19), 3664-3670.

EXPERIMENTAL SET-UP (XRD)

Soil Samples



Oven drying
(to eliminate humidity content)



Geologic mulling

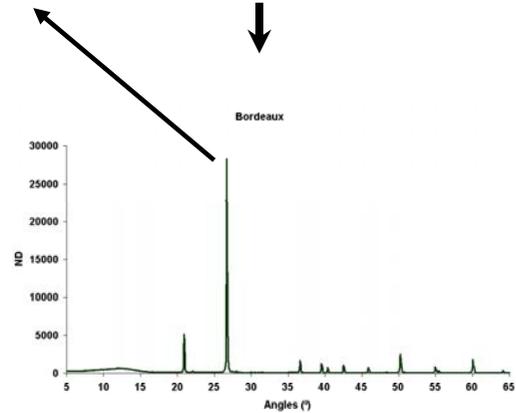
XRD



Bruker D5000
diffractometer



Quartz Peak



Diffractogram

EXPERIMENTAL SET-UP (WDXRF)

Soil Samples



**Oven drying
(to eliminate humidity content)**



Geologic mulling

Press



Powder compounds



**X-Ray Spectrometer (PW-2400)
to determine chemical
composition**

Sample lable	Place	Latitude	Longitude	Descriptions	USDA Soil Taxonomy
BS	Barrax, Spain	39° N	2° 6" 'W	Characteristic bare soil with high clay content and poorly developed.	<i>Inceptisol</i>
B	Bordeaux, France	44° 24' 19" N	0° 36' 14.6" W	Agriculture soil with high organic matter content	<i>Spodosol</i>
LL	Les Landes, France	44° 27' 24" N	0° 11' 51" E	Agriculture baresoil	<i>Inceptisol</i>
AG	Görmin, Germany	53° 59' 51" N	13° 16' 45" W	Characteristic bare soil for annual crop	<i>Mollisol</i>
H	Speulderbos, Holland	52° 14' 35" N	4° 26' 40" E	Red sand with high content of salts	<i>Entisol</i>
D1	Doñana National Park, Spain	36° 58' 49" N	6°29'48.3" W	Coastal Sand	<i>Entisol</i>
D2		37° 4' 18"N	6° 16' 54" W	Yellow Sand used for Bull Ring	<i>Entisol</i>
P	Pastoruri, Perú	9° 54' 32.2" S	77° 10' 58" W	Bare soil near Glaciers	<i>Rock/Lands near Ice Glaciers</i>
CH	Hudson, Chile	45° 54' S	72° 58' W	Volcanic ash	<i>Rock/Lands near Ice Glaciers</i>
MD	Madrid, Spain	40° 32' 52" N	3° 41' 49" W	Soccer field bare soil	<i>Inceptisol</i>
M 131	Marrakech, Morocco	31° 40' N	7° 35' W	Agriculture bare soil with high clay content	<i>Leptosols, Regosols (LP)</i>

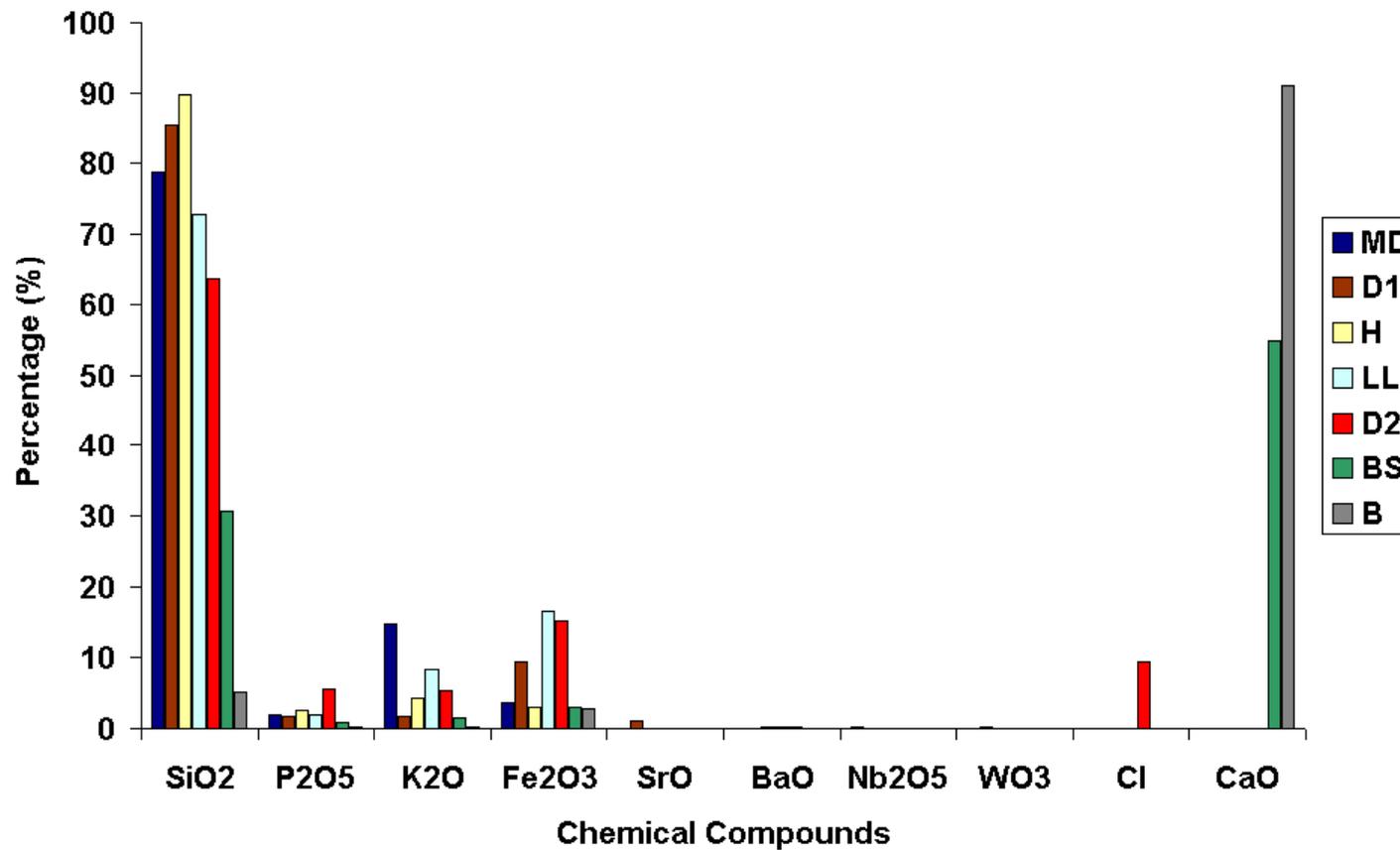
XRD

Mineralogical Phases Of some soil Samples Analyzed With XRD. (X) Main Phases, (•) Rest of Identified Minerals.

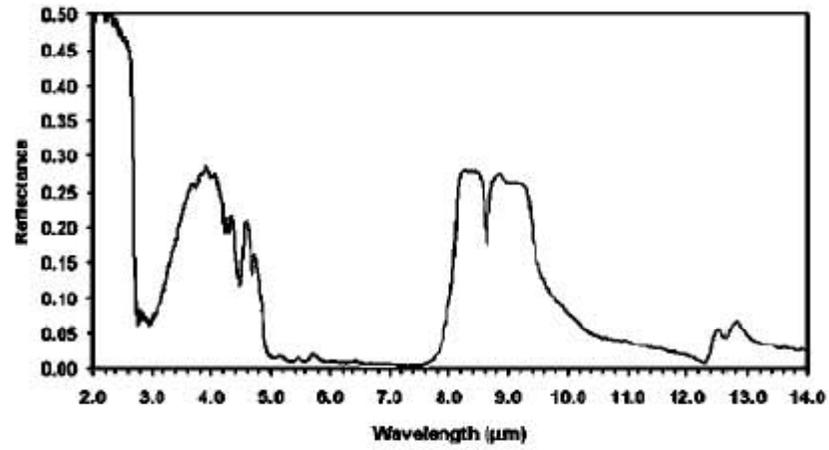
Soil code	Quartz	Calcite	Feldspar	Dolomite	Sheet-silicates
AG	X		•		
B	X		•		
BS	•	X			
CH	•		X	•	
D1	X				
D2	X	•			
H	X		•		
LL	X				•
M131	X	•	•		•
MD	X		•		
P	X				•

WDXRF

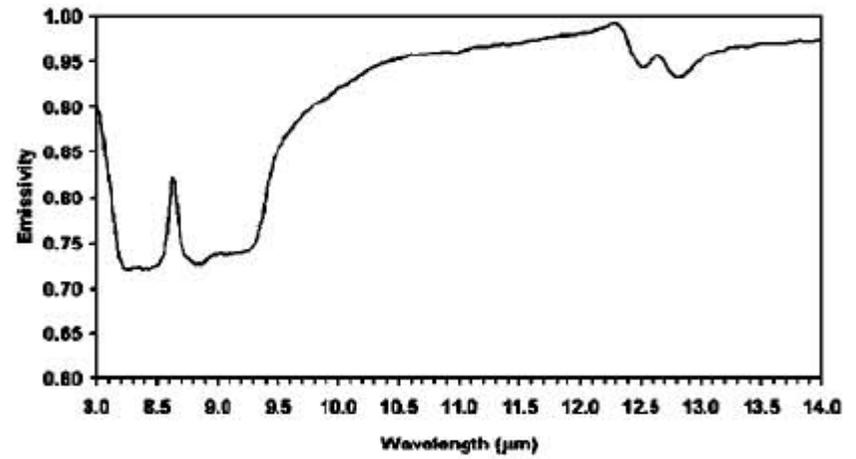
Chemical compounds in % for several soil samples analyzed using WDXRF. SiO and CaO are the predominant chemical compounds related with Quartz and Calcite.



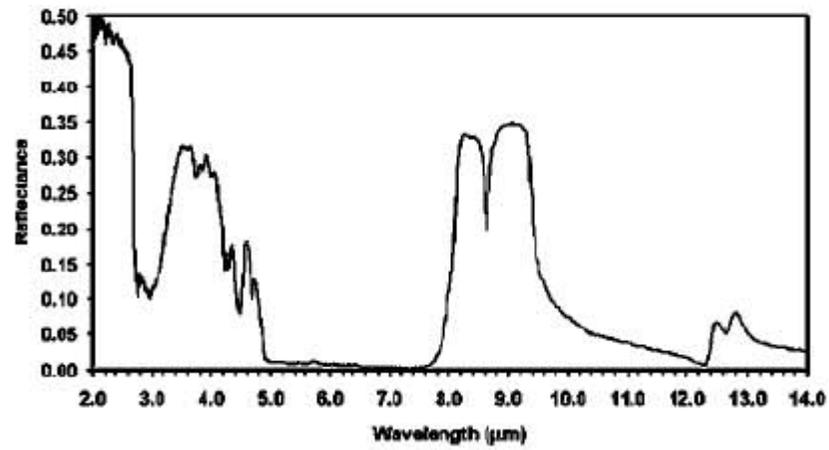
H



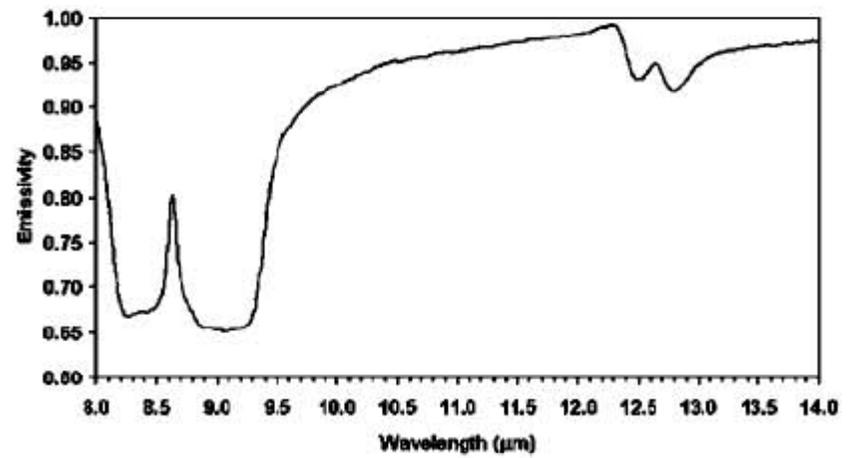
H



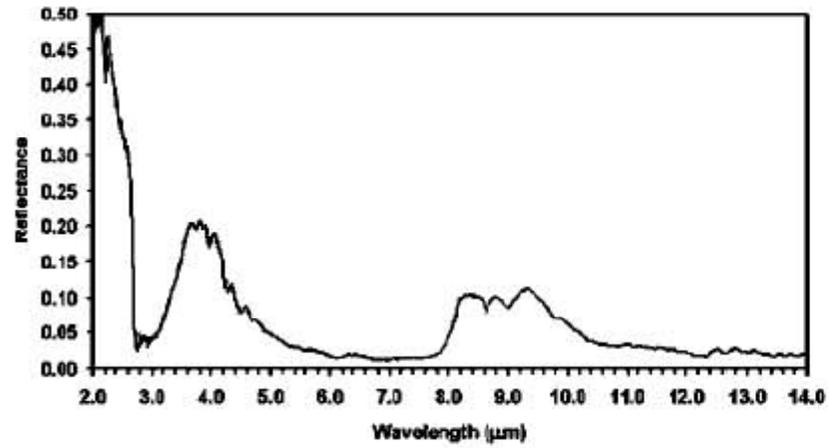
D1



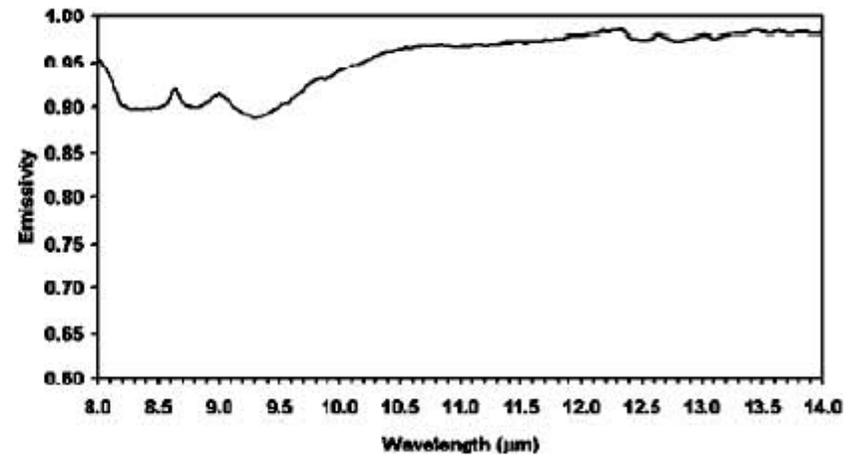
D1



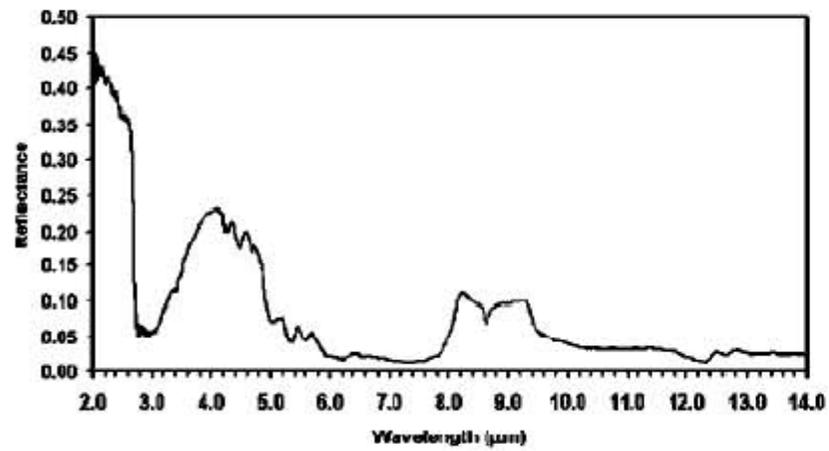
MD



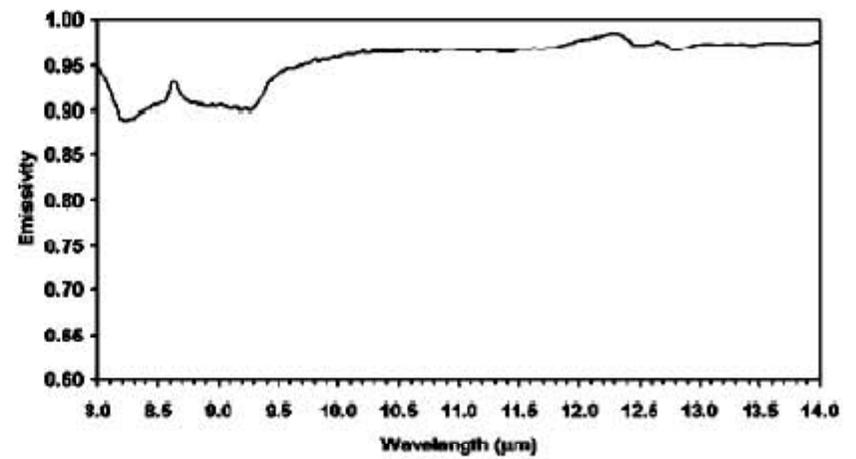
MD



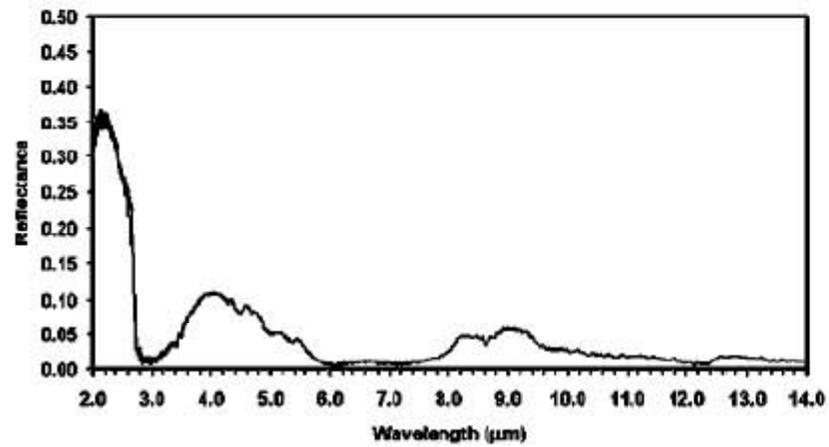
AG



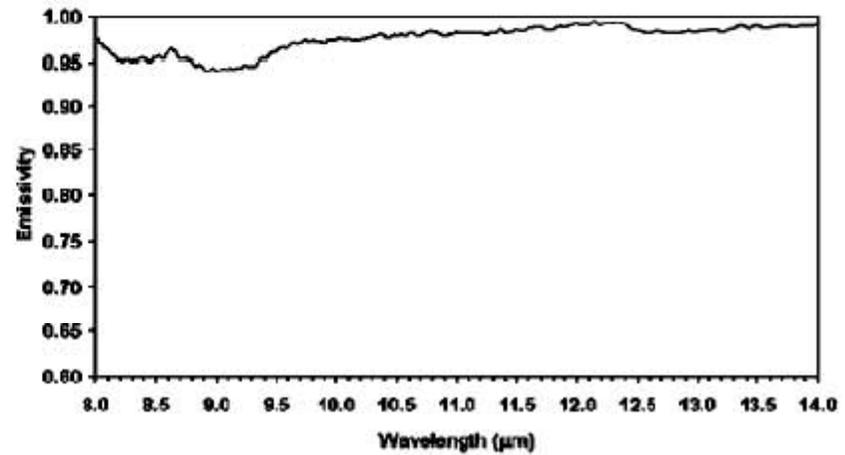
AG



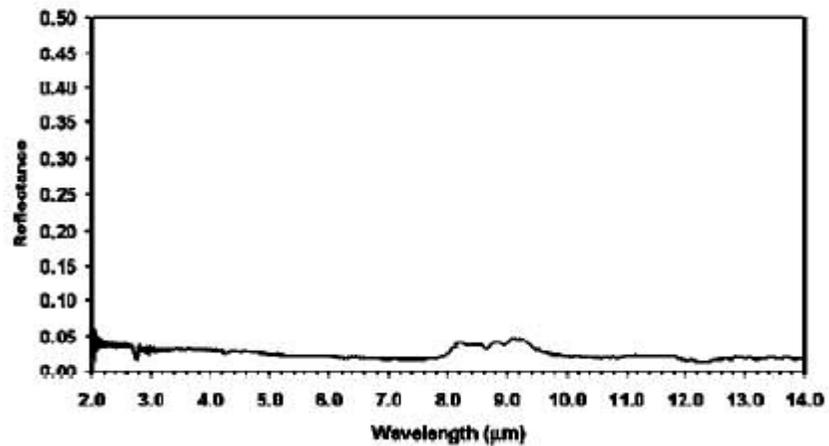
S



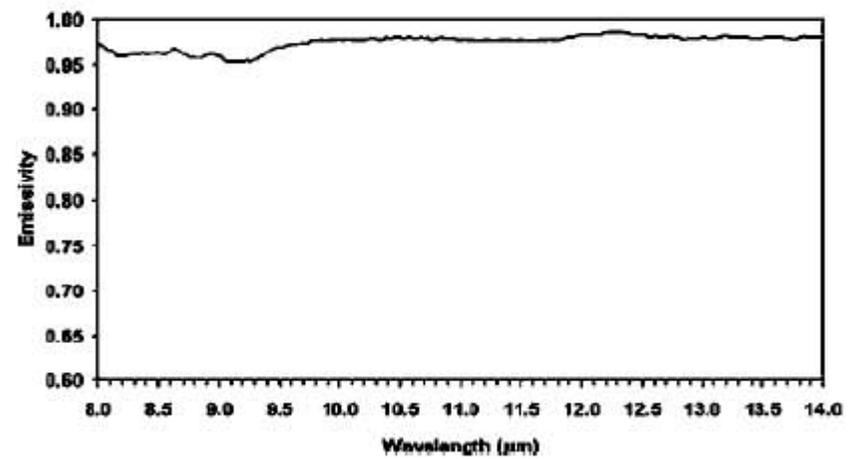
S



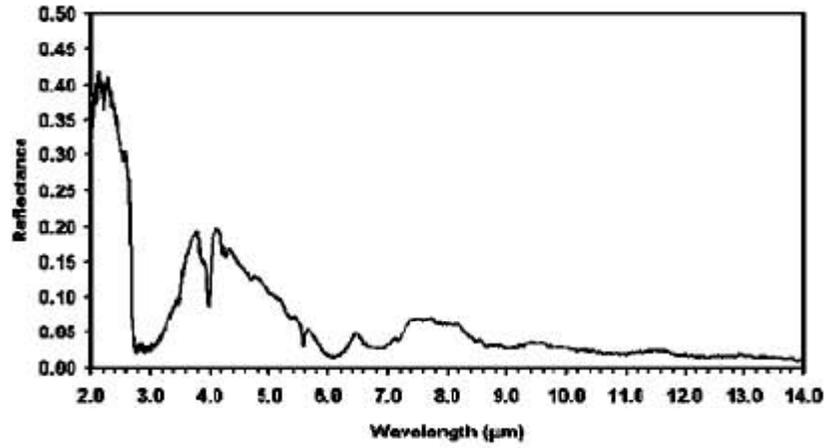
P



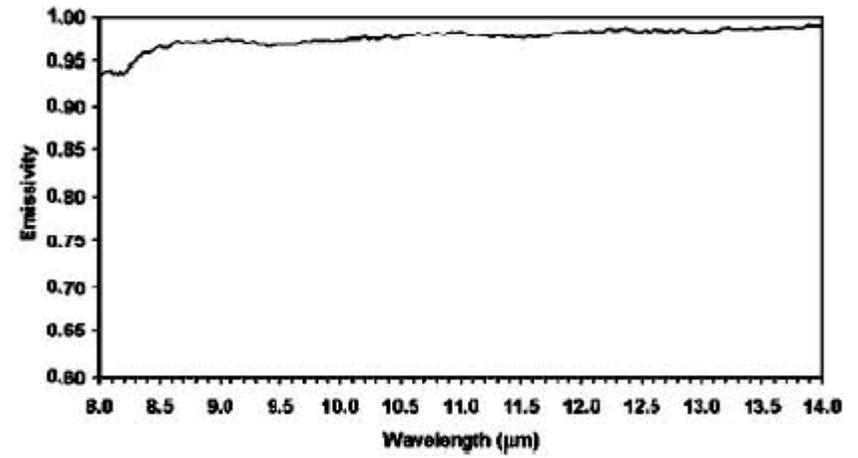
P



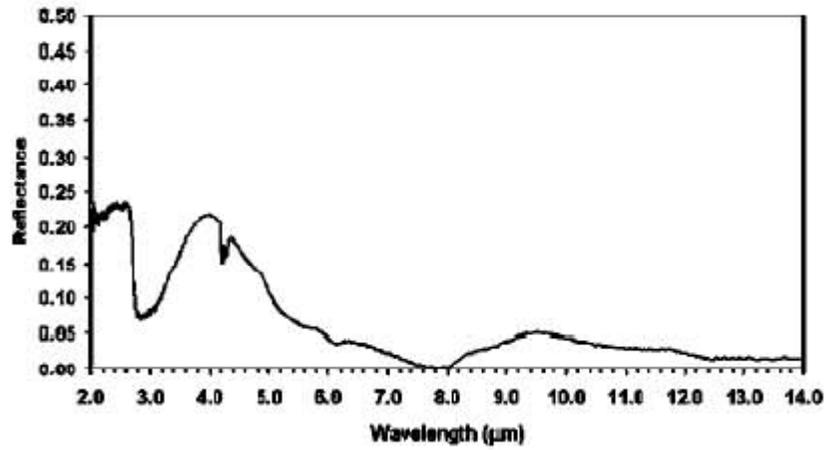
BS



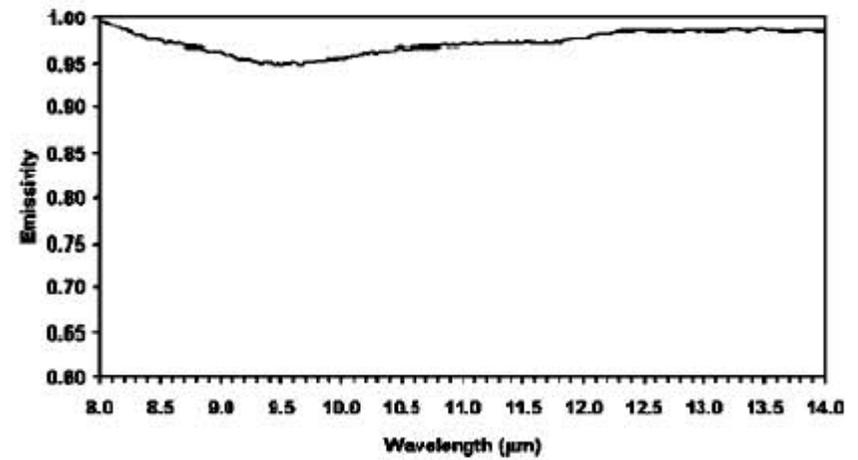
BS



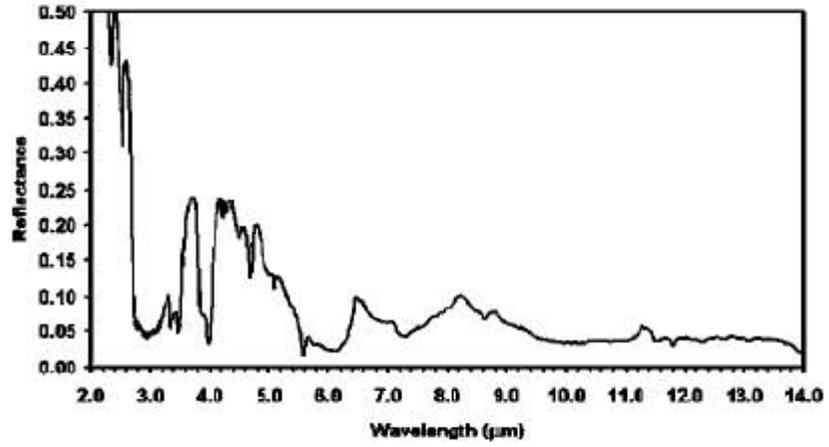
CH



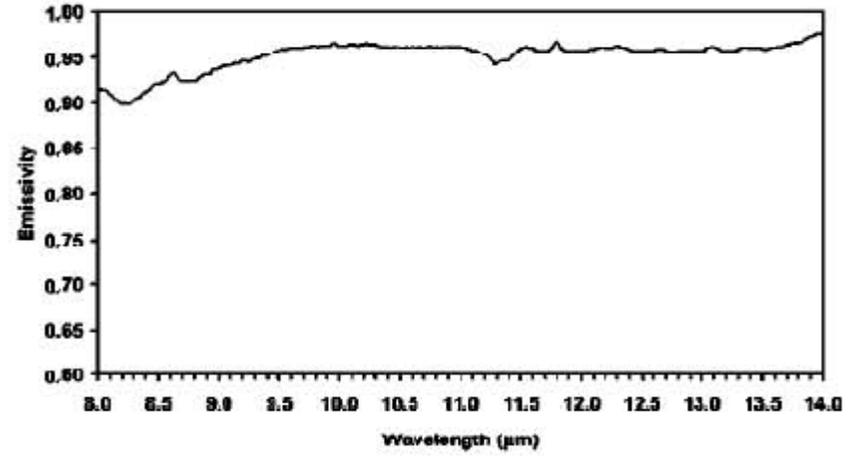
CH



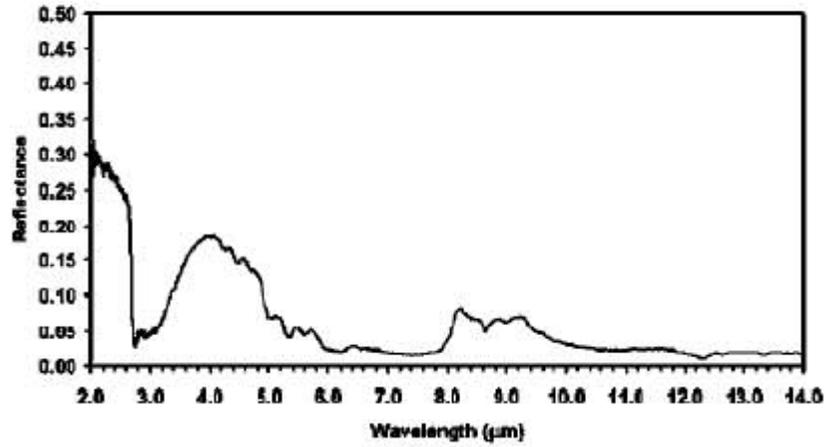
DZ



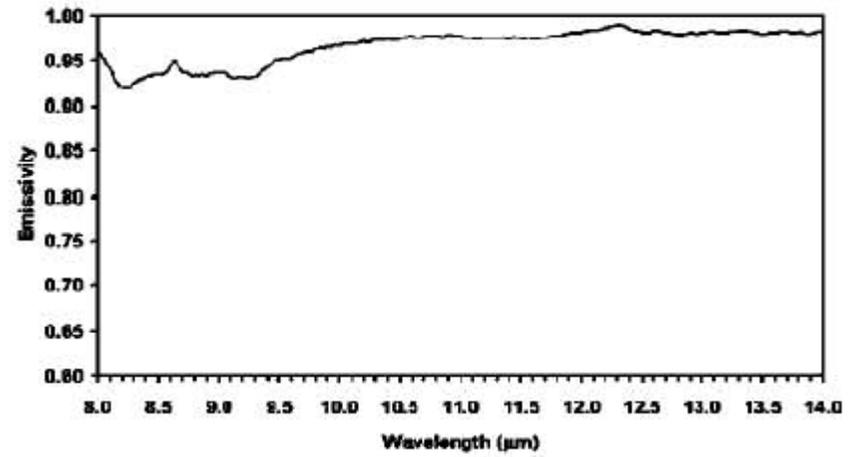
UZ



LL



LL



Actividades de calibración/validación

- sensores aerotransportados en el marco de campañas de campo financiadas por la Agencia Espacial Europea u otras entidades (DAIS, AHS).
- colaboración con el equipo ASTER (A. Gillespie) para cal/val del sensor ASTER y sus productos de temperatura y emisividad.

APLICACIONES en teledetección

Campañas de campo

Agricultural areas: **Barrax (Spain)**, **Demin (Germany)**, **Marmande (Bordeaux)**



DAISEX (1998, 1999, 2000)
SPARC (2003, 2004)
SEN2FLEX (2005)
AGRISAR (2006)
CEFLES2 (2007)

Surfaces:
Green vegetation
Senescent vegetation
Water
Bare soils

Forest sites: **Loobos (Holland)**, **Les Landes (Bordeaux)**



**CEFLES
(2007)**

Sand dunes: **Speulderbos (Holland)**

EAGLE (2006)



APLICACIONES en teledetección

Campañas de campo



DESIREX (2008)

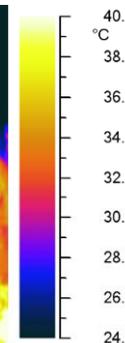
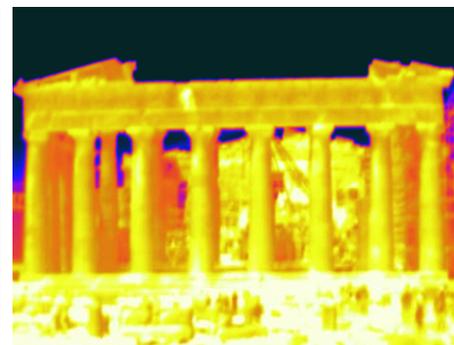
Measurements over URBAN AREAS
in Madrid (Spain)



CAMPAÑA THERMOPOLIS 2009 - ATENAS



Calibración con mástiles fijos en suelo desnudo y hierba, medidas en agua

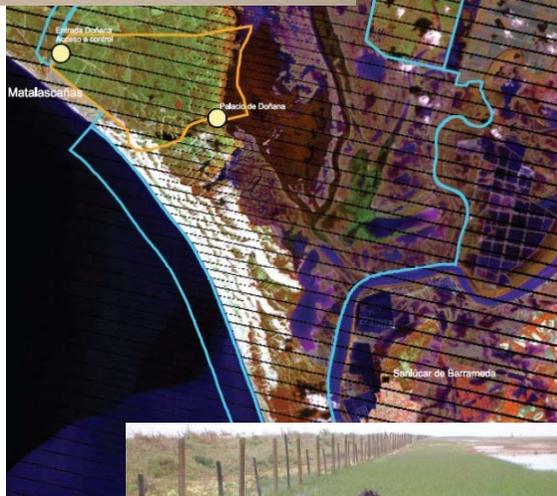


Caracterización de superficies urbanas



APLICACIONES en teledetección

Campañas de campo



**HYDRA
Doñana
2008**



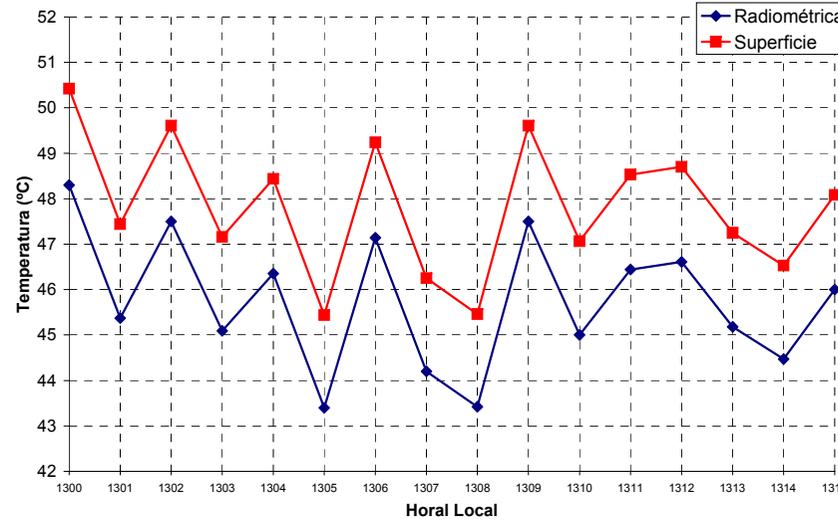
SEN3EXP (Pisa, Italia; Barrax, 2009)



CAMPAÑA SPARC-2004 (Barrax, Albacete)

Temperature measurements

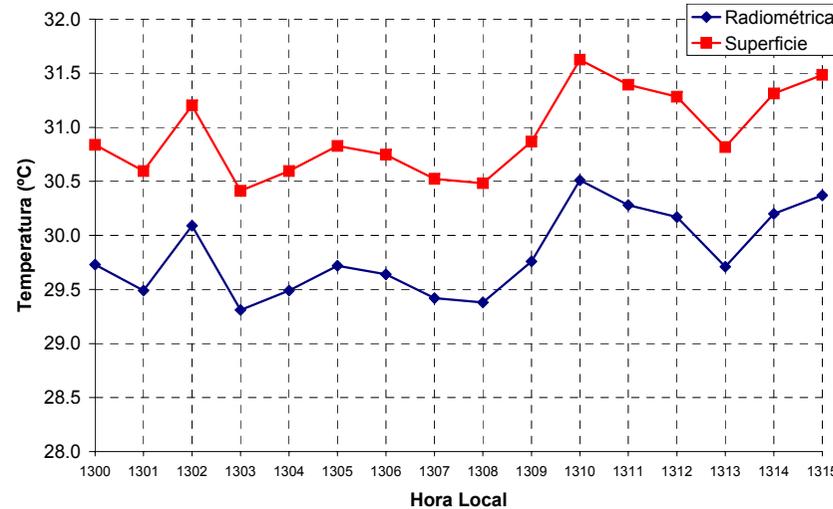
Period: 15 minutes



$$T_{\max} - T_{\min} = 5 \text{ }^{\circ}\text{C}$$

$$T_s - T_{\text{rad}} = 2 \text{ }^{\circ}\text{C}$$

$$T_s = (47.8 \pm 1.5) \text{ }^{\circ}\text{C}$$

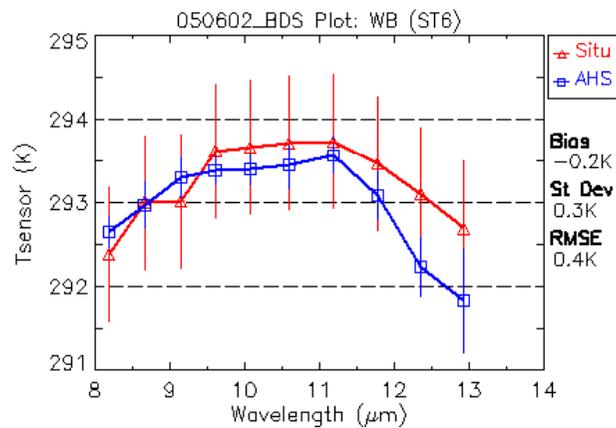
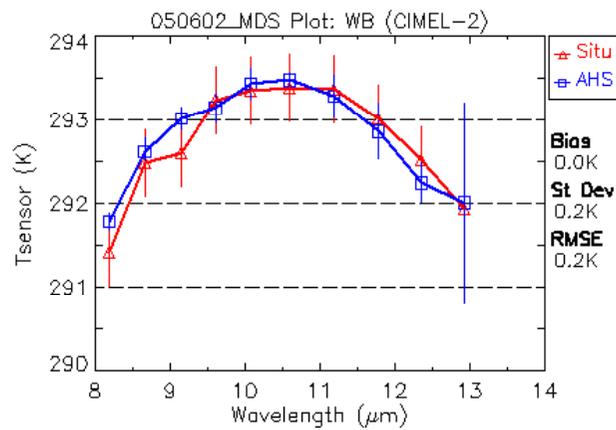


$$T_{\max} - T_{\min} = 1.2 \text{ }^{\circ}\text{C}$$

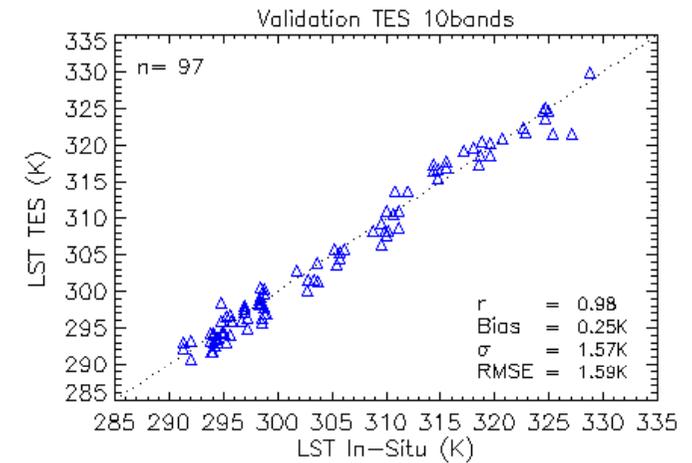
$$T_s - T_{\text{rad}} = 1 \text{ }^{\circ}\text{C}$$

$$T_s = (30.9 \pm 0.4) \text{ }^{\circ}\text{C}$$

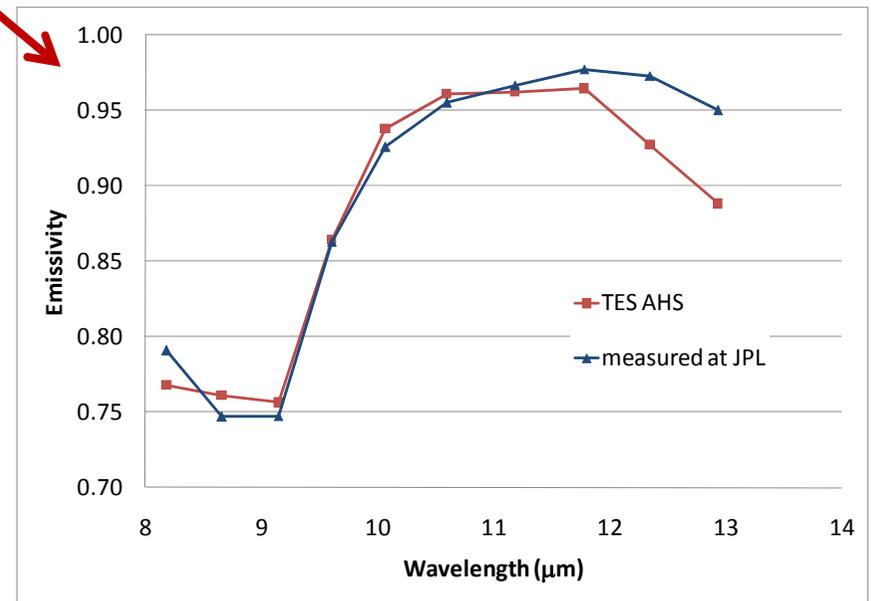
Ejemplo calibración AHS
SEN2FLEX 2005



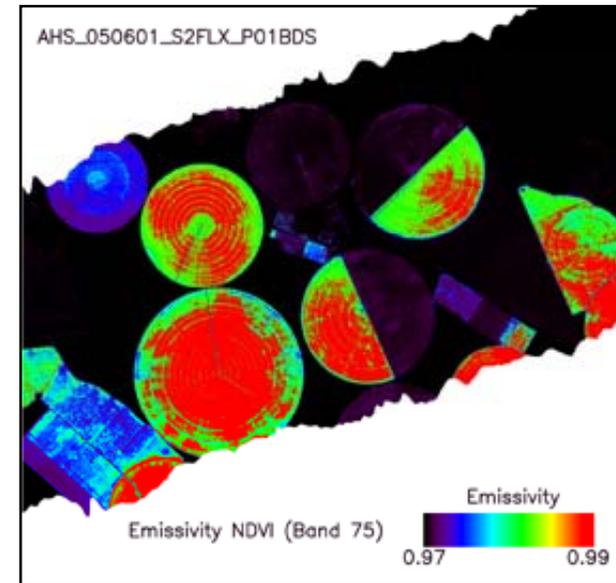
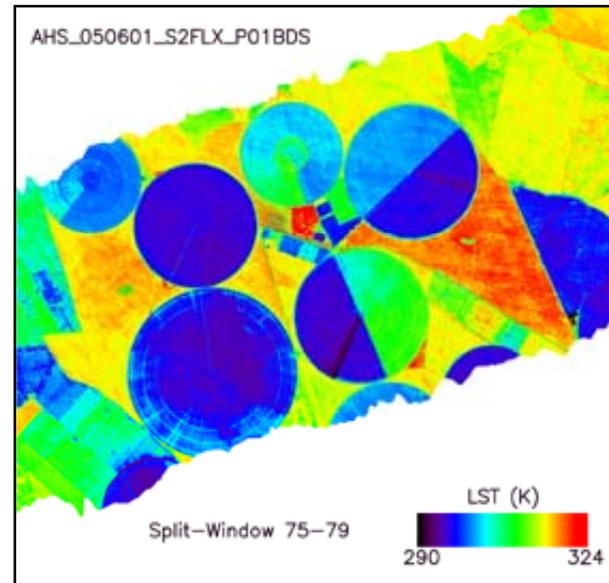
Ejemplo validación temperatura
AHS SEN2FLEX 2005



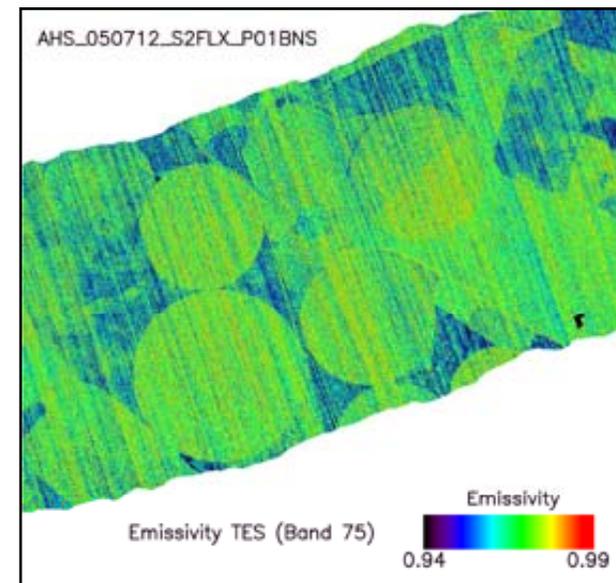
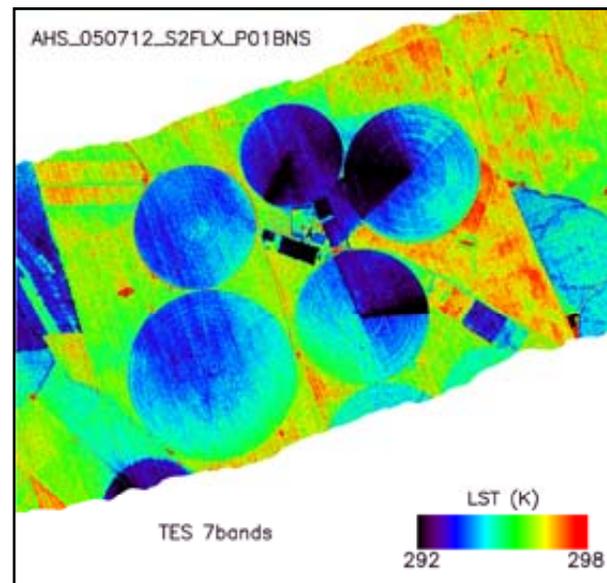
validación
emisividad
arena
(Holanda)



Daytime

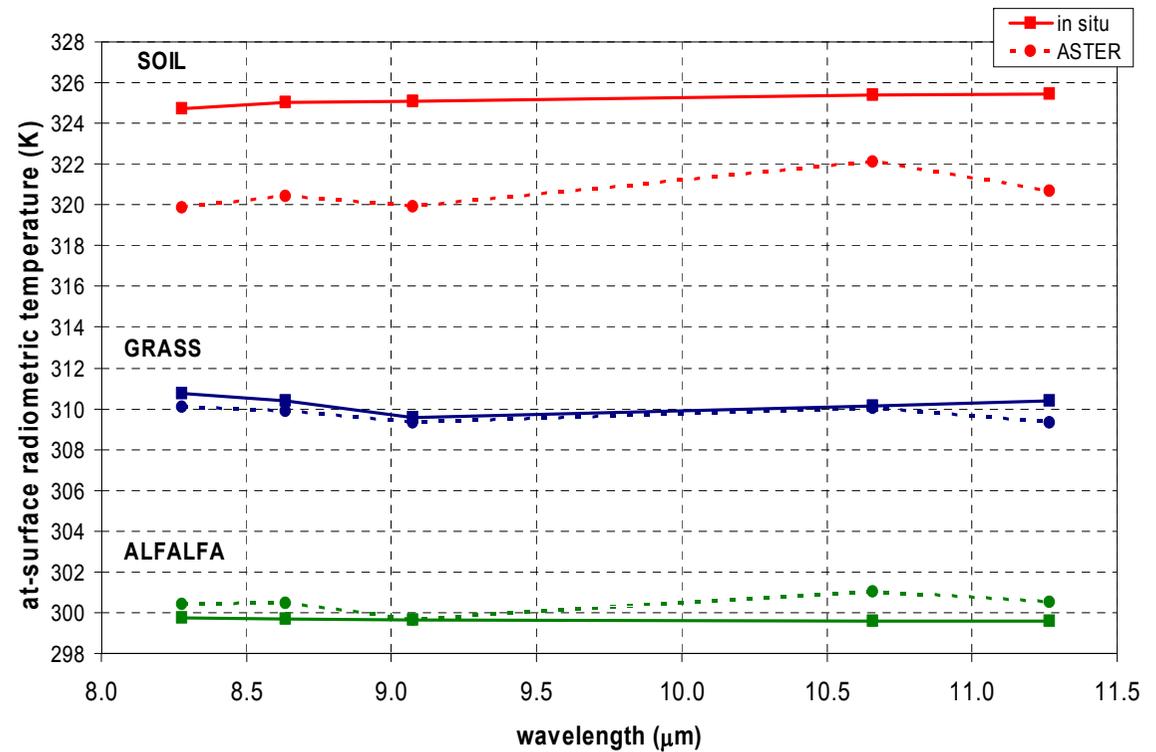
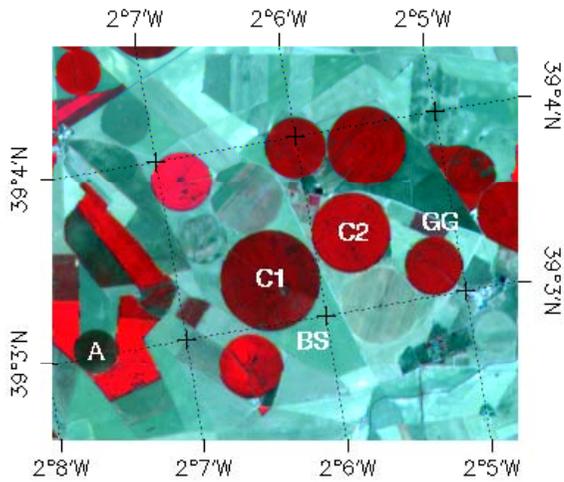


Nighttime

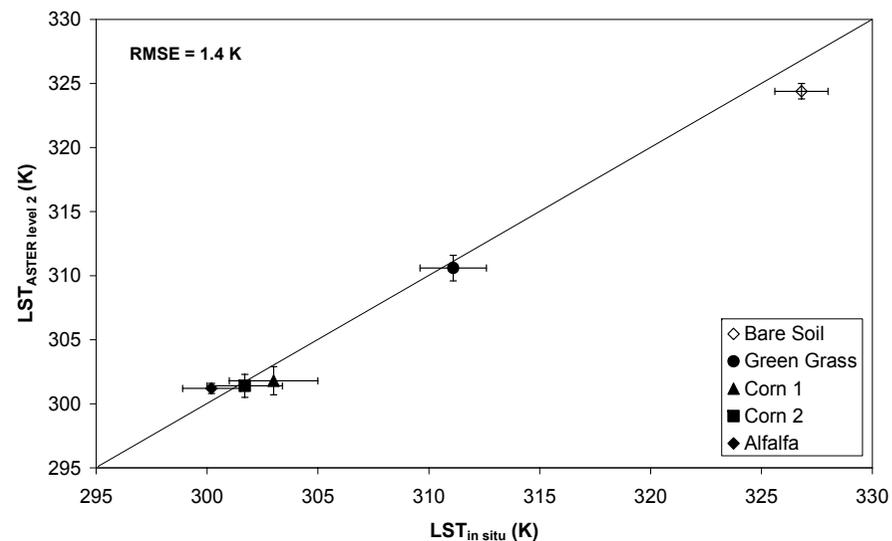
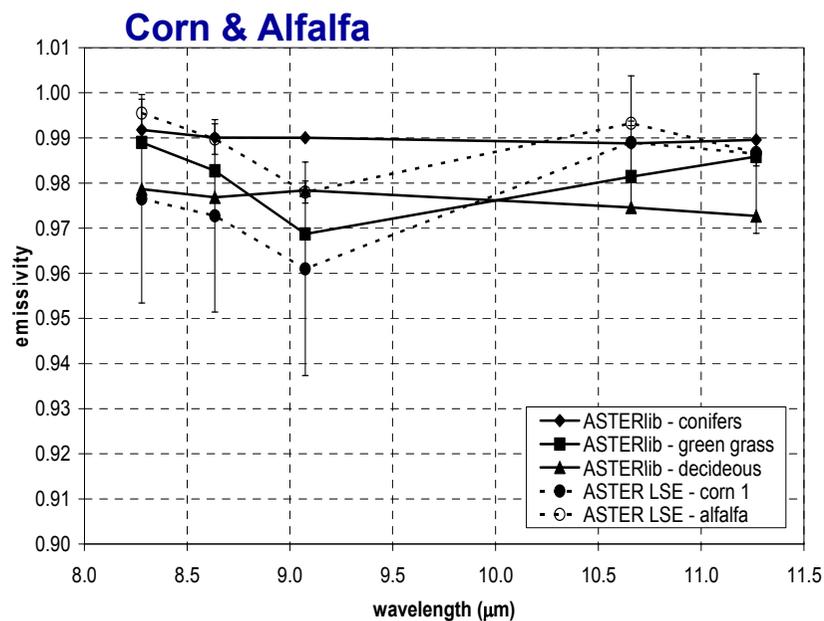
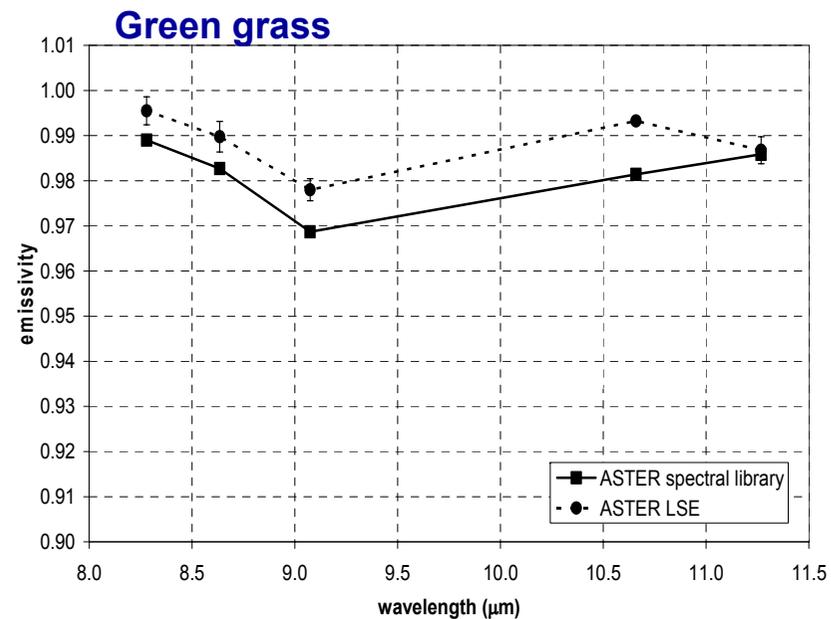
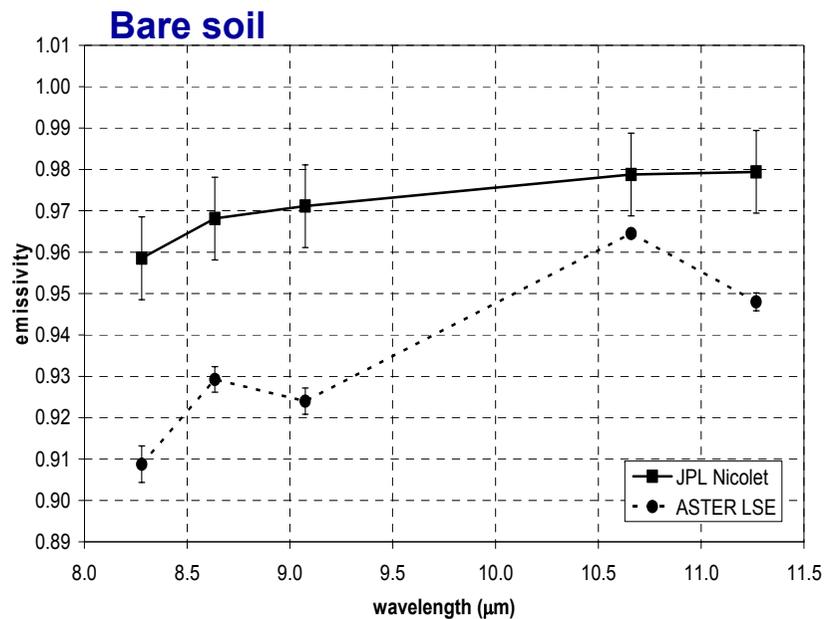


Productos ASTER

18-Julio-2004



RESULTS: Comparison library spectra and in-situ measurements



APLICACIONES en teledetección

Evapotranspiración

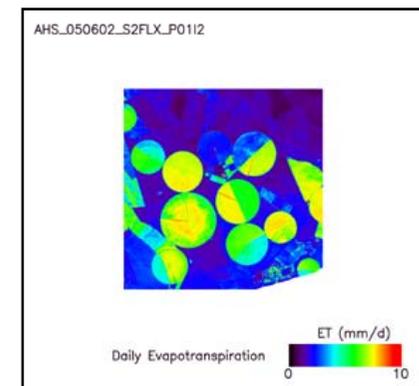
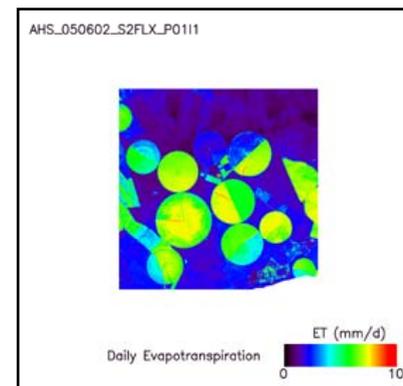
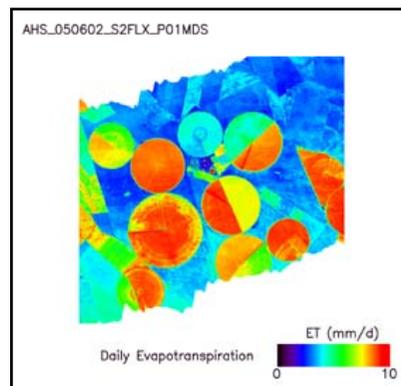
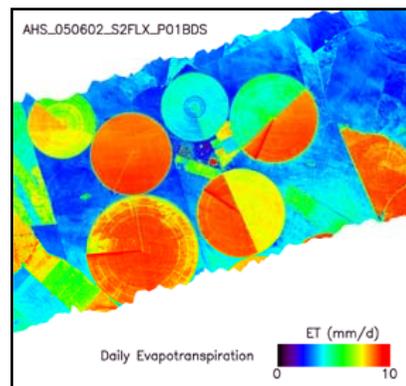
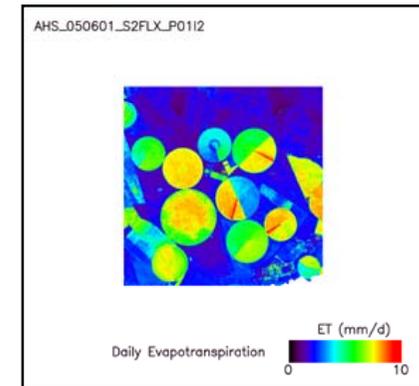
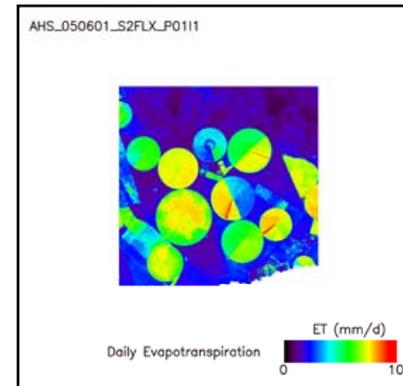
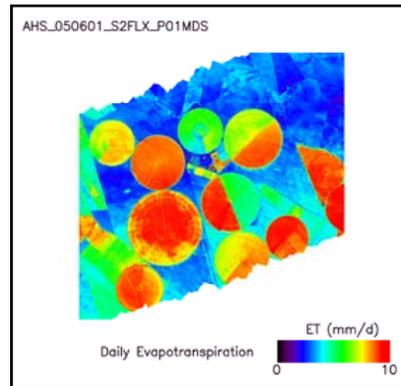
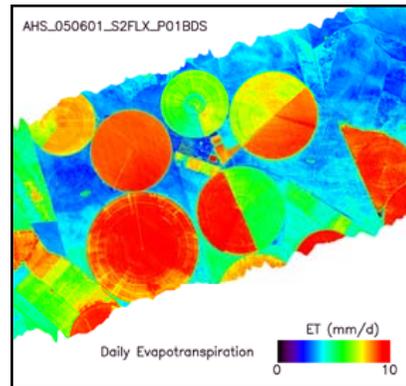
$$ET_d = \frac{\Lambda_i C_{di} R_{ni}}{L}$$



Radiación neta:

$$R_{ni} = (1 - \alpha_s) R_{sw}^{\downarrow} + \varepsilon R_{lw}^{\downarrow} - \varepsilon \sigma T_s^4$$

(son necesarios datos térmicos)

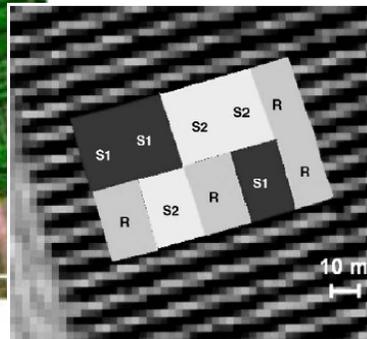




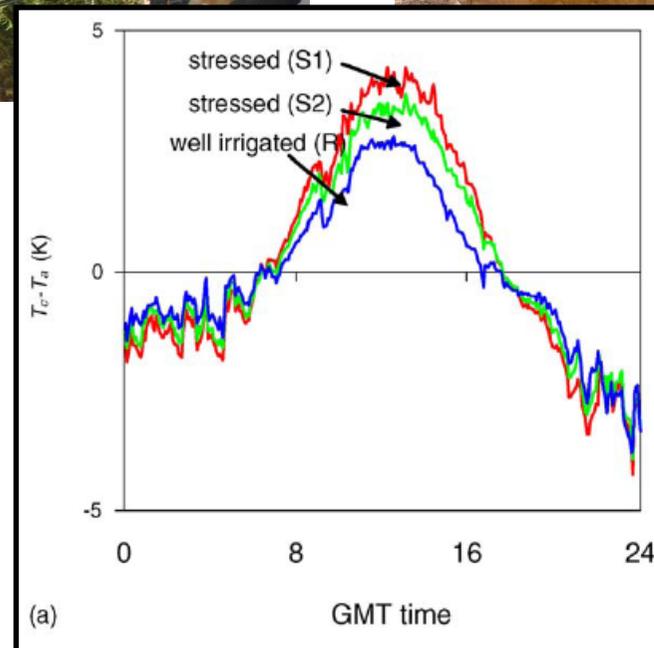
(a)



(b)



DETECCIÓN DE ESTRÉS HÍDRICO EN OLIVAR CON DATOS AHS
Sepulcre-Cantó et al., 2006, AFM, 136, 31-44.



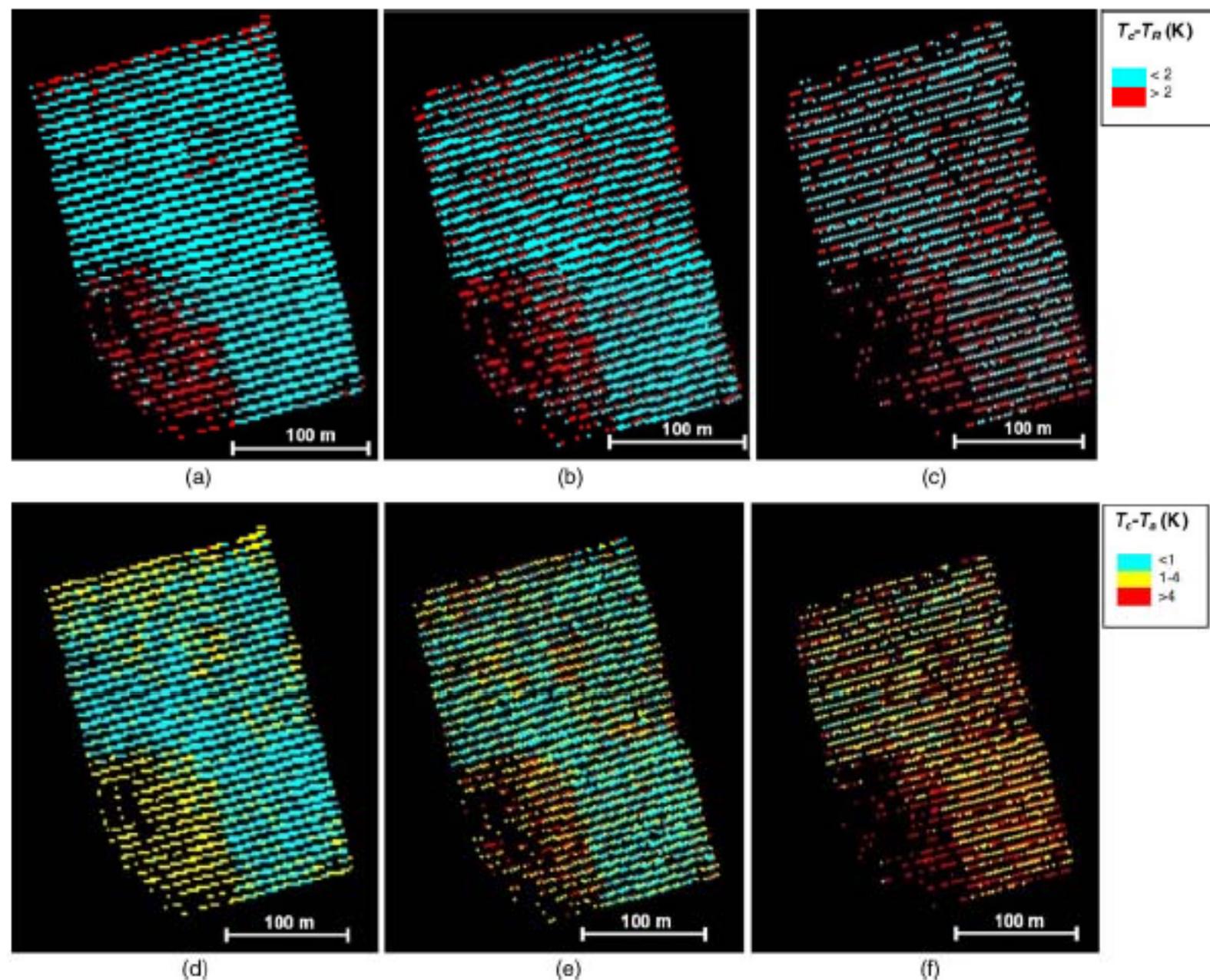
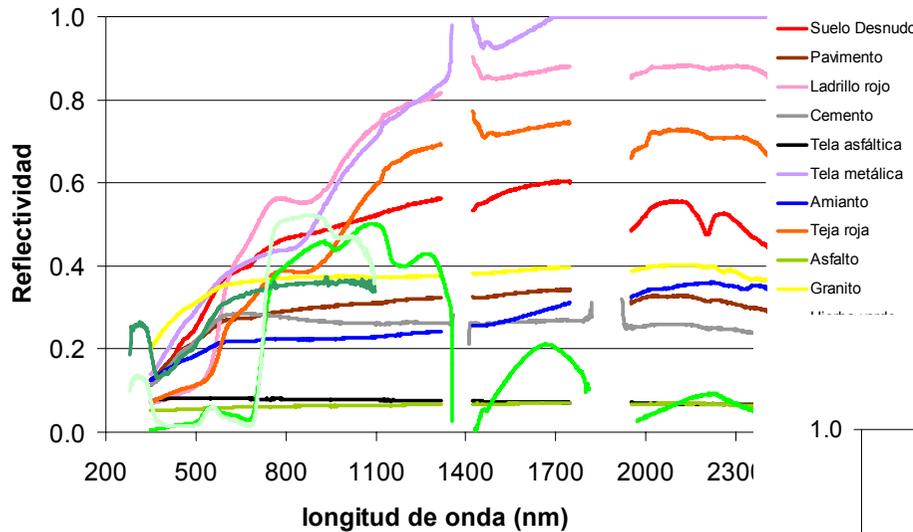


Fig. 10. (a-c) The $T_c - T_R$ (relative temperature difference compared to well-irrigated trees) images obtained with the AHS sensor on 25 July 2004 at three overflight times: (a) at 7:30 GMT, (b) at 9:30 GMT and (c) at 12:30 GMT. (d-f) The $T_c - T_a$ (canopy temperature minus air temperature) images obtained from the AHS sensor on 25 July 2004 at three over flight times: (d) at 7:30 GMT, (e) at 9:30 GMT and (f) at 12:30 GMT. The area represented is the same as that shown in Fig. 1 with a yellow border.

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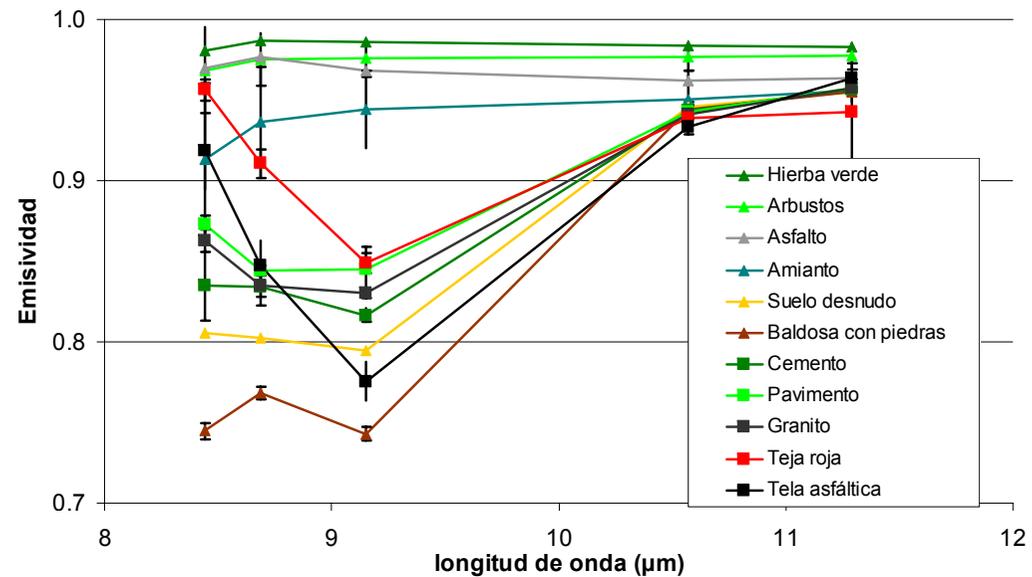
Reflectividad



Reflectance is a direct measurement, but emissivity is a retrieval, and TES fails over some kind of urban surfaces

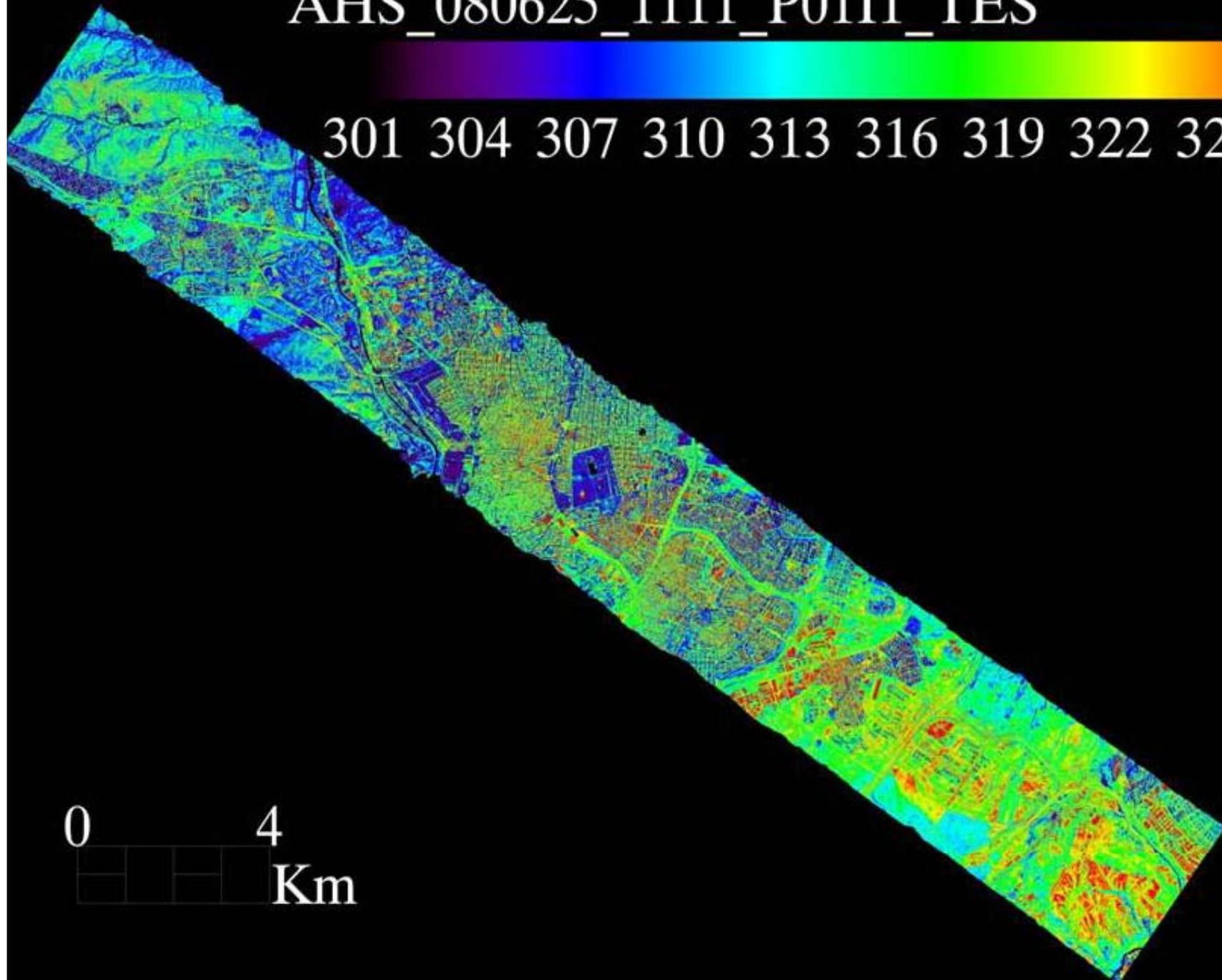
Reflectance and emissivity spectra were measured over different urban surfaces (asphalt, concrete, bricks, roofs...)

Emisividad



AHS_080625_1111_P01I1_TES

301 304 307 310 313 316 319 322 325 328

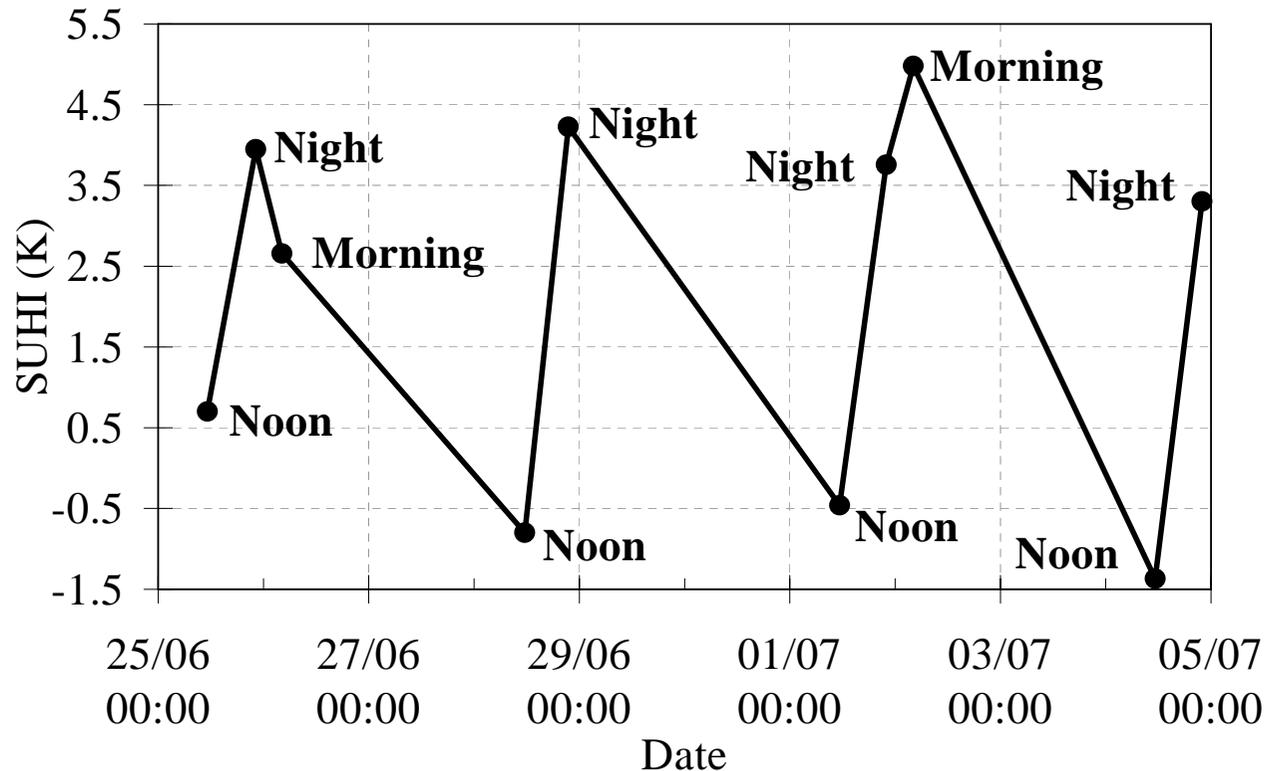


0 4
Km

SUHI (Surface Urban Heat Island Effect) (Voogt and Oke, 2003)

$$SUHI = LST_{Urban} - LST_{Rural}$$

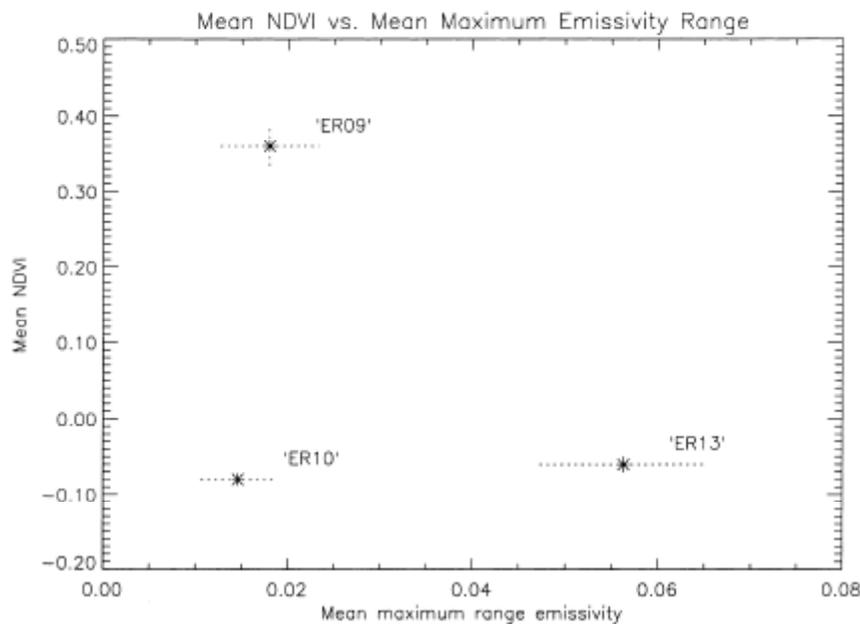
Negative SUHI values are obtained for images at noon, since the rural surfaces appear warmer than urban ones. For night and morning time the city is warmer. Results also show that positive SUHI values increase, reaching the value of 5 K on July 2nd.



OTRAS APLICACIONES

DISCRIMINACIÓN DE LA VEGETACIÓN SENESCENTE UTILIZANDO NDVI y MMD
French et al., 2000, Rem. Sens. Environ., 74, 249-254.

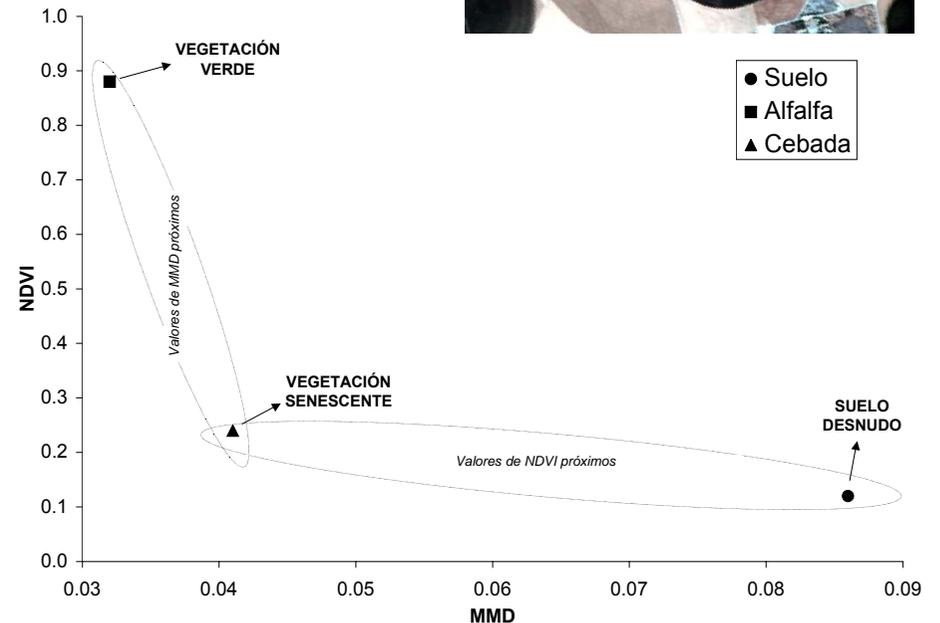
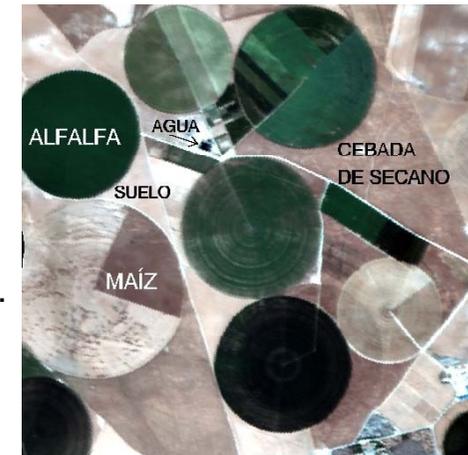
El Reno, Oklahoma



ER09: pastos
 ER10: trigo segado
 ER13: suelo arado

Resultados en Barrax

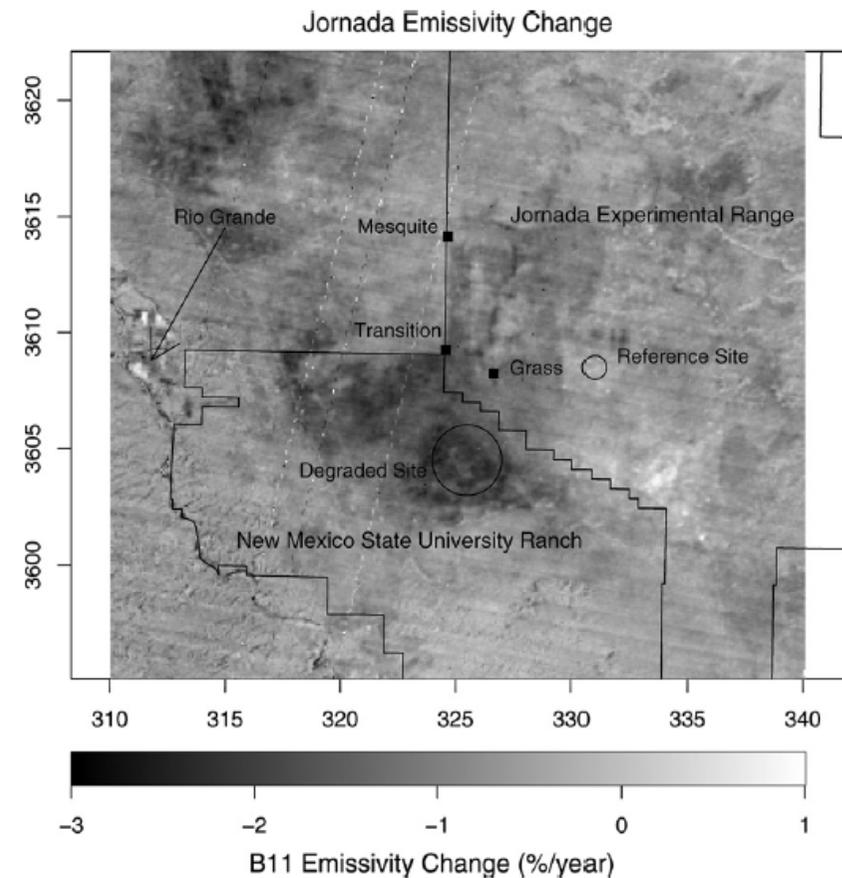
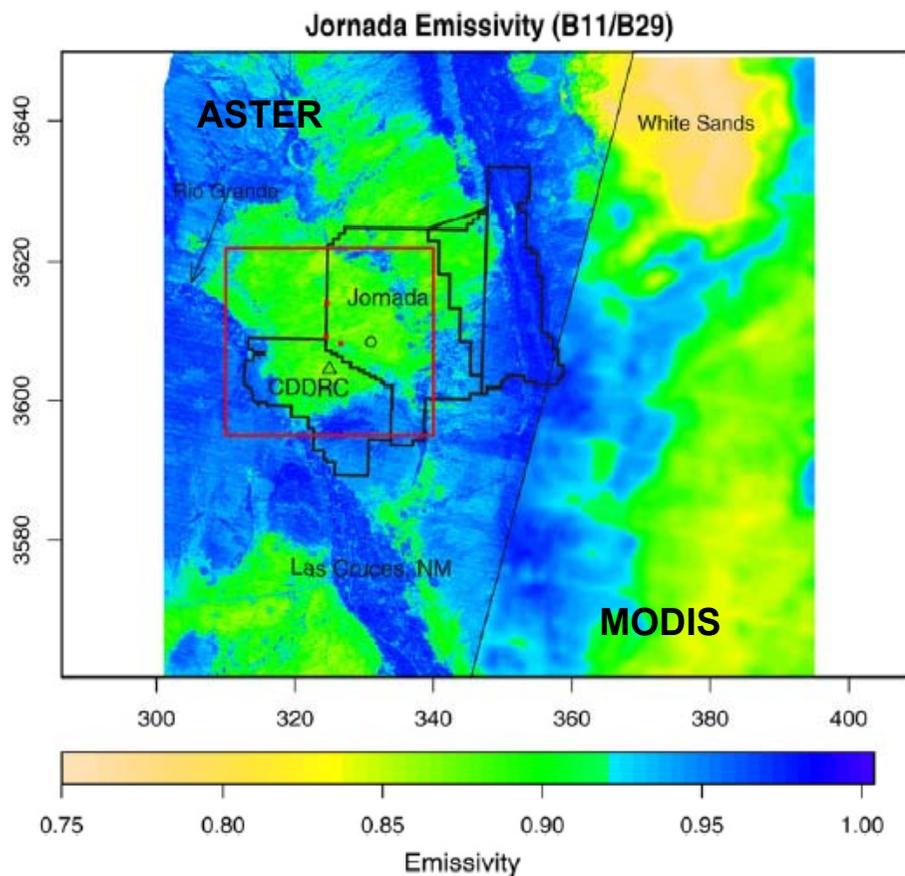
Jiménez-Muñoz et al.,
 2003, Revista de
 Teledetección, 19, 51-58.



OTRAS APLICACIONES

DETECCIÓN DE CAMBIOS EN LA COBERTURA TERRESTRE UTILIZANDO EMISIVIDAD

French et al., 2008, Rem. Sens. Environ., 112, 1730-1748.



cambios entre los años 2001 y 2003

OTRAS APLICACIONES

IDENTIFICACIÓN DE DISTINTAS ESPECIES DE PLANTAS A PARTIR DE RASGOS CARACTERÍSTICOS EN LOS ESPECTROS DE EMISIVIDAD

Ribeiro da Luz & Crowley, 2007, Rem. Sens. Environ., 109, 393-405.

Ribeiro da Luz & Crowley, 2009, Rem. Sens. Environ., in press.

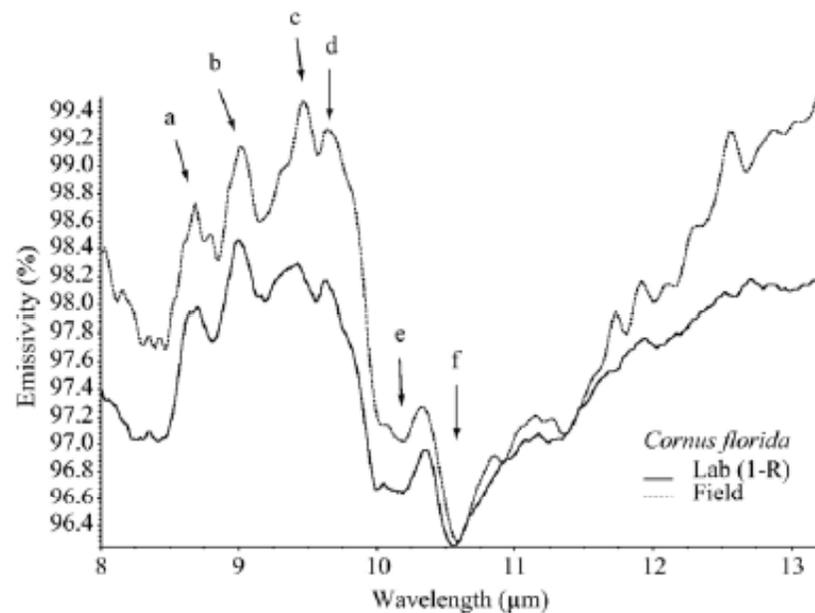


Fig. 10. DHR and field spectrometer measurements of *Cornus florida* (dogwood). Bands “a” to “d” are due to single particle emission of cellulose. Bands “e” and “f” are likely due to polysaccharides. Band positions: a) 8.62 μm ; b) 9.03 μm ; c) 9.47 μm ; d) 9.67 μm ; e) 10.22 μm ; f) 10.57 μm .

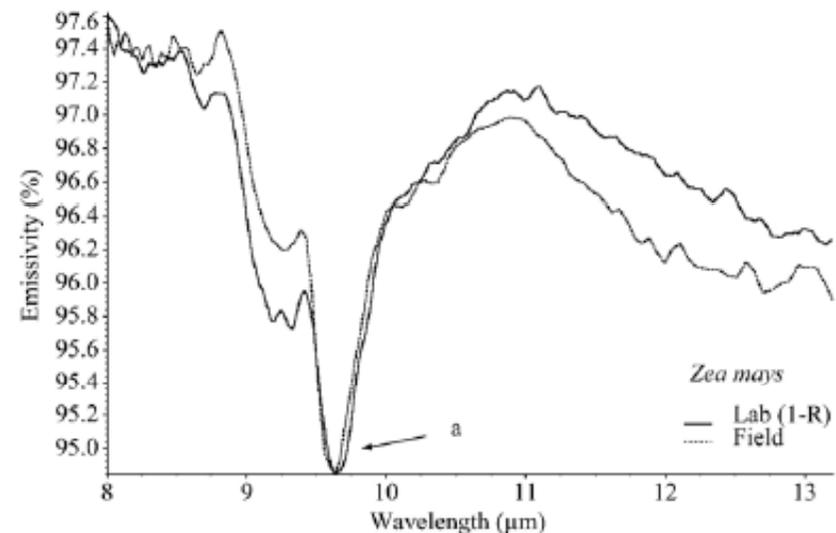


Fig. 11. DHR and field spectrometer measurements of *Zea mays* (corn). The laboratory and field spectra show a strong reststrahlen feature of the polysaccharide xylan at 9.67 μm (a) (also see Fig. 4).

OTRAS APLICACIONES

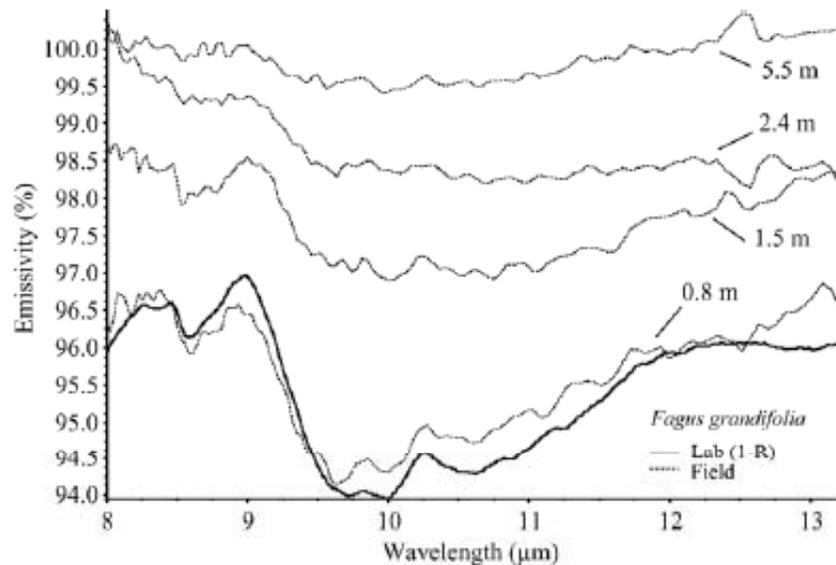


Fig. 16. "In situ" measurements. Comparison of spectra measured at different horizontal distances from a large *Fagus grandifolia* (beechn): 0.8 m, 1.5 m, 2.4 m and 5.5 m. The downwelling radiation was measured by using a gold plate 0.8 m from the spectrometer in all cases (cold blackbody: 20 °C.; warm blackbody: 35 °C). A laboratory DHR spectrum recalculated to emissivity (1 - R) is included for comparison.

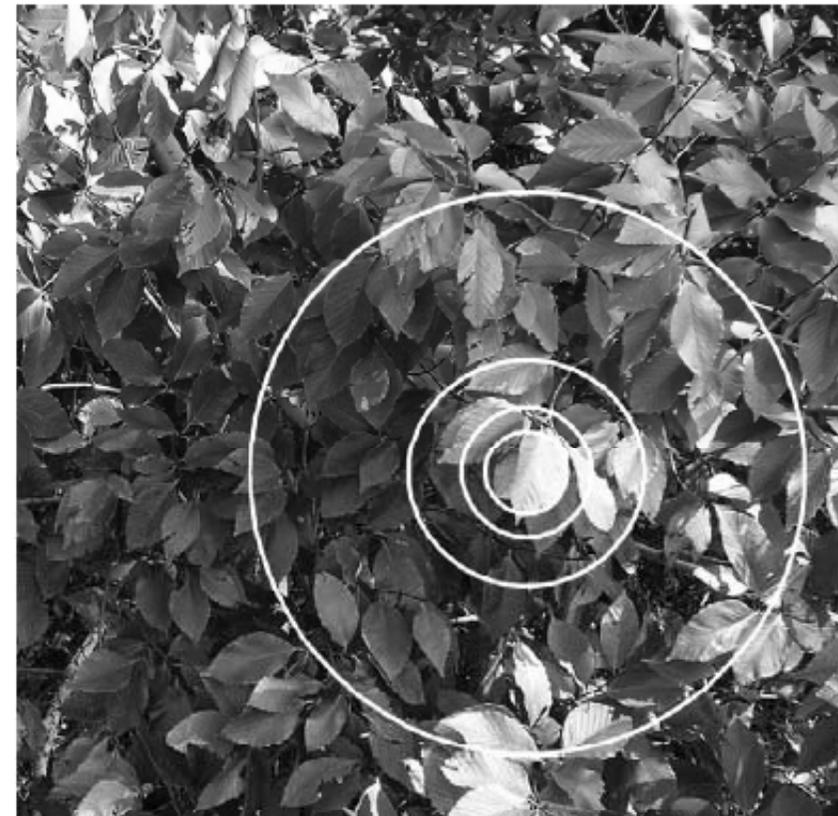
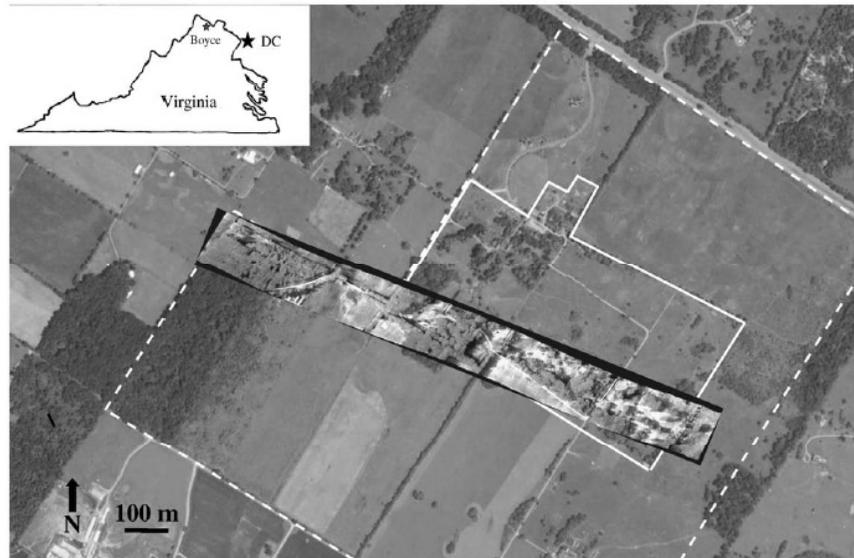


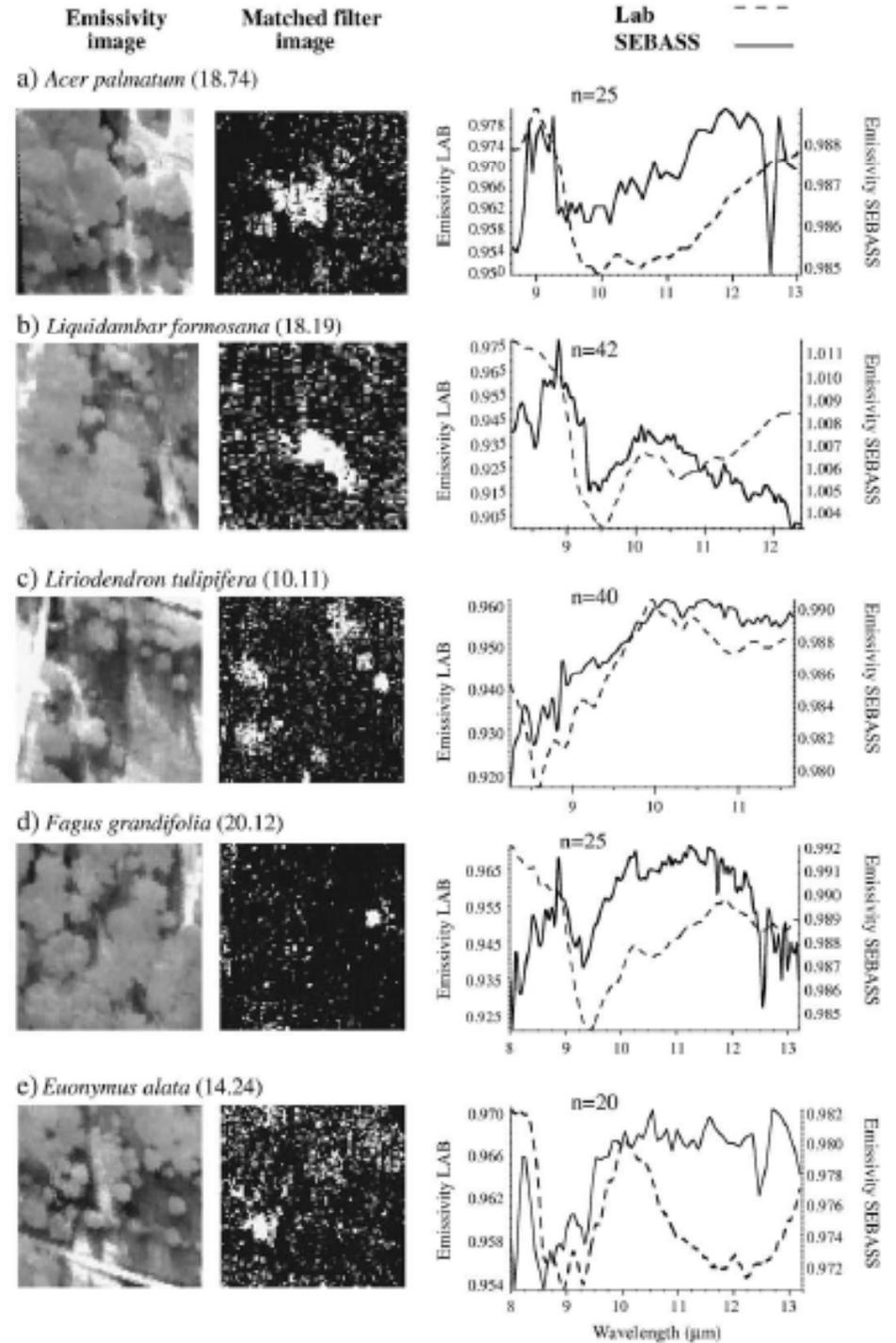
Fig. 18. *Fagus grandifolia* (beechn). The circles illustrate the approximate spectrometer FOV at different measurement distances, the smallest circle representing the closest measurement. At the closest measurement distance, 0.8 m (FOV ~6.4 cm) a single leaf essentially fills the FOV. At 1.5 m (FOV ~12 cm) about three leaves, some partially obscured by others, fill the FOV. At a distance of 2.4 m (FOV ~19 cm) more than 10 leaves are within the FOV, and at 5.5 m distance (FOV ~44 cm) there are many tens of leaves and cavities at a variety of orientations within the FOV.

EFFECTO DE ESCALA

IDENTIFICACIÓN DE ESPECIES UTILIZANDO DATOS SEBASS



W78° 03' 57"



CONCLUSIONES

- Los sensores infrarrojos térmicos (campo, avión, satélite) permiten realizar medidas de temperatura y emisividad de la superficie terrestre. Esta última magnitud (espectral) es la que está directamente relacionada con la línea de espectroscopía.
- La medida de la emisividad puede realizarse por emisión o por reflexión. En el caso de emisión se necesita desacoplar la temperatura y la emisividad, mientras que en el caso de reflexión la medida es directa.
- Medidas espectroscópicas de emisividad permiten detectar rasgos característicos en los espectros, permitiendo la identificación de minerales o de especies vegetales.
- Las medidas de campo de Temp/Emis sirven para calibrar/validar datos de teledetección adquiridos por los distintos sensores de Observación de la Tierra.
- Los mapas de Temp/Emis (datos térmicos) tienen su aplicación en la gestión de los recursos hídricos, detección de estrés hídrico, cambios de la cobertura terrestre, efecto de isla térmica, etc.

ESPECTROSCOPIA

del laboratorio al satélite

Remote Sensing of Landscapes with Spectral Images
J. B. Adams & A. R. Gillespie (Cambridge University Press, 2006)

- ▶ Algunos materiales no muestran bandas de resonancia claras.
- ▶ Algunos materiales, a pesar de mostrar bandas de resonancia, no pueden ser identificados inequívocamente.
- ▶ Sólo algunos de los materiales que pueden ser identificados mediante espectroscopía resultan de interés en aplicaciones de teledetección.
- ▶ Puede ocurrir que el material a identificar no se encuentre con una suficiente abundancia como para ser detectado remotamente.
- ▶ Las bandas de absorción o emisión pueden enmascarse por la presencia de pequeñas cantidades de otros materiales, como carbón opaco u óxidos metálicos. Las bandas también pueden quedar enmascaradas por el tamaño de la partícula u otros efectos geométricos.
- ▶ Para caracterizar adecuadamente una banda, el sensor debe tener bandas en longitudes de onda cercanas al centro de la banda y fuera de ella. Por lo tanto, las bandas del sensor tienen que ser más estrechas que la banda de resonancia a identificar.
- ▶ Bandas de sensores estrechas registran menos cantidad de energía radiante, con los consiguientes problemas de sensibilidad (ruido).
- ▶ Existen pocos sensores con las características adecuadas (elevado número de bandas y estrechas).
- ▶ Debido a un cierto tamaño de píxel, los espectros obtenidos mediante teledetección están compuestos por mezclas de distintos materiales. Estas mezclas “diluyen” las bandas de resonancia, siendo su detección más difícil.