Calibration of Thermal Infrared Remote Sensing Sensors over the Iberian Peninsula

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INTRODUCTION

SENSORS

DATA PROCESSING

UNCERTAINTIES OF IN-SITU MEASUREMENTS

VICARIOUS CALIBRATION AND LST VALIDATION

CONCLUSIONS

INTRODUCTION

Thermal InfraRed (TIR)

TIR (8-14 μm) →

Essential Climate Variable

- Sea Surface Temperature (SST)
- Land Surface Temperature (LST)

Key parameter in the exchanges of energy, momentum, moisture and gases between the Earth surface and atmosphere

Land Surface Emissivity (LSE)

Surface or object's efficiency into emit TIR energy

Because of its importance:

Reliable and uniform LST/SST time series are required → Accurate knowledge of satellite TIR

INTRODUCTION

LANDSAT 1 (1972) → Collect global Earth land cover data with moderate spatial resolution

Since that milestone > 200 satellites launched

Committee on Earth Observation Satellites (CEOS)

- Working Group on Calibration and Validation (WGCV)
  - Establish globally recognized guidelines for calibration and validation (cal/val) processes
  - Efficient data management, distribution and processing

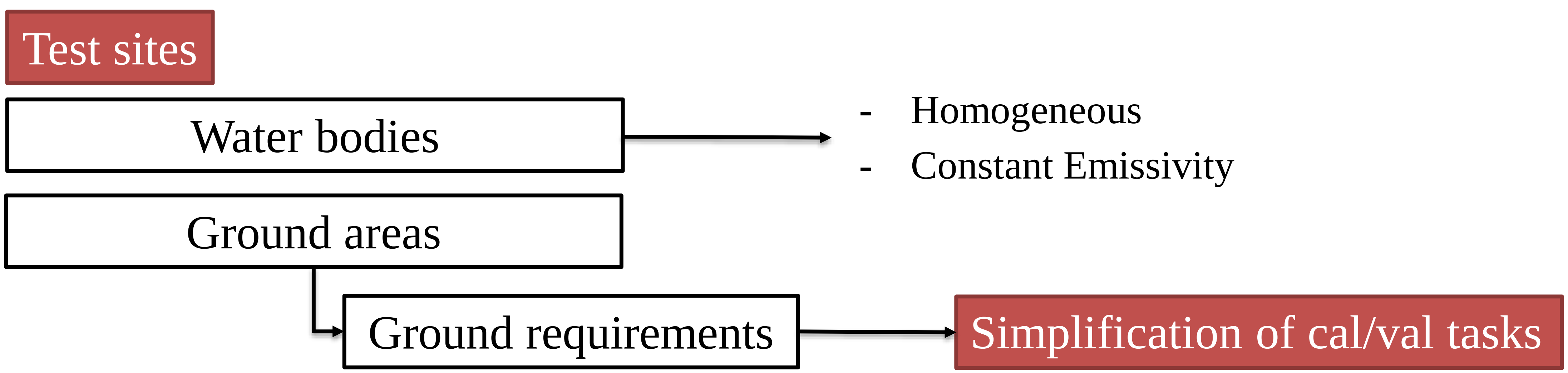
Calibration is control of satellite raw data.

Validation is the accuracy assessing of data products.

INTRODUCTION

TIR control:

- In-flight calibration methods, referred to as Vicarious Calibration (VC)
  - Satellite vs In-situ data
  - Through test sites TIR in-situ measurements can be performed for cal/val



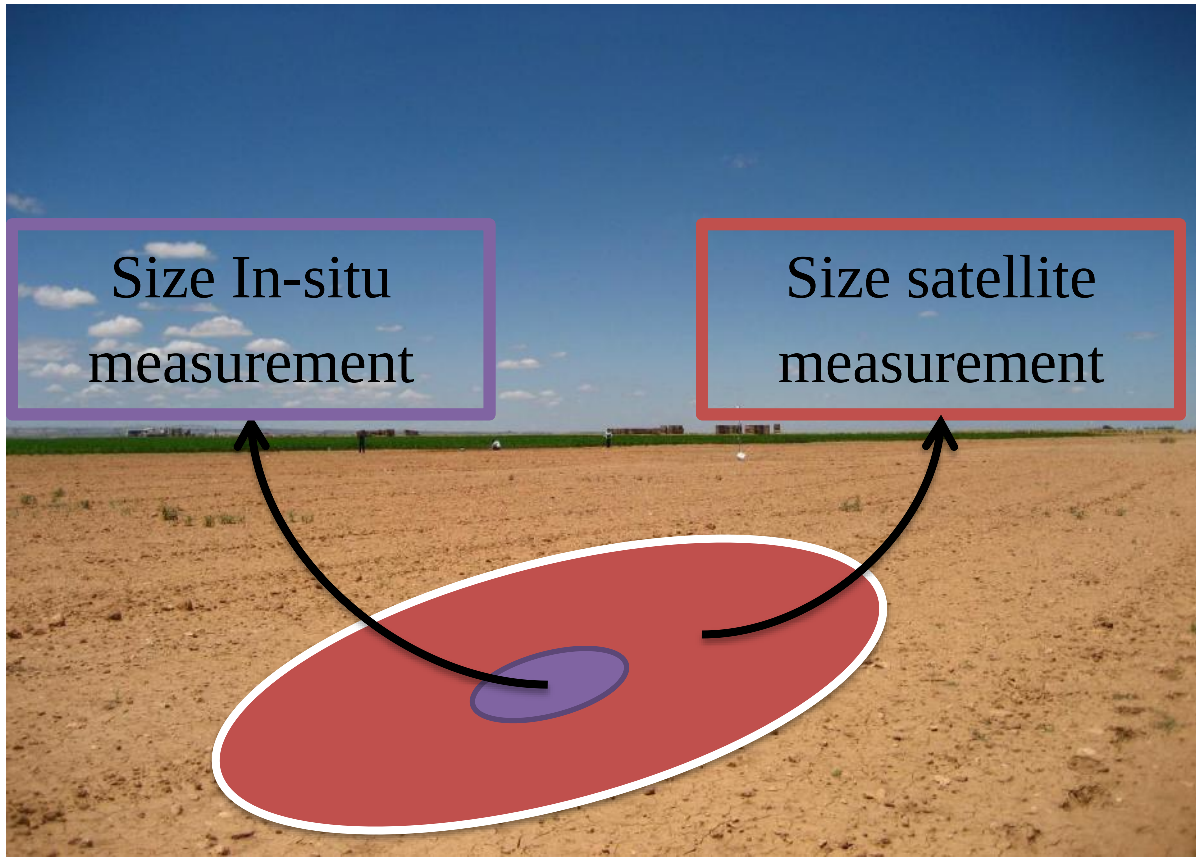
INTRODUCTION

Test sites

Water bodies → - Homogeneous
- Constant Emissivity

Ground areas

Ground requirements → Simplification of cal/val tasks

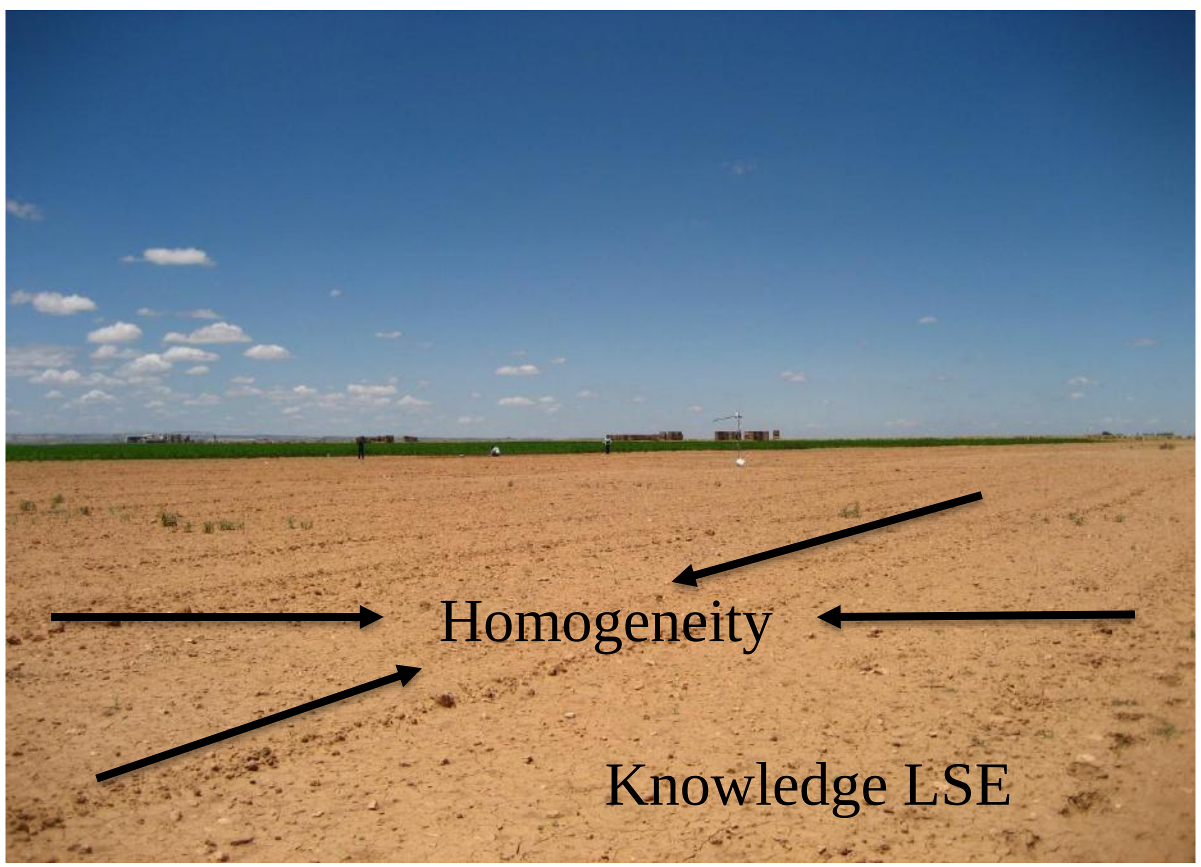


- High spatial homogeneity over large areas guarantee minimal discrepancies between satellite and in-situ measurements.

INTRODUCTION

Test sites

- **Water bodies** →
  - Homogeneous
  - Constant Emissivity
- **Ground areas** → **Ground requirements** → **Simplification of cal/val tasks**

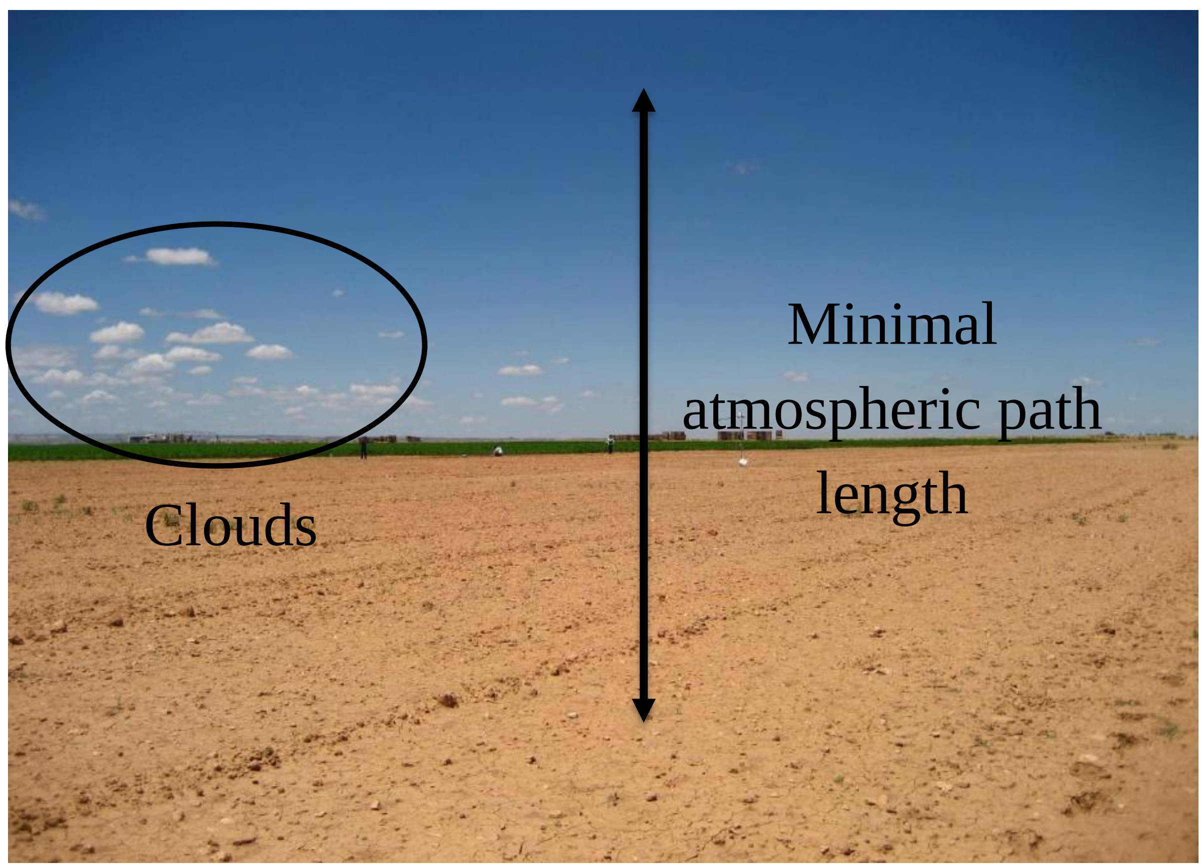


- High spatial homogeneity over large areas guarantee minimal discrepancies between satellite and in-situ measurements.
- Knowledge of changes in Land Surface Emissivity (LSE) and, consequently, the correct retrieval of the LST.
- Easy accessibility to the test site is also an important factor.

INTRODUCTION

Test sites

- Water bodies →
  - Homogeneous
  - Constant Emissivity
- Ground areas
  - Ground requirements → **Simplification of cal/val tasks**



- Knowledge of changes in Land Surface Emissivity (LSE) and, consequently, the correct retrieval of the LST.
- Easy accessibility to the test site is also an important factor.
- Minimal atmospheric path length between satellite and ground reduces calibration atmospheric-associated errors.
- High probability of cloud-free days.

SENSORS

Sensors used have been selected because of its data availability

Sensors

Moderate resolution

Sensors	
Landsat-7 (L7)	Enhanced Thematic Mapper Plus (ETM+)
Landsat-8 (L8)	Operational Land Imager (OLI)
	TIR Sensor (TIRS)

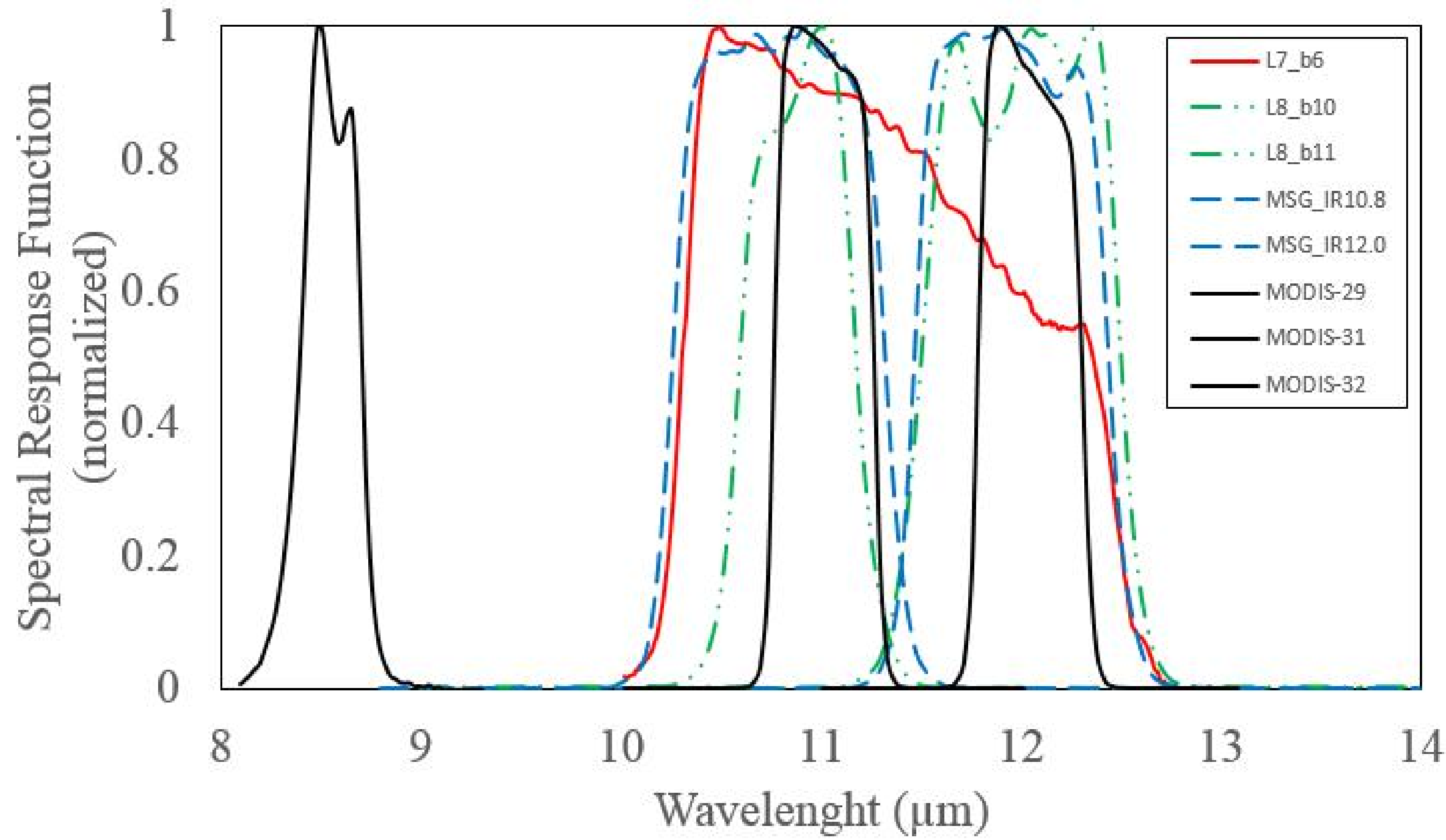
Low resolution

Sensors	
Terra/Aqua	MODIS
Meteosat	Spinning Enhanced Visible and Infrared Imager (SEVIRI)

High resolution

Sensors	
Airborne	Airborne Hyperspectral Scanner (AHS)

Spatial resolution 3-7 m
10 TIR bands



DATA PROCESSING

Sensor imagery

Landsat-7 ETM+ / **Landsat-8 TIRS**
- April 2013 to June 2016
- 44 daytime scenes (Landsat-7 ETM+) / 47 daytime scenes (Landsat-8 TIRS)
- Landsat radiance images
- Selected plot: 3×3 pixels

Terra/Aqua MODIS
- January 2012 to 2016
- > 1,000 scenes
- MOD02 radiance, MOD07 atmosphere, MOD11 LST, NASA SST
- Selected plot: 1×1 pixels

MSG SEVIRI
- October 2012
- May 2015, 2013
- 15 scenes
- LST product
- Selected plot: 1×1 pixels

LSE estimation

LSE is estimated from information collected of NDVI

$$FVC = \frac{NDVI - NDVIs}{NDVIv - NDVIs}$$

Fraction Vegetation Cover

$$\varepsilon = a + b\rho_{red} \quad (FVC = 0)$$

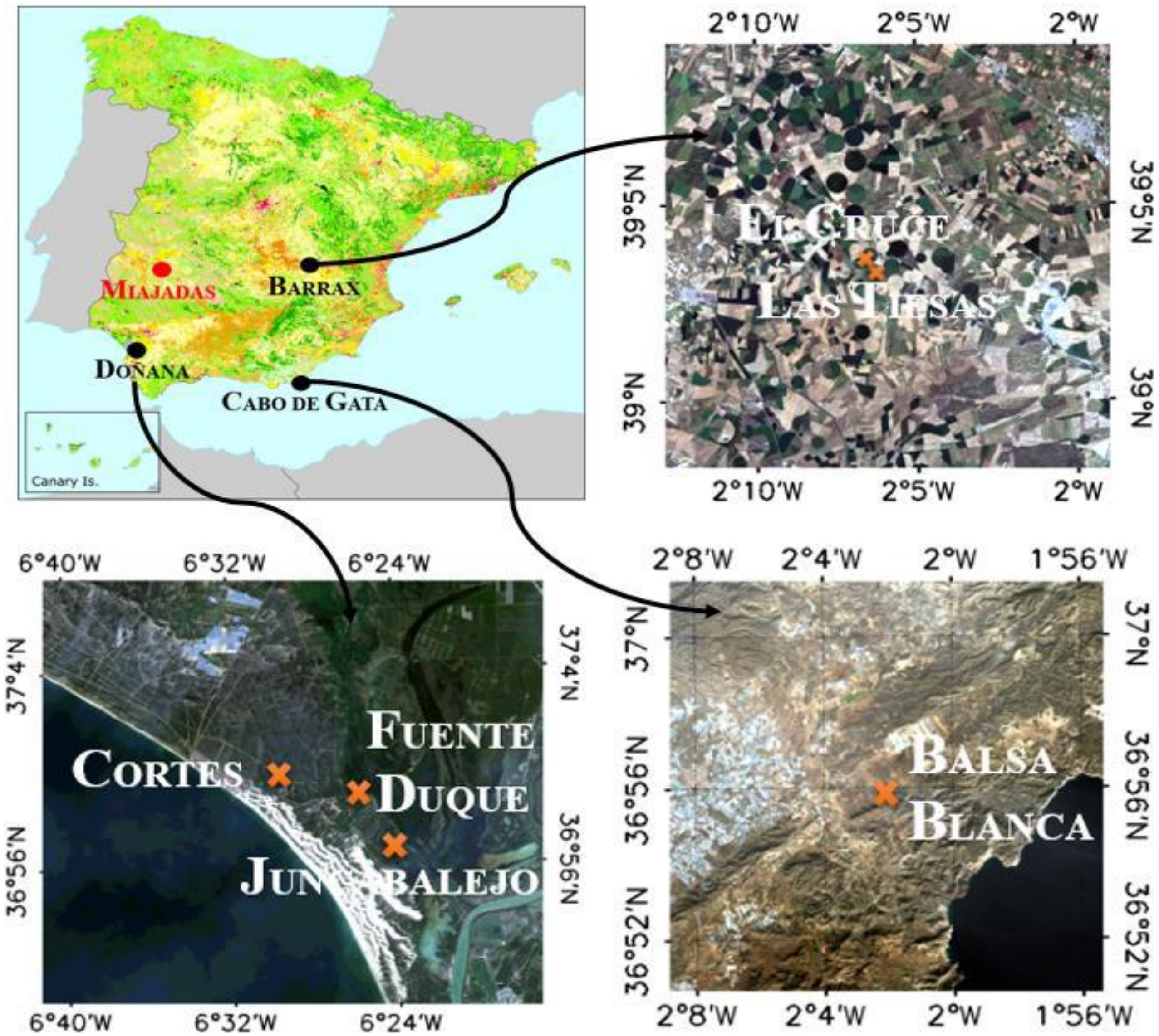
$$\varepsilon = \varepsilon_s(1 - FVC) + \varepsilon_v FVC + C \quad (0 < FVC < 1)$$

$$\varepsilon = 0.99 \quad (FVC = 1)$$

DATA PROCESSING

In-situ data

Ground test sites



Three test sites for direct validation plus an extra site for indirect validation:

- Barrax (39°N, 2°W, 700 m a.s.l.)
  - Agricultural area covered by bare soils and crops
  - Uniform land-use units (approximately size of 1×1 Km)
- Doñana (37˚ N, 6˚25' W, sea level)
  - National Park
  - Width marshland area (> 10×10 Km) periodically flooded (precipitation dependence)
  - Areas covered by bushes, pine forest and sand dunes
- Cabo de Gata (37˚ N, 2˚ W, 100 m a.s.l.)
  - National Park
  - volcanic origin of 40×20 Km
  - Covered bare soils and senescent vegetation
- Majadas (40˚ N, 5˚46' W, 250 m a.s.l.)
  - No uniform surface
  - Clear forest with a grassland and bush

DATA PROCESSING

Fixed stations Permanent stations for continuous in-situ measurements

Cabo de Gata

BALSA BLANCA

Bare soil and vegetation

Doñana

FUENTE DUQUE

Green or senescent vegetation

JUNCABALEJO

Green or senescent vegetation

CORTES

Pine forest

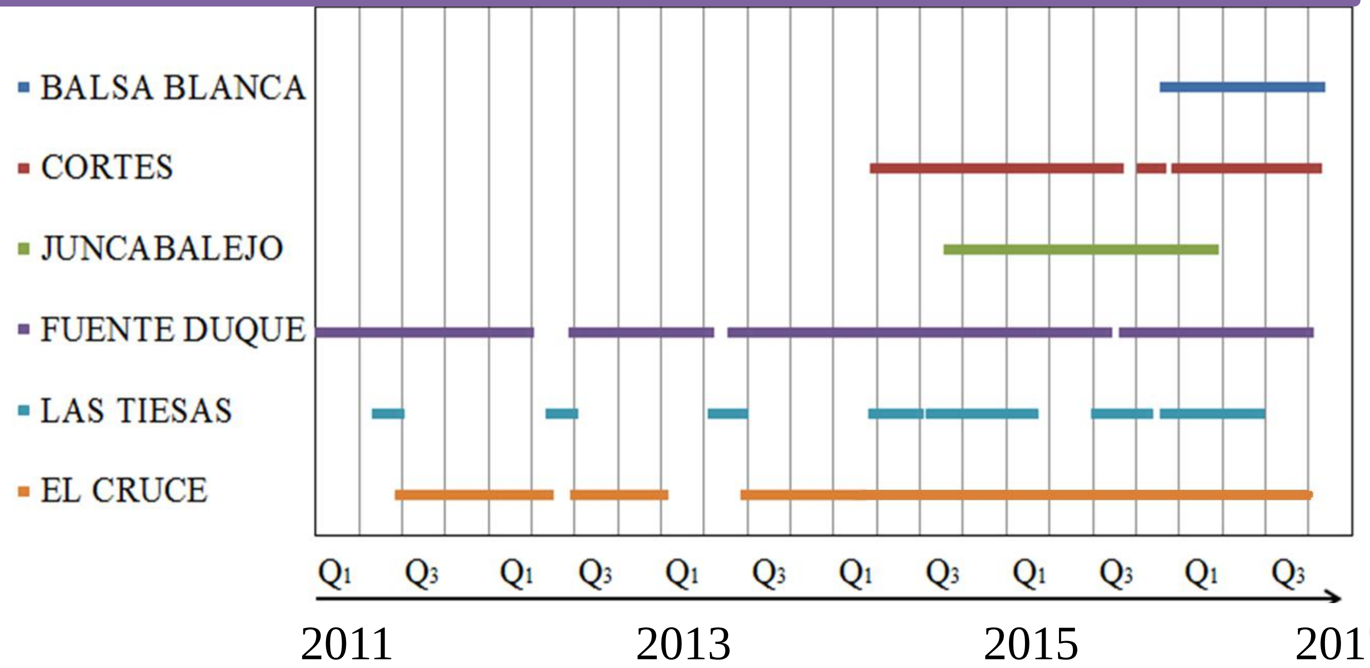
Barrax

LAS TIESAS

Bare soil and crops

EL CRUCE

Grass field



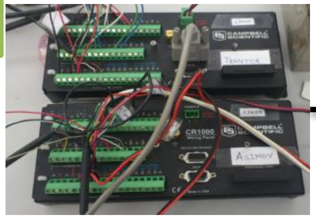
DATA PROCESSING

Fixed stations

Flux radiometers

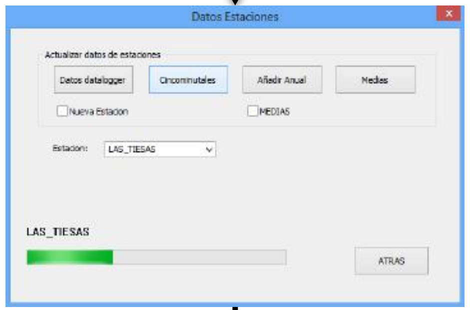
Temperature

Radiometers



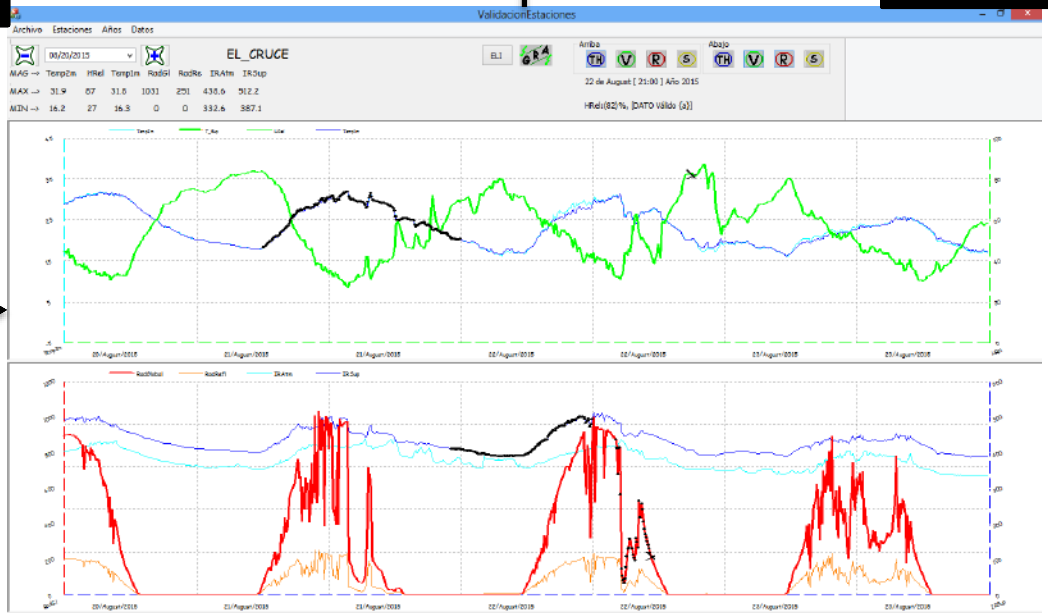
- In all test sites broadband radiometers for LST estimation have been installed.
- Temperature, humidity, radiance, soil moisture, etc.
- Periodical maintenance campaigns have been developed for calibration, reparation or, if necessary, replacement of instruments as well as for downloading of data.

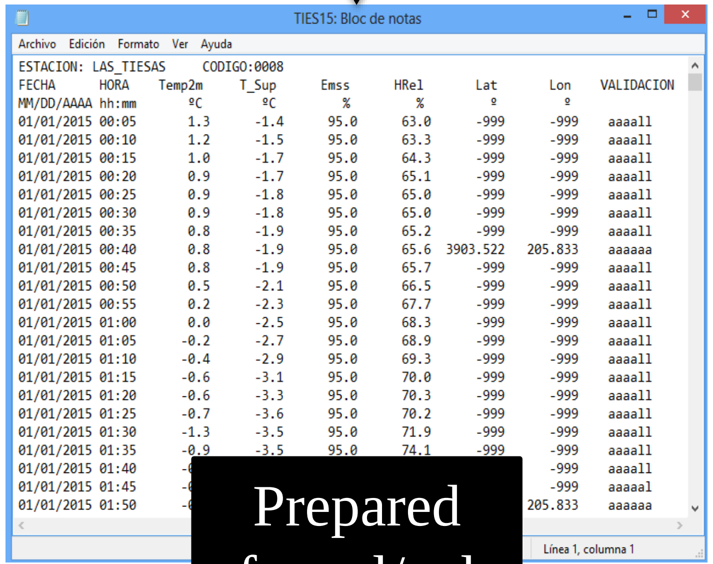
Processed



Validated

Stored




TIES15: Bloc de notas

Archivo Edición Formato Ver Ayuda

ESTACION: LAS_TIESAS CODIGO:0008

FECHA	HORA	Temp2m	T_Sup	Emss	HRel	Lat	Lon	VALIDACION
MM/DD/AAAA	hh:mm	ºC	ºC	%	%	º	º	
01/01/2015	00:05	1.3	-1.4	95.0	63.0	-999	-999	aaaall
01/01/2015	00:10	1.2	-1.5	95.0	63.3	-999	-999	aaaall
01/01/2015	00:15	1.0	-1.7	95.0	64.3	-999	-999	aaaall
01/01/2015	00:20	0.9	-1.7	95.0	65.1	-999	-999	aaaall
01/01/2015	00:25	0.9	-1.8	95.0	65.0	-999	-999	aaaall
01/01/2015	00:30	0.9	-1.8	95.0	65.0	-999	-999	aaaall
01/01/2015	00:35	0.8	-1.9	95.0	65.2	-999	-999	aaaall
01/01/2015	00:40	0.8	-1.9	95.0	65.6	3903.522	205.833	aaaaaa
01/01/2015	00:45	0.8	-1.9	95.0	65.7	-999	-999	aaaall
01/01/2015	00:50	0.5	-2.1	95.0	66.5	-999	-999	aaaall
01/01/2015	00:55	0.2	-2.3	95.0	67.7	-999	-999	aaaall
01/01/2015	01:00	0.0	-2.5	95.0	68.3	-999	-999	aaaall
01/01/2015	01:05	-0.2	-2.7	95.0	68.9	-999	-999	aaaall
01/01/2015	01:10	-0.4	-2.9	95.0	69.3	-999	-999	aaaall
01/01/2015	01:15	-0.6	-3.1	95.0	70.0	-999	-999	aaaall
01/01/2015	01:20	-0.6	-3.3	95.0	70.3	-999	-999	aaaall
01/01/2015	01:25	-0.7	-3.6	95.0	70.2	-999	-999	aaaall
01/01/2015	01:30	-1.3	-3.5	95.0	71.9	-999	-999	aaaall
01/01/2015	01:35	-0.9	-3.5	95.0	74.1	-999	-999	aaaall
01/01/2015	01:40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-999	aaaall
01/01/2015	01:45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-999	aaaaal
01/01/2015	01:50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	205.833	aaaaaa

Línea 1, columna 1

Prepared for cal/val

DATA PROCESSING

Fixed stations Continuous field campaigns performed for LSE control

CABO DE GATA

Bare soil and vegetation

DOÑANA

Green or senescent vegetation

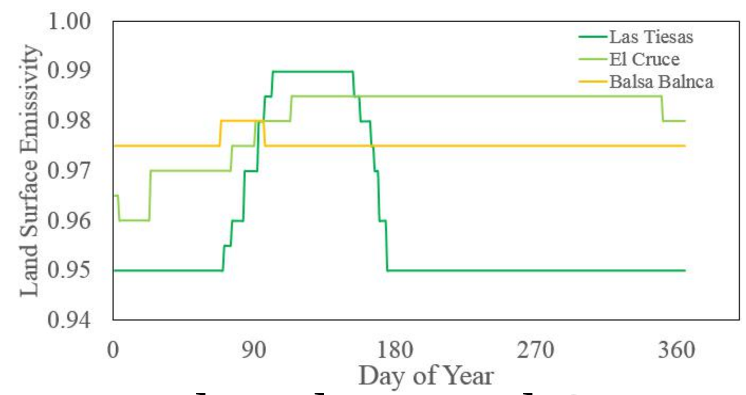
Green or senescent vegetation

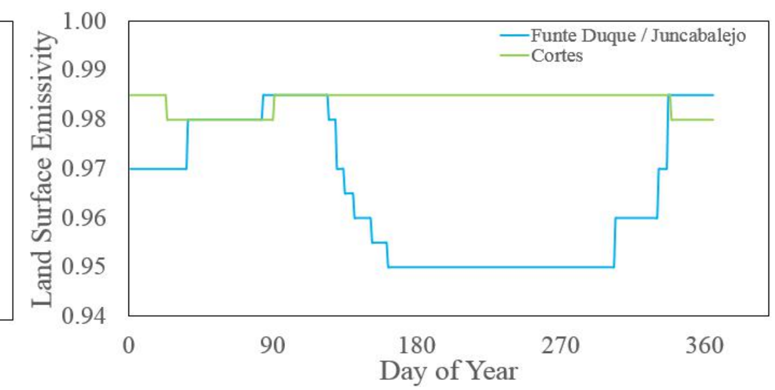
Pine forest

BARRAX

Bare soil and crops

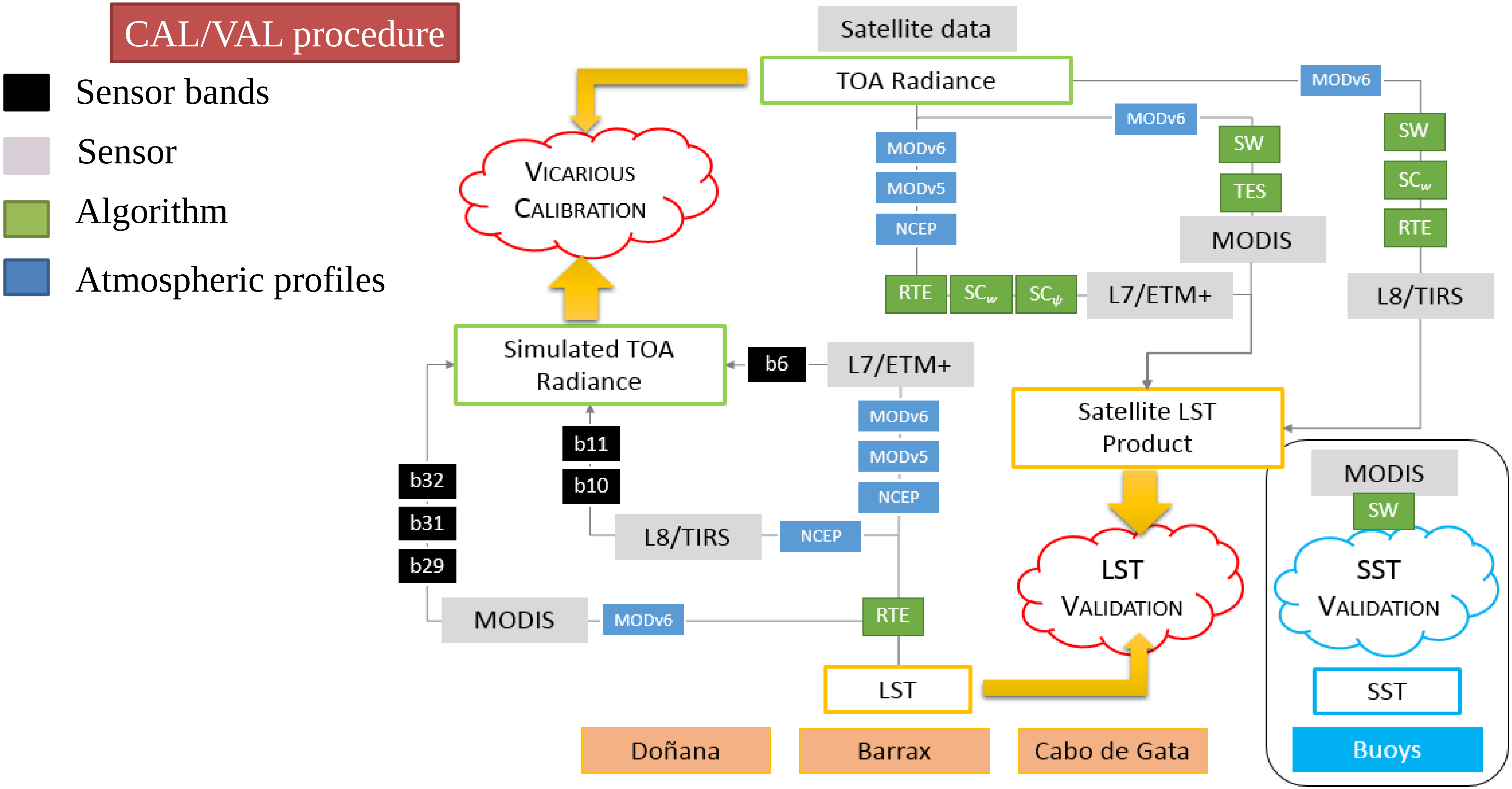
Grass field





- Balsa Blanca and Cortes: Stable LSE of 0.975-0.98
- El Cruce/Las Tiesas: Grass and crop evolution
- Fuente Duque/Juncabalejo: Direct relation with marshland floods and drying out periods

DATA PROCESSING



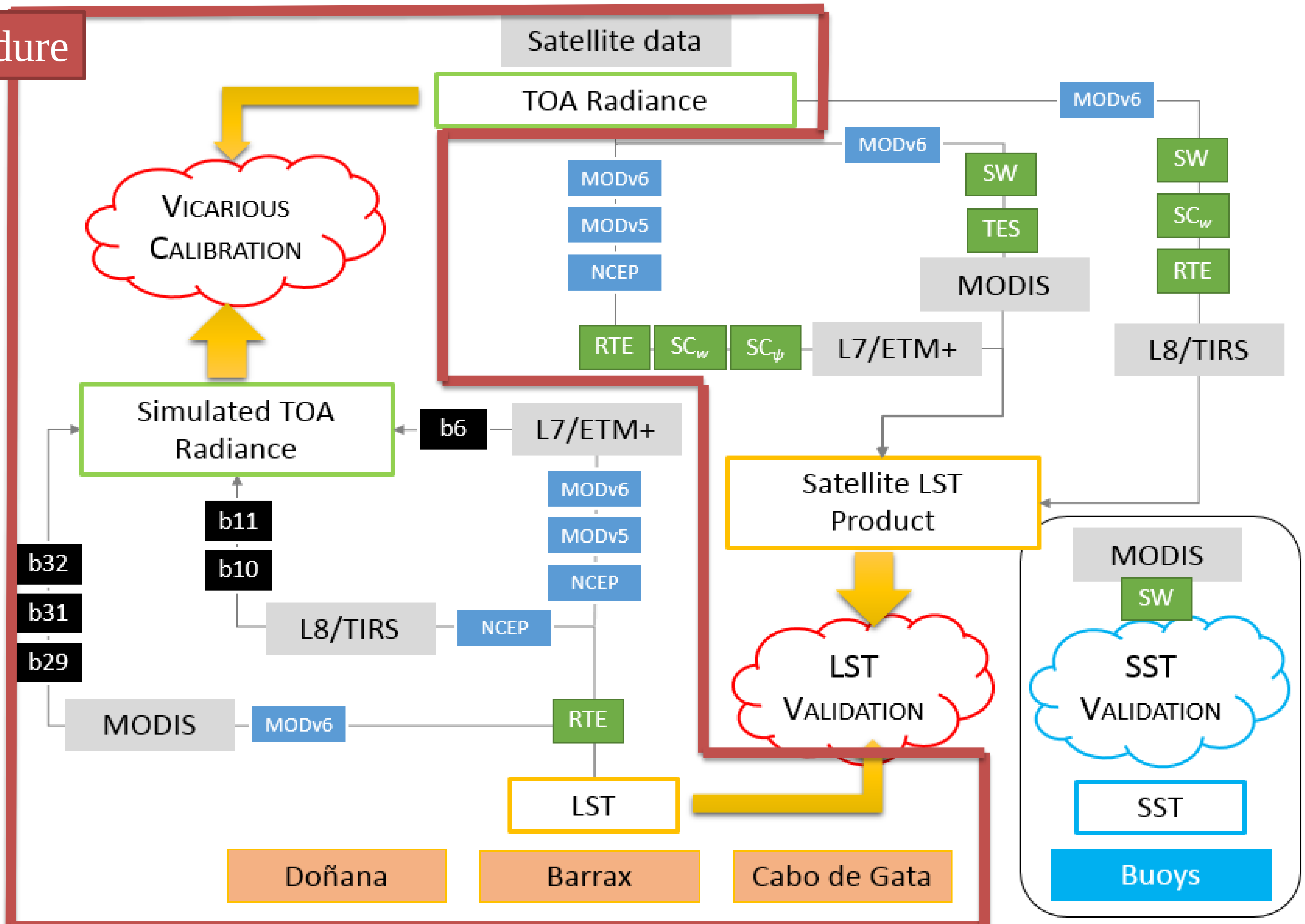
DATA PROCESSING

CAL/VAL procedure

- Sensor bands
- Sensor
- Algorithm
- Atmospheric profiles

Vicarious Calibration

Simulate from in-situ data to Top of Atmosphere or satellite level



DATA PROCESSING

CAL/VAL procedure

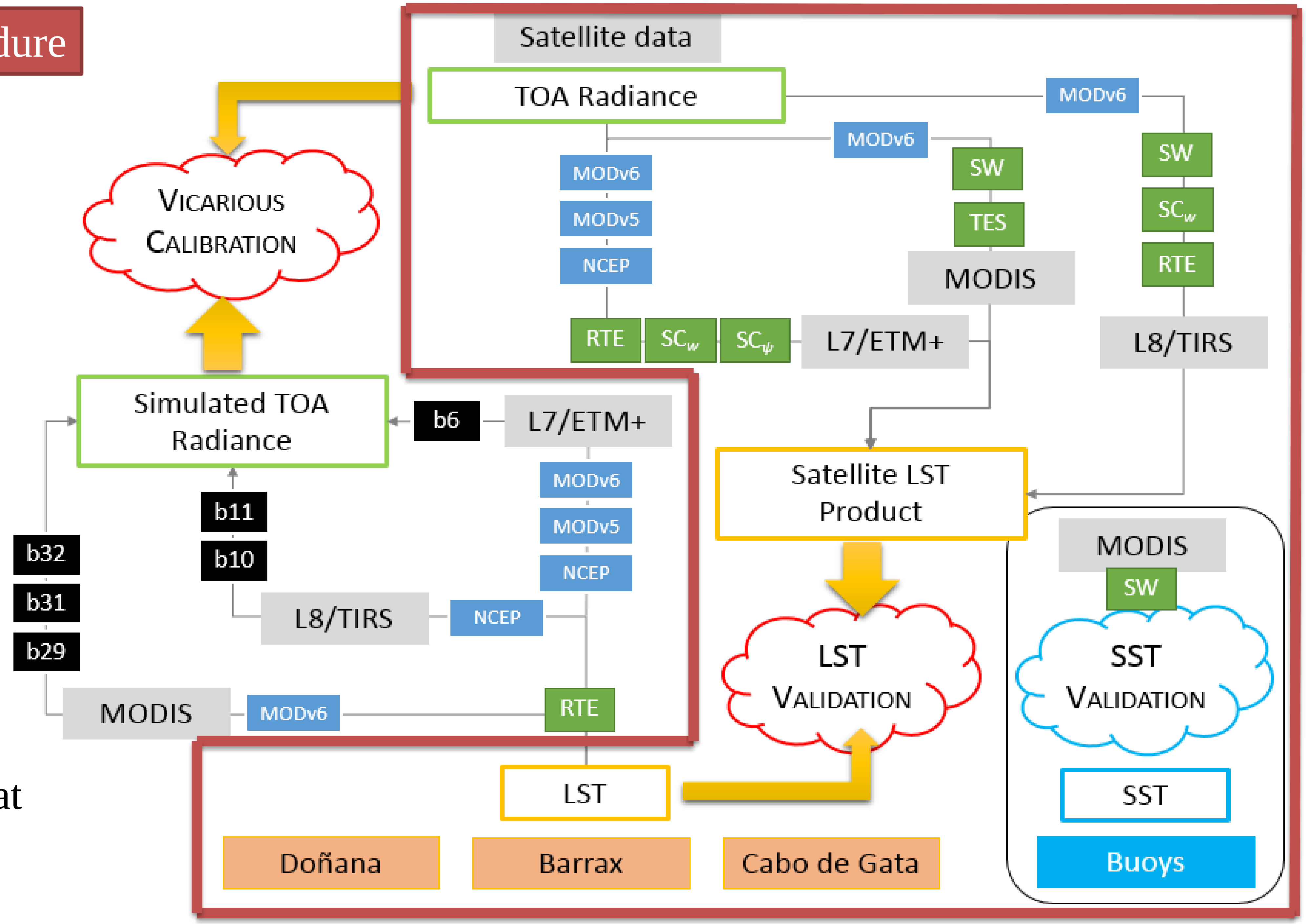
- Sensor bands
- Sensor
- Algorithm
- Atmospheric profiles

Vicarious Calibration

Simulate in-situ data to Top of Atmosphere or satellite level

LST/SST validation

Retrieve with satellite TOA radiance LST/SST at ground level

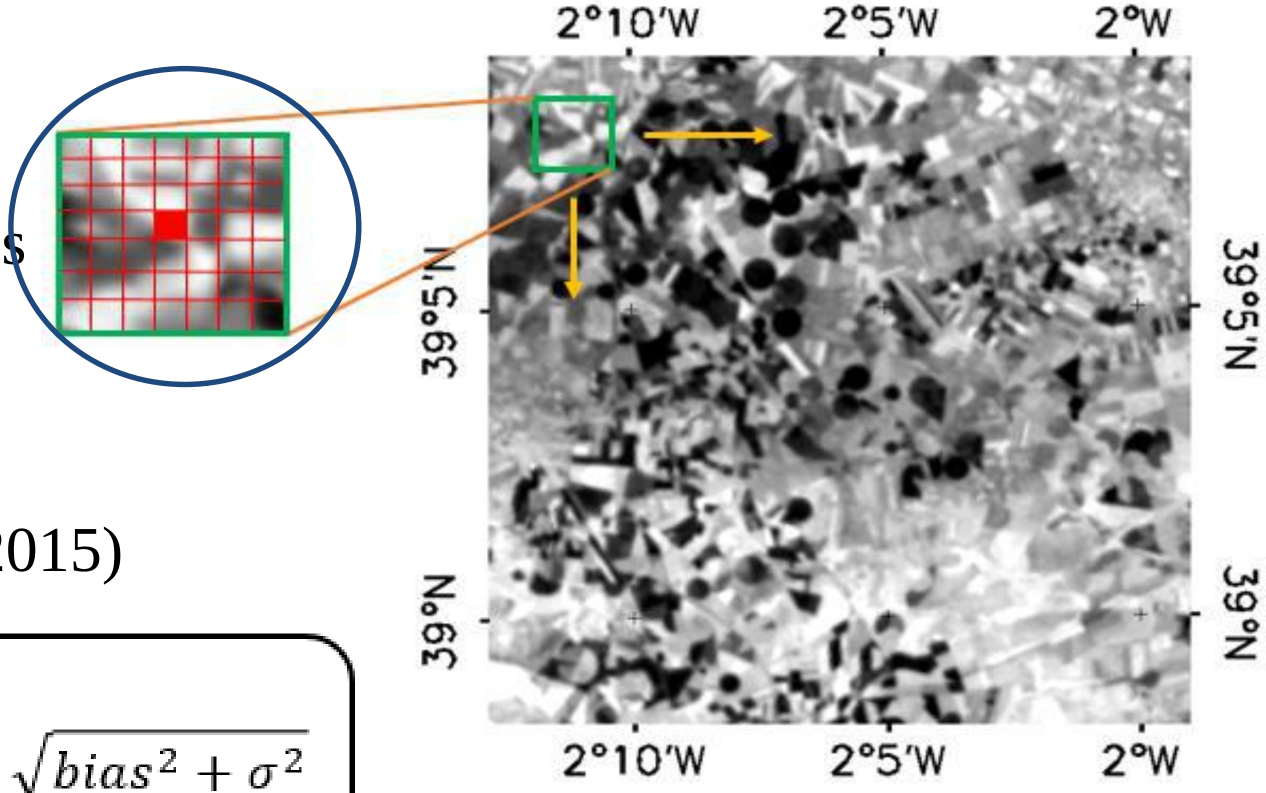


UNCERTAINTIES OF IN-SITU MEASUREMENTS

LST Homogeneity

Most important uncertainty factor for cal/val activities

- Variation of LST in a considered area



Estimation of Inhomogeneity (INH): (Sobrino et al, 2015)

$$bias = {}^{1}/_{n}\sum_{i=1}^{n} T_C - T_i \qquad \sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}|T_i - \bar{T}|} \qquad INH = \sqrt{bias^2 + \sigma^2}$$

→ Statistical parameters

Area, represented by window, slides across image retrieving INH of central pixel

- Window represents sensor spatial resolution
- Higher resolution image is needed for INH computation

INH index for:
- Moderate resolution sensors (ETM+, TIRS)
- Low resolution sensors (MODIS, SEVIRI)

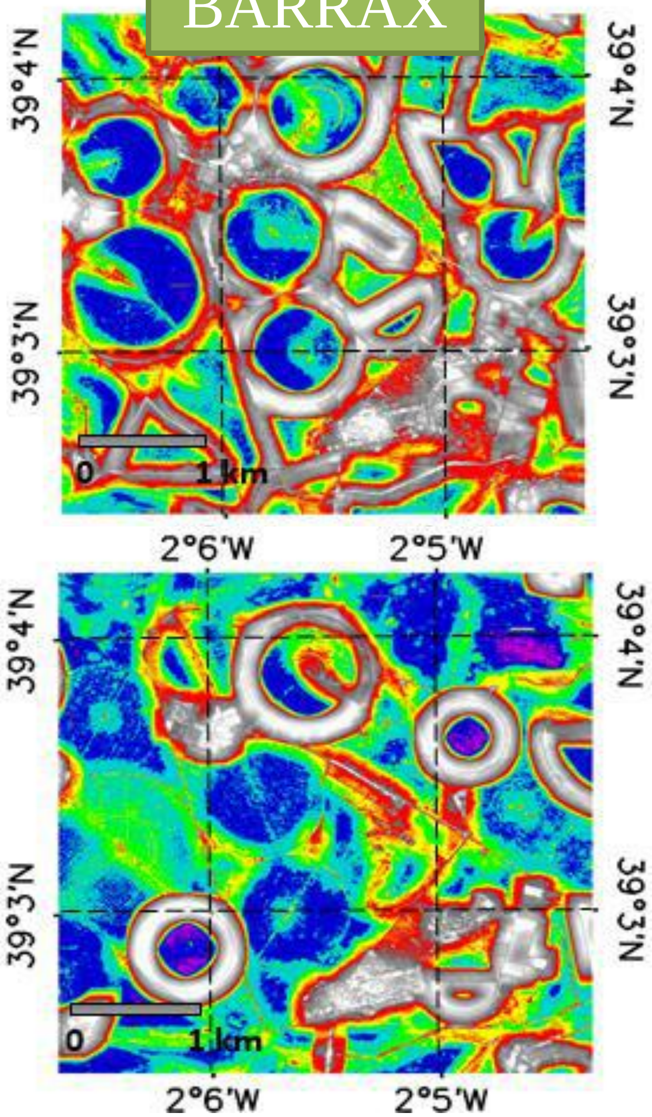
Sobrino, J.A.; Skokovi´c, D.; Jiménez-Muñoz, J.C. Spatial analysis of the homogeneity of the land surface temperature in three Spanish test sites. Int. J. Remote Sens. 2015, 36, 4793–4807

UNCERTAINTIES OF IN-SITU MEASUREMENTS

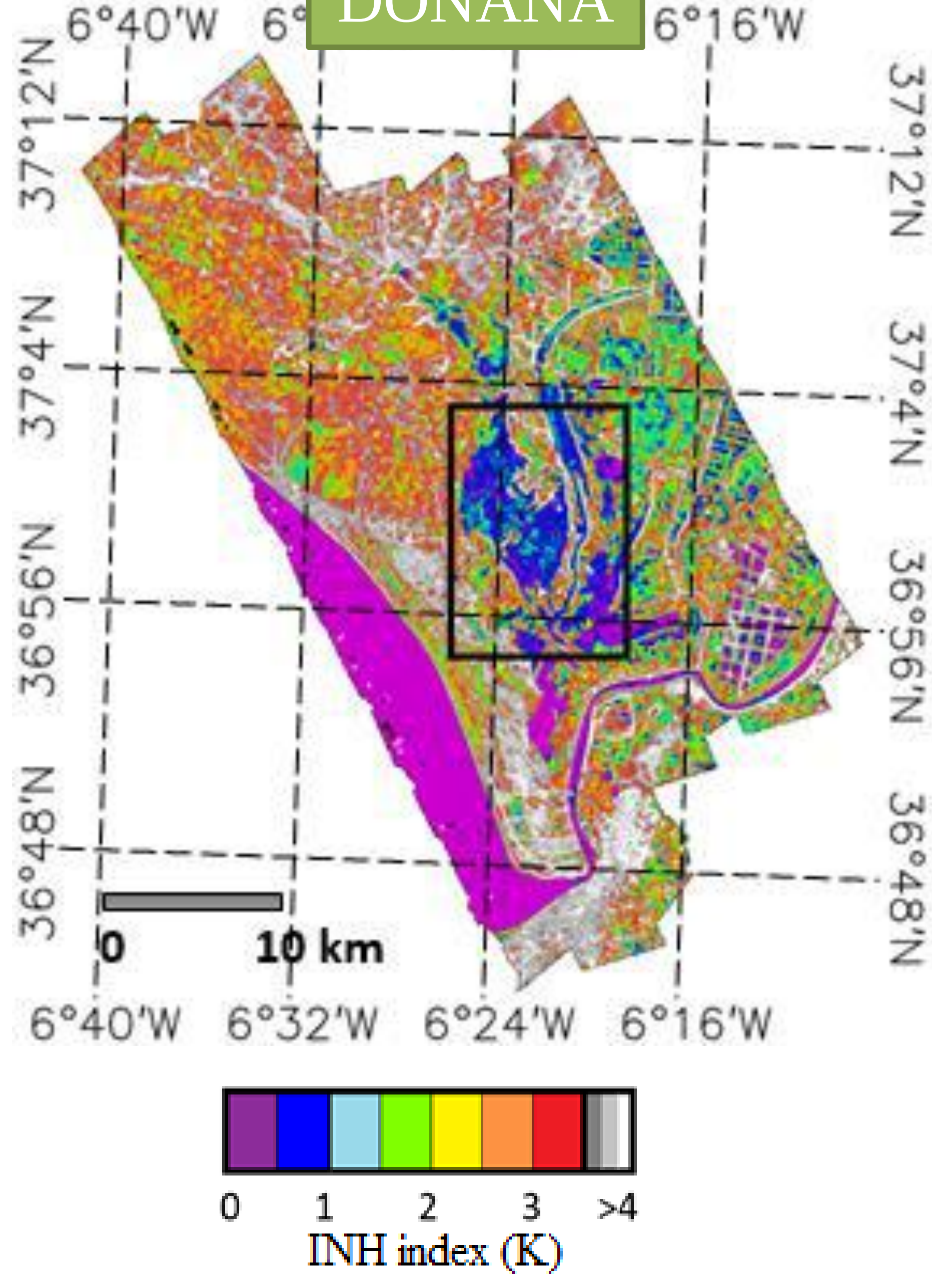
LST Homogeneity

INH index estimated over AHS images (high resolution images)

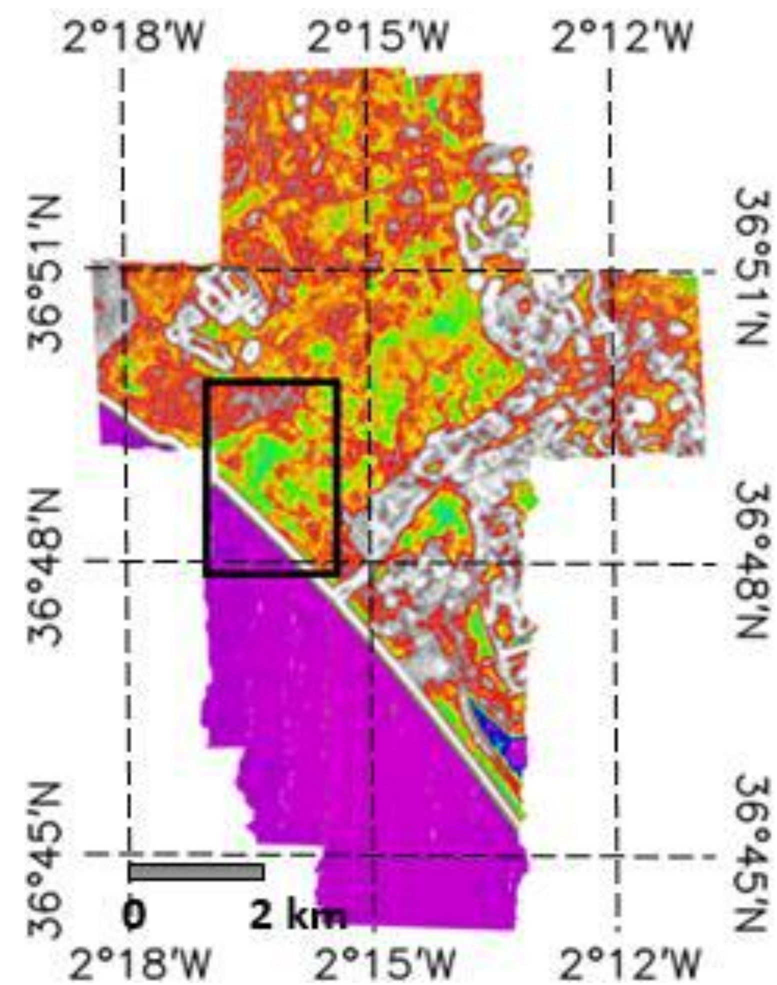
BARRAX



DOÑANA



CABO DE GATA

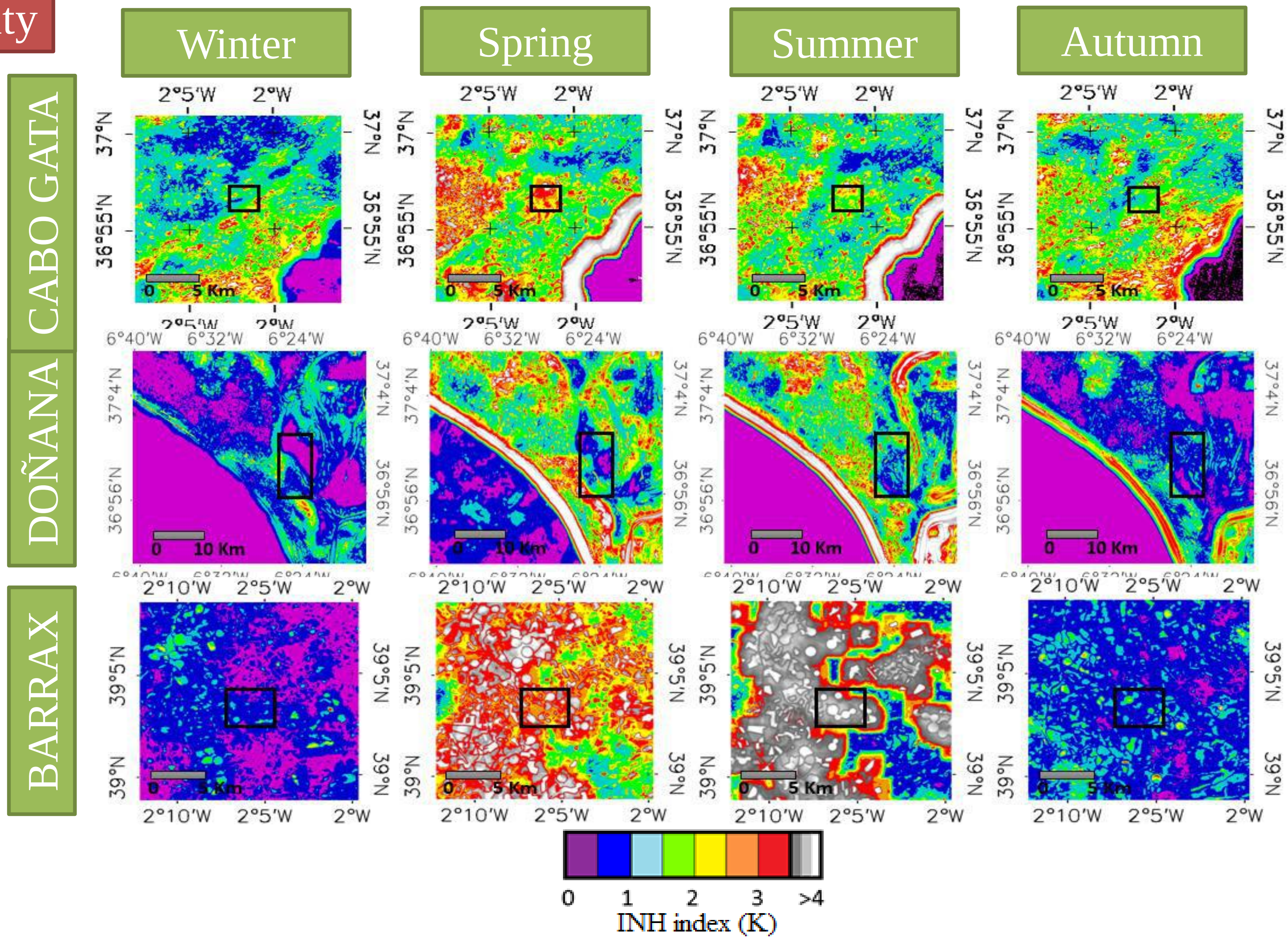


UNCERTAINTIES OF IN-SITU MEASUREMENTS

LST Homogeneity

MODIS

INH index estimated over TIRS (Landsat-8) images (moderate resolution images)



Doñana:
Autumn and winter:
- INH < 1.0 K

Spring:
- INH > 2.0 K

Marshland, stable INH is observed all the year

UNCERTAINTIES OF IN-SITU MEASUREMENTS

Uncertainty Summary

- Major contribution to LST uncertainties come from INH
- Other uncertainty sources contribute only with errors below 0.5 K

- Set periods cal/val is allowed:

Cal/Val not recommended when total uncertainty > 1.5 K

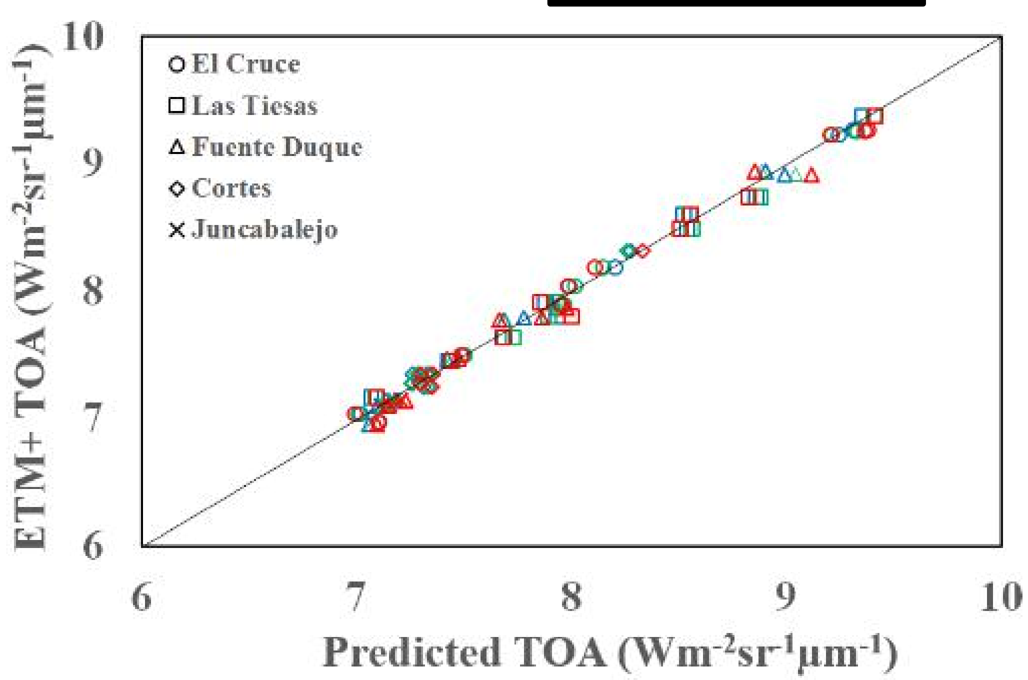
Test site	ETM+/TIRS				MODIS/SEVIRI			
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Las Tiesas	Yes	Yes	Yes	Yes	Yes	No	No	Yes
El Cruce	Yes	Yes	Yes	Yes	No	No	No	No
Cortes	Yes	No	No	Yes	No	No	No	No
Juncabalejo	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Fuente Duque	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Balsa Blanca	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes

VICARIOUS CALIBRATION AND LST/SST VALIDATION

Vicarious Calibration

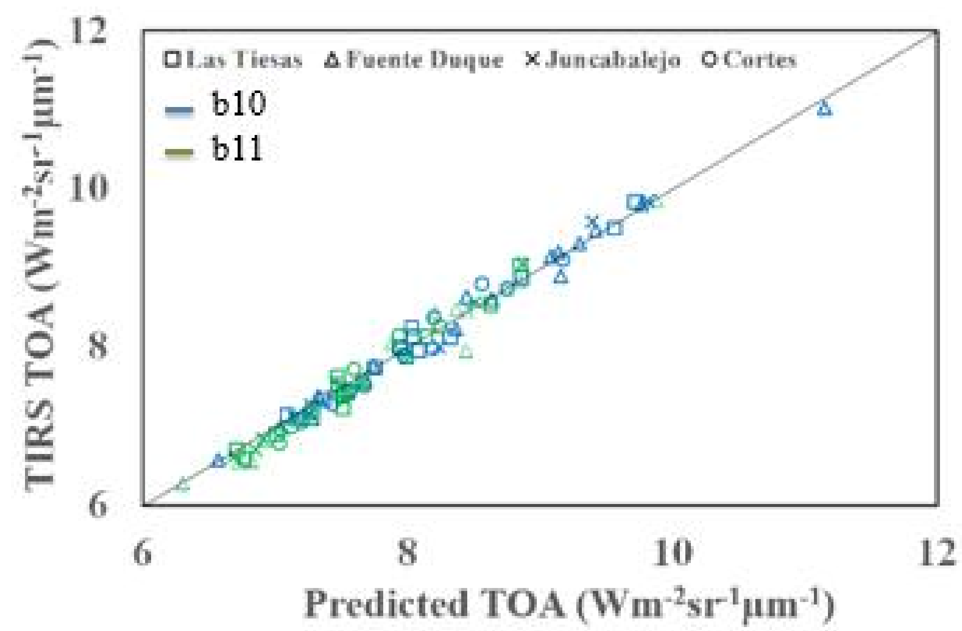
- Ensure highest precision in VC, three consideration:
  - ✓ Only days with atmospheric water vapor content below 1.6 g/cm^2
  - ✓ Measurements with minimal satellite zenith angle < 35º
  - ✓ Periods with low INH index

ETM+ N= 35 points



ETM+ band 6: Bias near zero (-0.2 K)
Precision: 0.6 K

TIRS N= 44 points



TIRS band 10: Bias near zero (-0.2 K) Precision: 0.8 K
TIRS band 11: Bias = -0.4 K Precision: 1.3 K

VICARIOUS CALIBRATION AND LST/SST VALIDATION

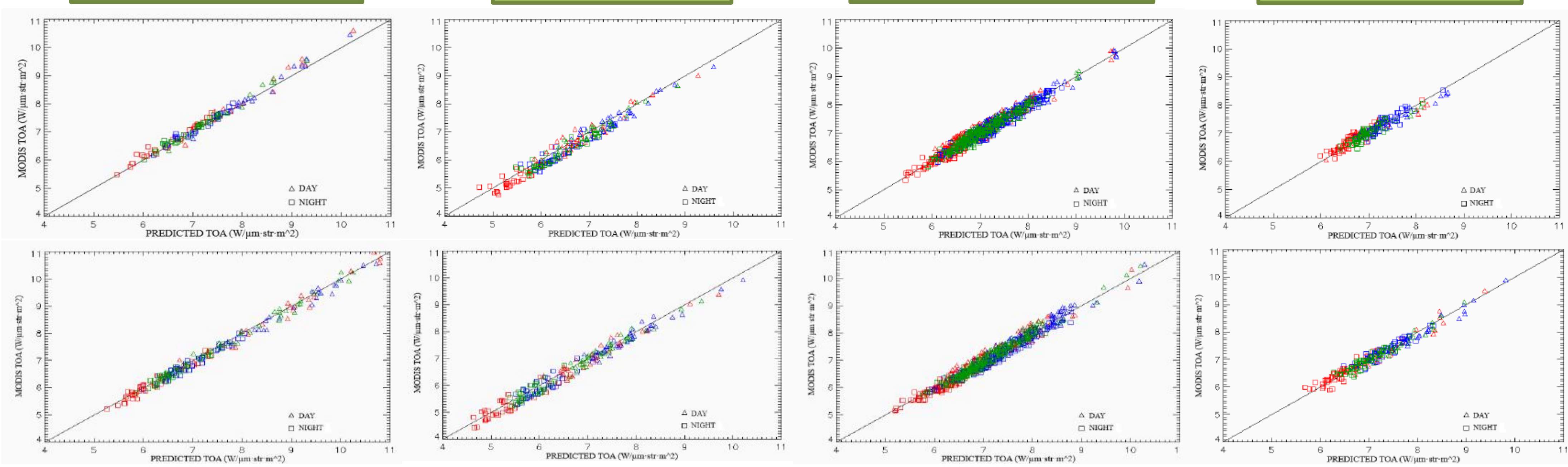
Vicarious Calibration

MODIS

	Balsa Blanca	Las Tiesas	Fuente Duque	Juncabalejo

Terra

Aqua



Platform		N	R^2	Bias (K)	σ (K)	RMSE (K)
Terra	B29	381	0.98	-0.1	0.8	0.8
	B31		0.98	-0.4	1.0	1.0
	B32		0.98	-0.3	0.9	0.9
Aqua	B29	398	0.97	0.2	0.8	0.9
	B31		0.96	-0.1	1.0	1.0
	B32		0.97	0.0	1.0	1.0

All MODIS bands

- Bias below |0.5| K
- VC precision around 1.0 K

VICARIOUS CALIBRATION AND LST/SST VALIDATION

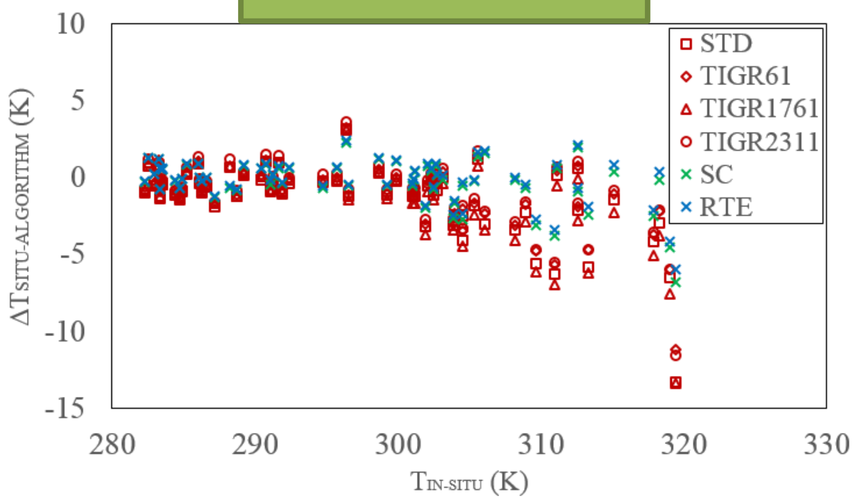
Direct Validation

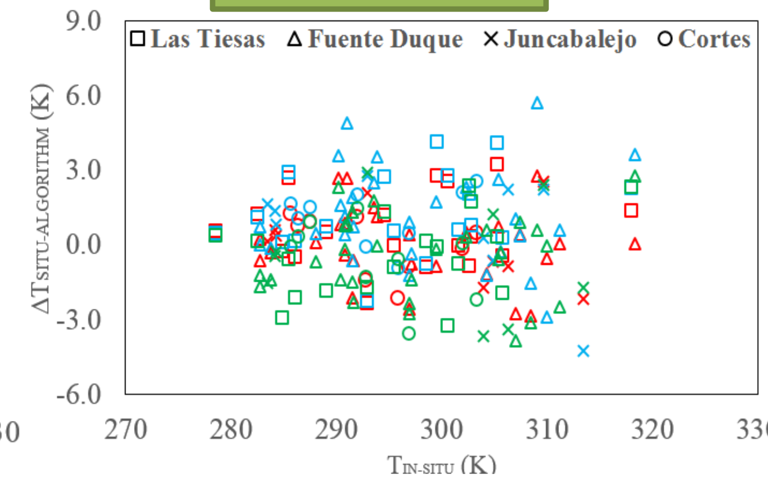
ETM+ / TIRS

L7 ETM+

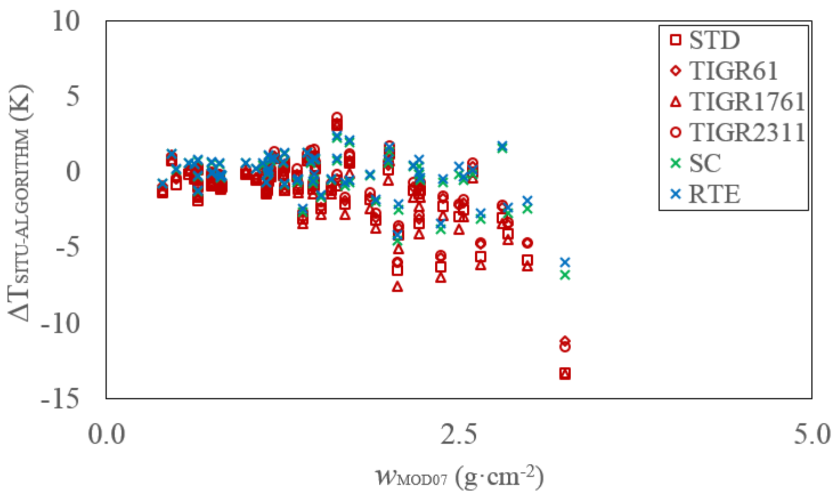
L8 TIRS

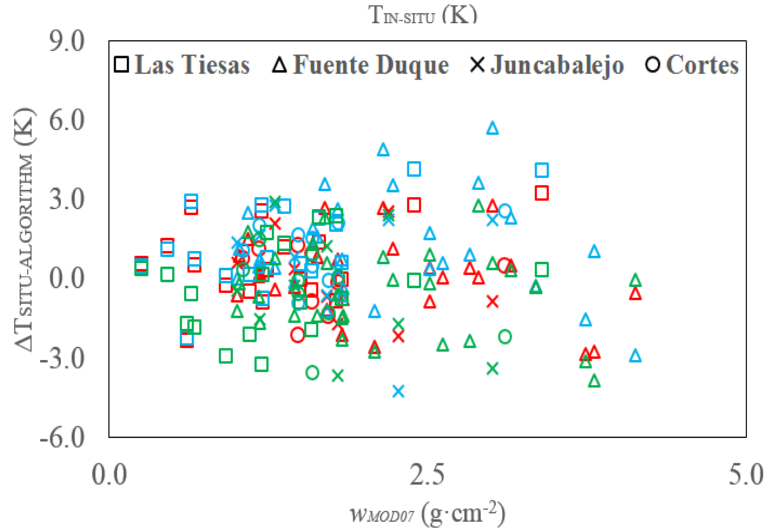
LST_{SITU}





water vapor





- Divided for two atmospheric conditions:
  - ✓ $w < 1.6$ g/cm^2
  - ✓ $w > 1.6$ g/cm^2

Low *w*:

- Similar RMSE < 1.0 K retrieved:
  - ✓ SC*w*
  - ✓ Inverse RTE
- RMSE higher (1.5 K) in SW

High *w*:

Imprecision increase in all algorithms

- SC*w*
  - ➢ Precision > 2.0 K
  - ➢ Bias > |1.0| K
- SW algorithm showed major stability in precision (σ)
  - ➢ Increase of 0.4 K

VICARIOUS CALIBRATION AND LST/SST VALIDATION

Direct Validation

MODIS LST

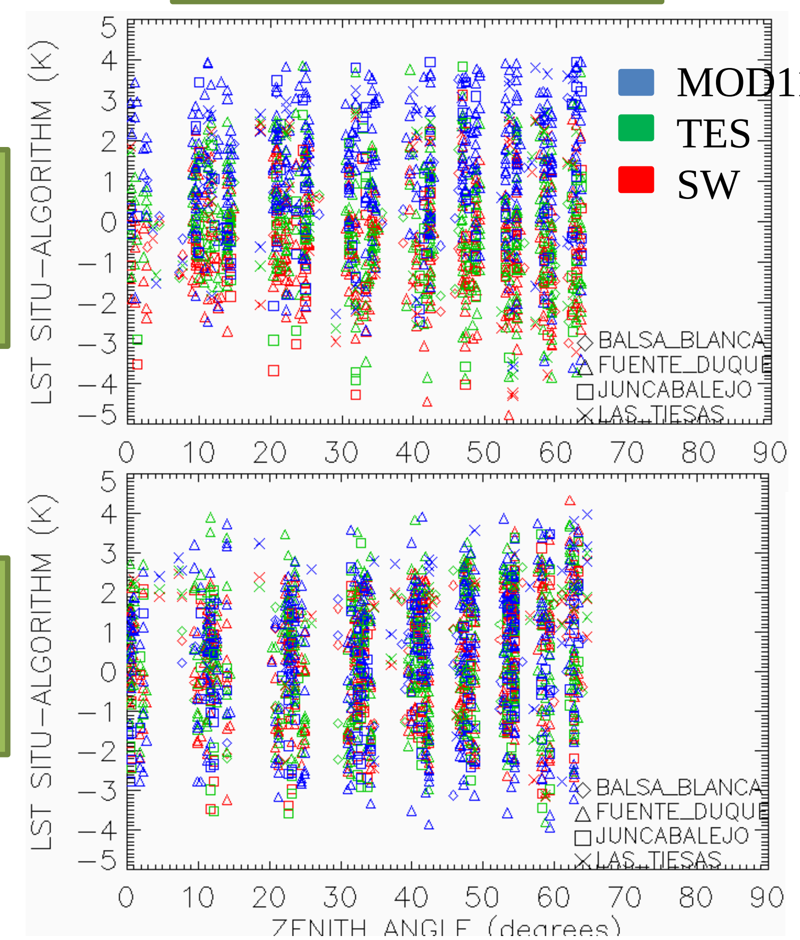
Divided three groups: $w < 2\ g/cm^2\ \&\ \theta < 35^o$ | $\theta < 35^o$ | $\theta > 35^o$

Condition	Platform	Algorithm	n	r^2	$\Delta_{LST-ALG}$ (K)	σ (K)	RMSE (K)
θ < 35º w < 2 g/cm²	Aqua	TES	398	0.972	0.2	1.3	1.3
		SW	398	0.959	0.2	1.4	1.4
		M11	398	0.947	0.1	1.6	1.5
	Terra	TES	378	0.966	-0.2	1.2	1.2
		SW	378	0.963	0.2	1.2	1.2
		M11	378	0.954	0.9	1.5	1.7
θ < 35º	Aqua	TES	559	0.976	0.2	1.4	1.3
		SW	559	0.970	0.3	1.5	1.5
		M11	559	0.968	0.2	1.6	1.5
	Terra	TES	499	0.984	-0.3	1.2	1.2
		SW	499	0.981	0.3	1.3	1.4
		M11	499	0.963	1.1	1.5	1.8
Θ > 35º	Aqua	TES	1244	0.976	0.3	1.4	1.4
		SW	1244	0.974	0.5	1.5	1.5
		M11	1244	0.972	0.4	1.7	1.6
	Terra	TES	1109	0.980	-0.3	1.4	1.4
		SW	1109	0.976	0.2	1.5	1.5
		M11	1109	0.961	1.2	1.6	2.0

Zenith angles

Terra

Aqua



- No significant differences between conditions (< 0.3 K)

VICARIOUS CALIBRATION AND LST/SST VALIDATION

Direct Validation

MODIS LST

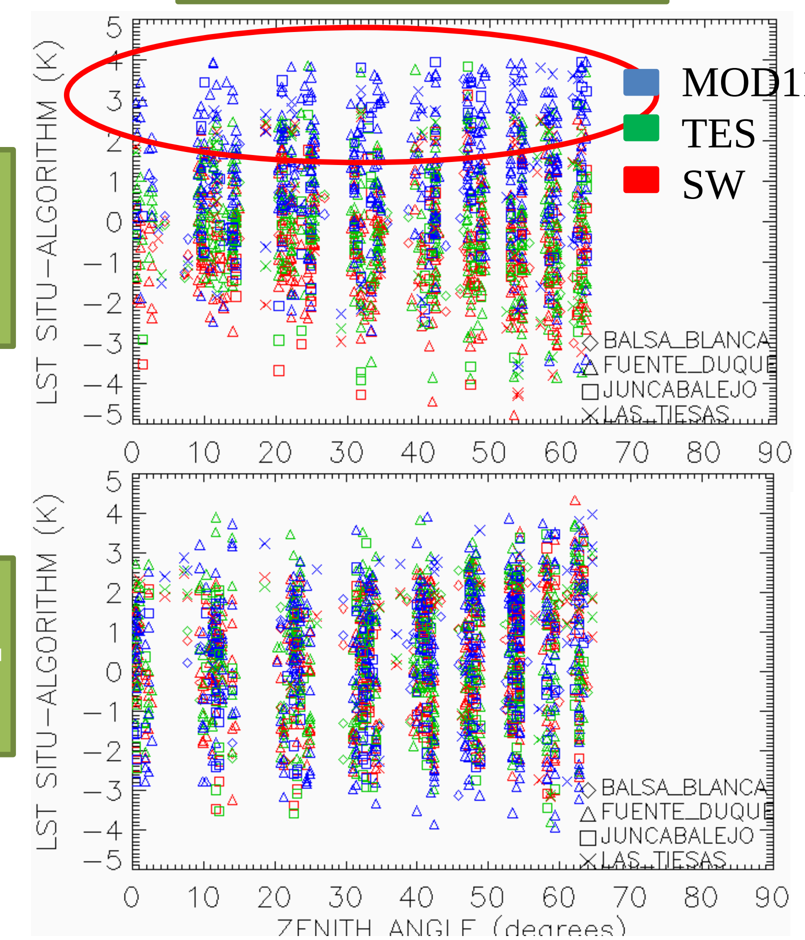
$LST_{SITU-ALGORITHM}$

Divided three groups: $w < 2$ g/cm^2 & $\theta < 35^o$ | $\theta < 35^o$ | $\theta < 65^o$

Condition	Platform	Algorithm	n	r^2	$\Delta_{LST-ALG}$ (K)	σ (K)	RMSE (K)
$\theta < 35^o$ $w < 2$ g/cm^2	Aqua	TES	398	0.972	0.2	1.3	1.3
		SW	398	0.959	0.2	1.4	1.4
		M11	398	0.947	0.1	1.6	1.5
	Terra	TES	378	0.966	-0.2	1.2	1.2
		SW	378	0.963	0.2	1.2	1.2
		M11	378	0.954	0.9	1.5	1.7
$\theta < 35^o$	Aqua	TES	559	0.976	0.2	1.4	1.3
		SW	559	0.970	0.3	1.5	1.5
		M11	559	0.968	0.2	1.6	1.5
	Terra	TES	499	0.984	-0.3	1.2	1.2
		SW	499	0.981	0.3	1.3	1.4
		M11	499	0.963	1.1	1.5	1.8
$\theta < 65^o$	Aqua	TES	1244	0.976	0.3	1.4	1.4
		SW	1244	0.974	0.5	1.5	1.5
		M11	1244	0.972	0.4	1.7	1.6
	Terra	TES	1109	0.980	-0.3	1.4	1.4
		SW	1109	0.976	0.2	1.5	1.5
		M11	1109	0.961	1.2	1.6	2.0

Terra

Aqua



- No significant differences between conditions (< 0.3 K)
- Terra platform, bias of 1.0 K detected on MOD11 product in all the conditions

CONCLUSIONS

1. The setup of the fixed stations was the first step for the beginning of the cal/val activities. As one station was not enough for covering all the land, atmospheric and sensor characteristics, the **web of stations started to grow** in order to obtain more in-situ data and **to encompass as much satellite sensors as possible**.

2. Currently, **three** automatic stations are operating in **Doñana National Park**, **two in Barrax** and **one in the National Park of Cabo de Gata**. All the stations are managed by our team in collaboration with Doñana, Barrax and Almeria staff.

3. Because of the **increase** of available **LST in-situ data**, the **control** of in-situ LST **uncertainty** was required.
    - With each uncertainty source contribution (LSE, down-welling radiance, radiometers and inhomogeneity), it was possible to establish the precision of our in-situ measurements regarding the sensor's spatial resolution.
        - ➢ **Average uncertainties of 1.0 K** have been retrieved for our in-situ measurement

CONCLUSIONS

CONCLUSIONS

5. **VC** was performed on Landsat (TIRS and ETM+) and Terra/Aqua (MODIS) TIR bands. According to the results obtained in the VC, a **bias below 0.5 K** was retrieved for all the analyzed bands.

5. In general, **direct validation of LST** algorithms for ETM+, TIRS and MODIS showed **uncertainties below 2.0 K**, always dependent of the atmospheric conditions and the algorithms used.

Gracias