An Effective and Linear Regression Based Downscaling Strategy for Land Surface Temperature

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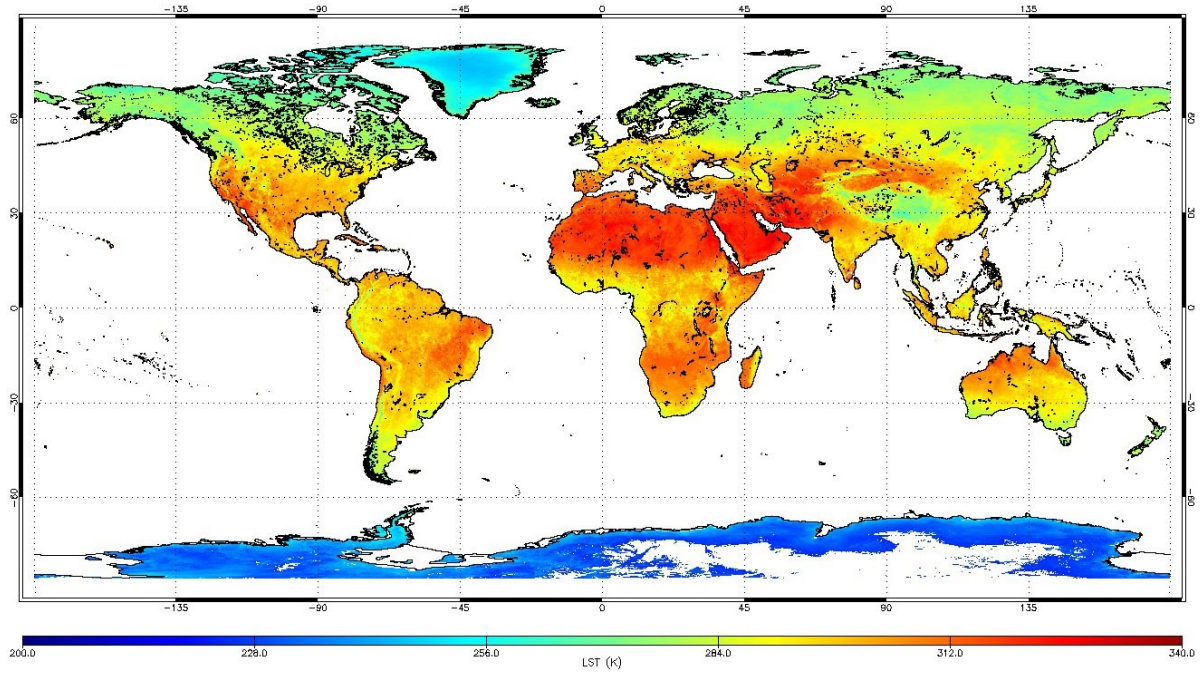
Land surface temperature (LST) is a key variable in:

- study of the thermal environment
- modelling of surface energy fluxes
- estimation of evapotranspiration
- estimation of soil moisture
- characterization of urban heat island effects

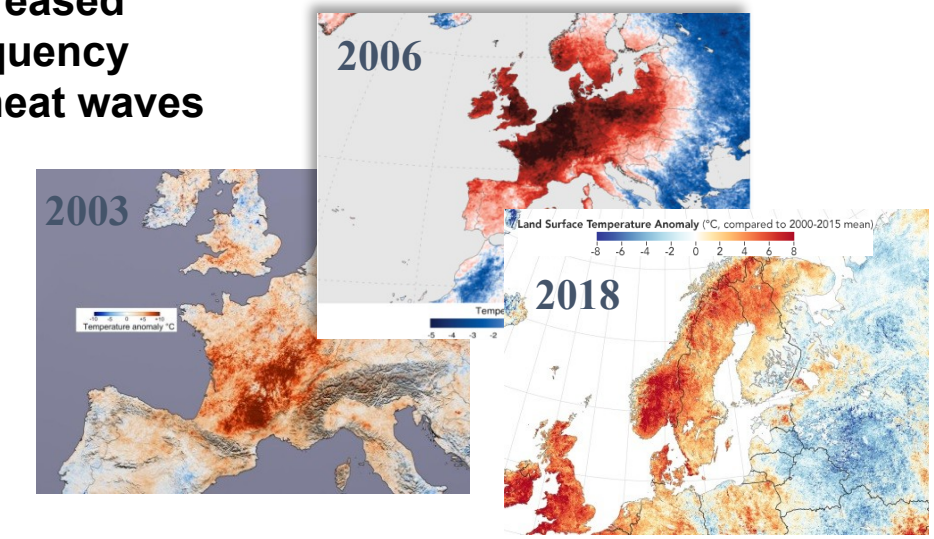


LST can be retrieved from remotely sensed data, but:

- sensors on board satellites with high revisit time usually have low spatial resolution
- spatial information high spatial resolution sensors have typically a low revisit time

to ensure global coverage a compromise is needed, but in practical the spatial resolution is still too coarse

Increased frequency of heat waves

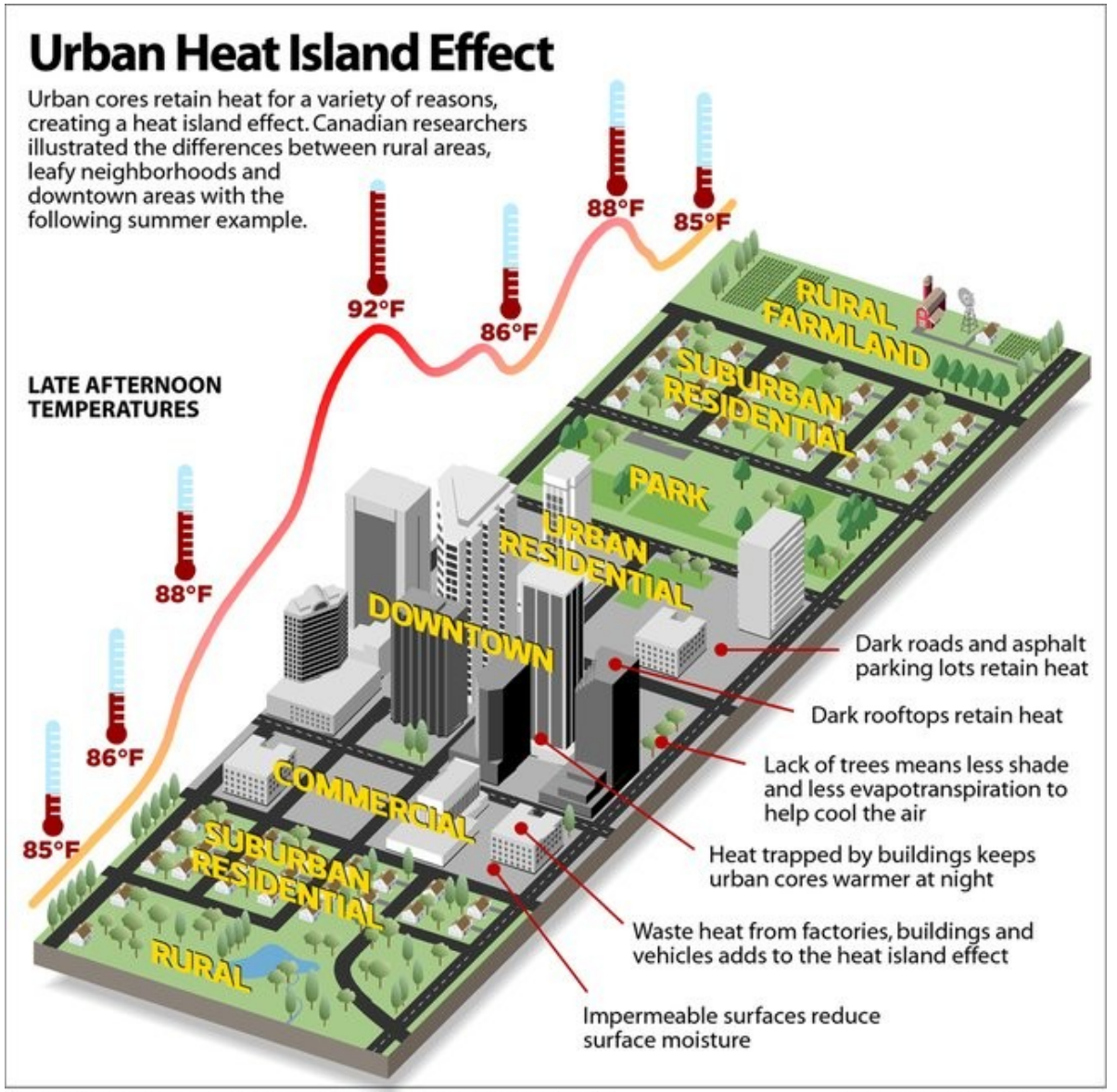


Urbanization

1900	2 out of every 10 people lived in an urban area
1990	4 out of every 10 people lived in an urban area
2010	5 out of every 10 people lived in an urban area
2030	6 out of every 10 people will live in an urban area
2050	7 out of every 10 people will live in an urban area

Defined by UN HABITAT as a city with a population of more than 10 million

Annual global temperatures from 1850 to 2017



SOURCE: D.S. Lemmen and F.J. Warren, Climate Change Impacts and Adaptation

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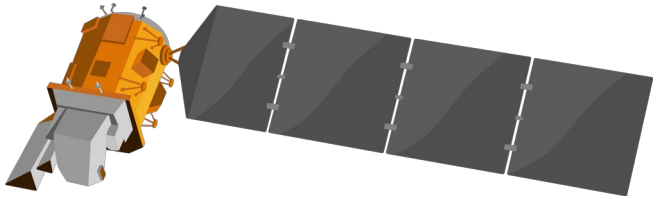
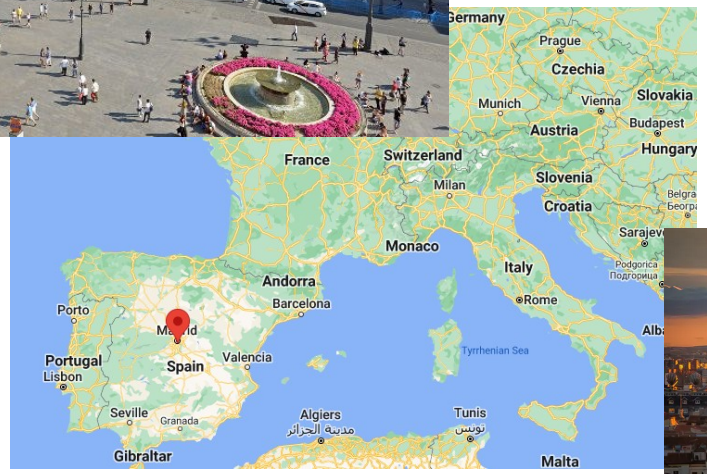
NASA/USGS Landsat-8 (L8):



- launched on 11 Feb 2013
- 16 day revisit cycle
- 2 thermal infrared (TIR) bands at 30m spatial resolution (100m effective)
- L8 collection 2 level 2 includes LST science products



Madrid, Spain, studied area:

- fine resolution at 30m
- WGS84/UTM projection
- 45km by 45km area on city center

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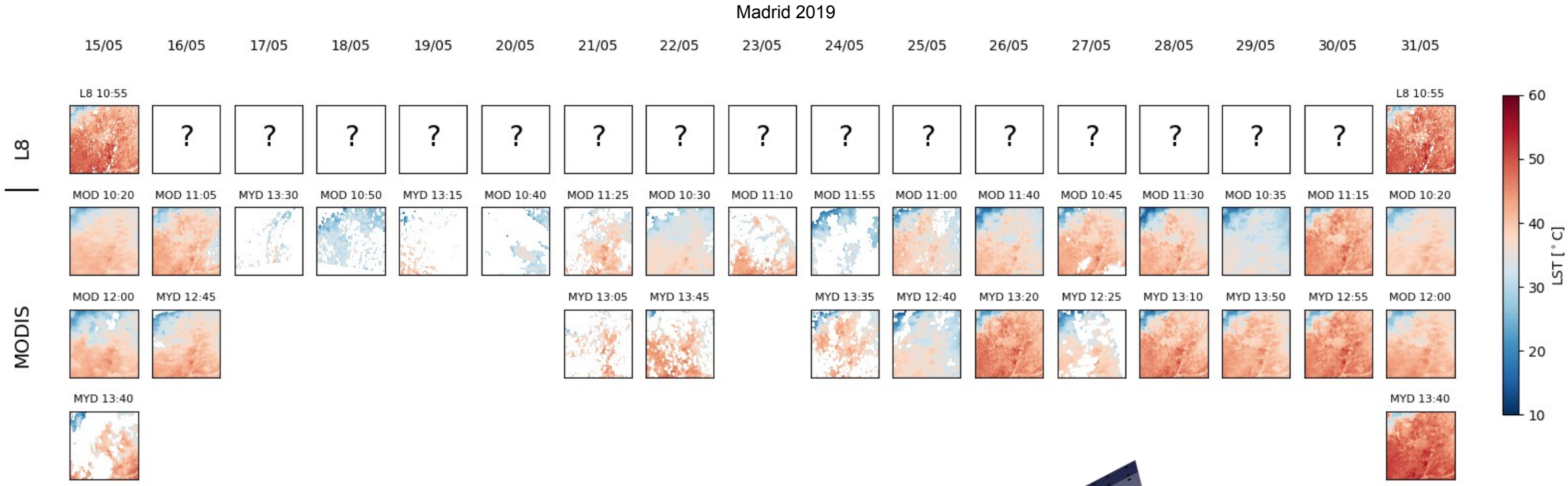
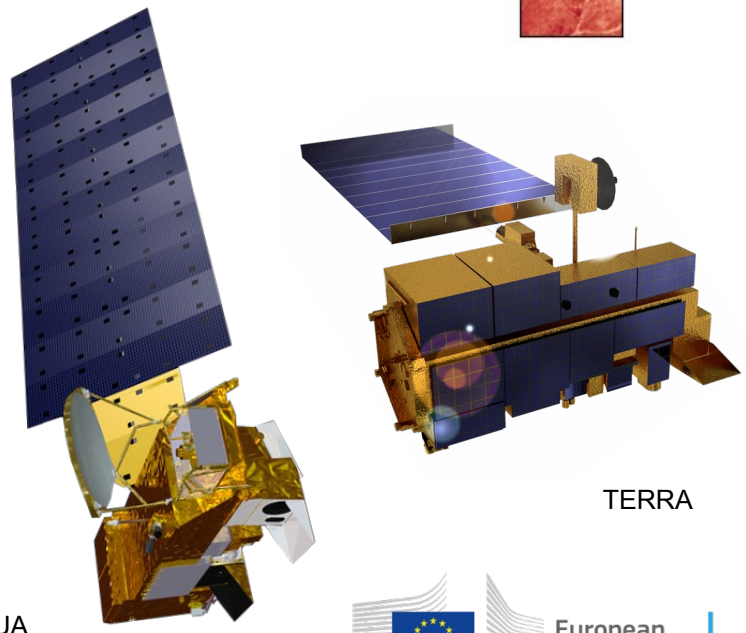


LST at daily fine spatial resolution?

A widely studied strategy is to downscale the daily TIR data provided by the NASA Moderate-resolution Imaging Spectroradiometer (MODIS):

- on-board of t the two NASA platforms Terra (MOD) and Aqua (MYD)
- TIR measurements multiple times per day, with a nominal resolution of 1 km



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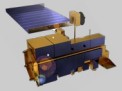
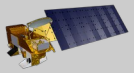
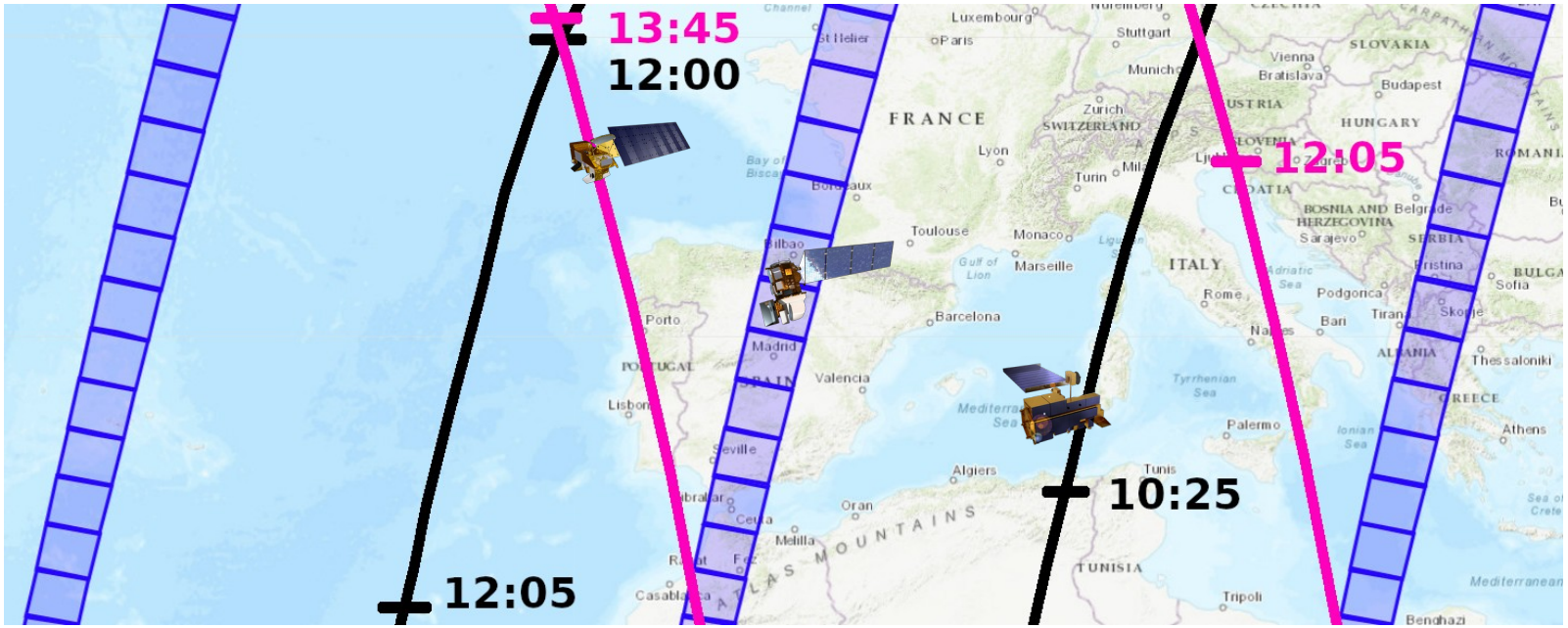
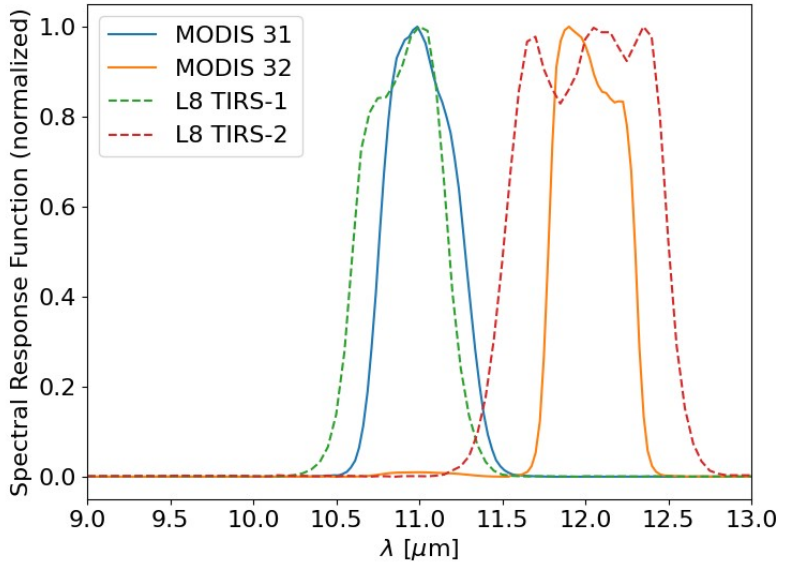
L8 vs MODIS:

- good TIR bands matching
- but the relative positions bring to two relevant aspects:
  1) L8 and MODIS detections are never at the same time
  2) MODIS effective spatial resolution on L8 detected area is always significantly lower than 1 km

	MODIS Terra	MODIS Aqua	Landsat 8
			
	sun-synchronous, near-polar, circular		
mode	descending	ascending	descending
altitude	705 km	705 km	705 km
inclination	98.5 deg	98.2 deg	98.2 deg
orbit	99 mins	99 mins	99 mins
cycle	16 days	16 days	16 days
TIR resolution	1000 m	1000 m	30 m



L8 (blue), Terra (black), and Aqua (pink) orbits over Madrid



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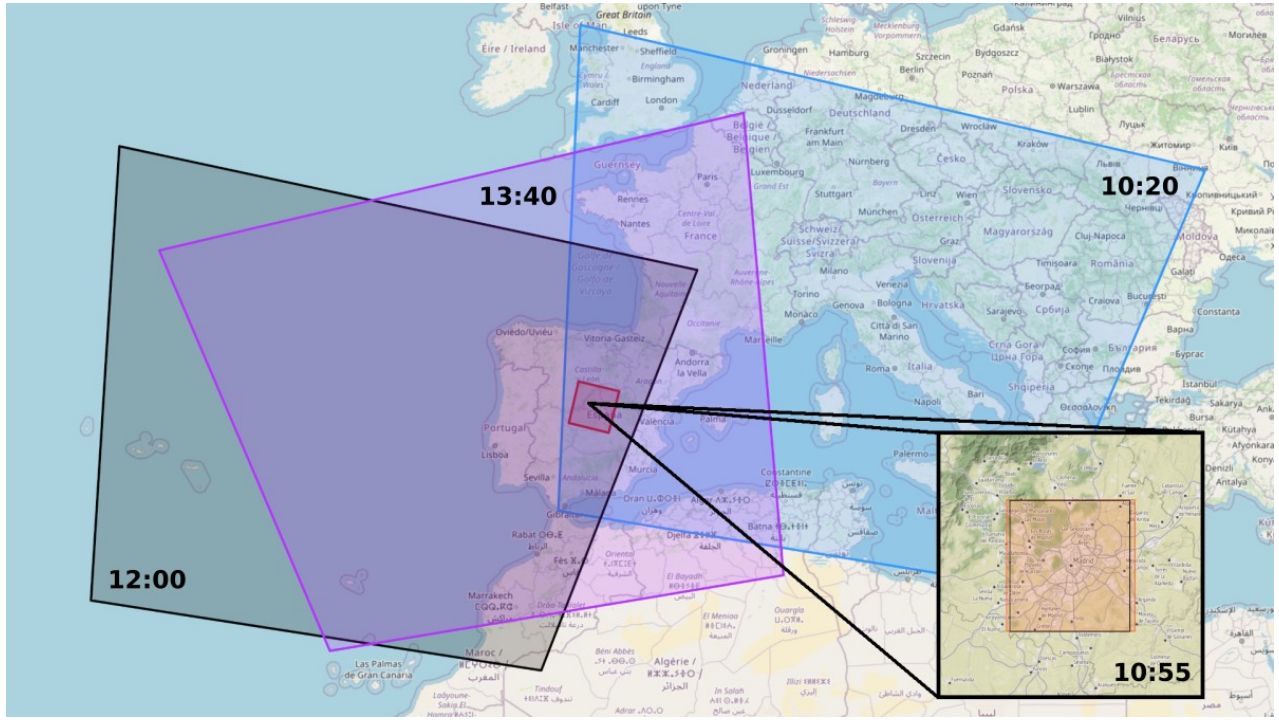
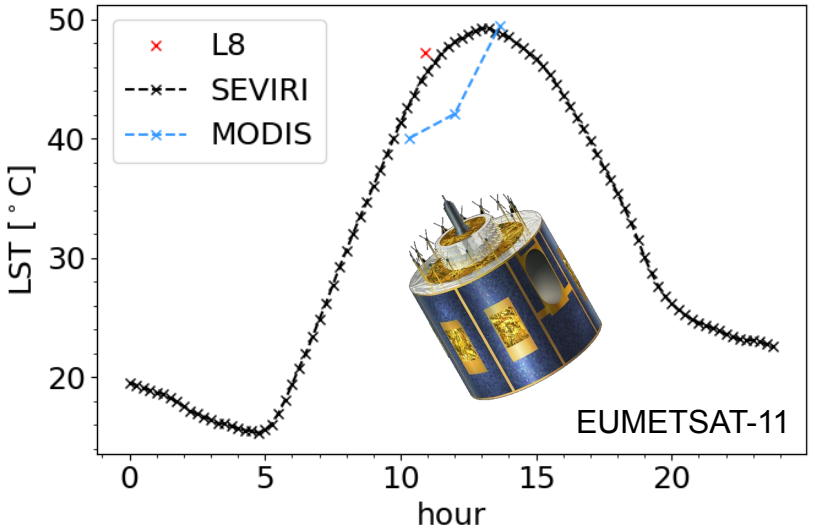
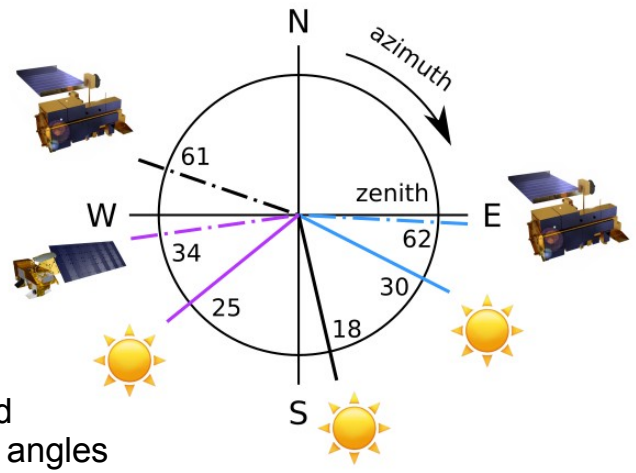


High temporal resolution daily LST from Spinning Enhanced Visible and Infrared Imager (SEVIRI) sensor on board of the European Organization for the Exploitation of Meteorological Satellite 11 (EUMETSAT-11), Madrid 04/07/2020.





Sun and MODIS angles of view on Madrid

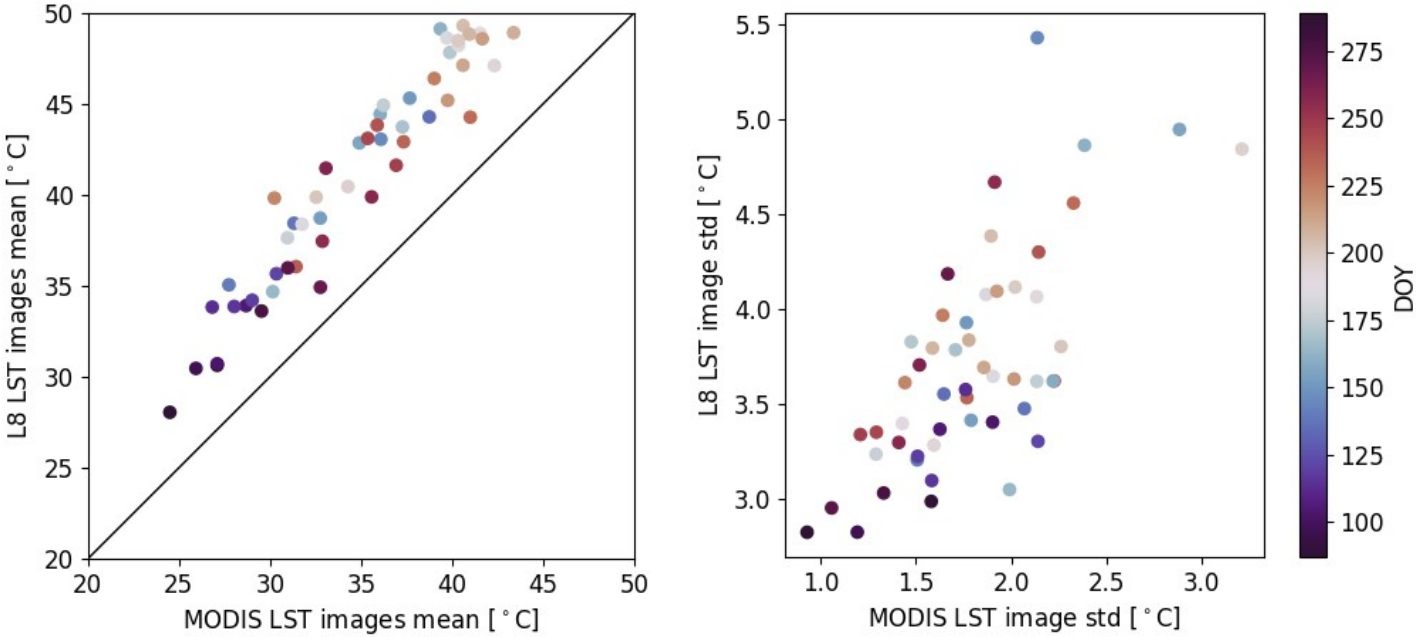
Relevant questions:

1) can the MODIS vs L8 acquisition time difference be neglected?
   → change in thermodynamic situation
2) is MODIS a valid predictor?
   → MODIS large angles of view? need for other predictors?
3) what is the MODIS vs L8 correlation?
   → Linear, or non-linear? LST or energy (radiance) downscaling?

Methods for LST downscaling proposed in the literature:

- usually need a high resolution image as reference (e.g. STARFM, STAARCH, SADFAT)[1]
- mixing effects due to the heterogeneity of neighboring pixels are difficult to control
- usually do not account for the change in the local variance generated by the thermodynamic entropy
- some works claim the need of highly non linear approaches, coupled with the use of a large number of predictors[2]

[1] Gao F. *et al.*, *IEEE Geoscience and Remote Sensing Magazine* 3 (2015) 47
[2] Moosavi V. *et al.*, *Remote Sensing of Environment* 169 (2015) 243



L8 vs MODIS image mean and variance on Madrid between 2014 and 2020

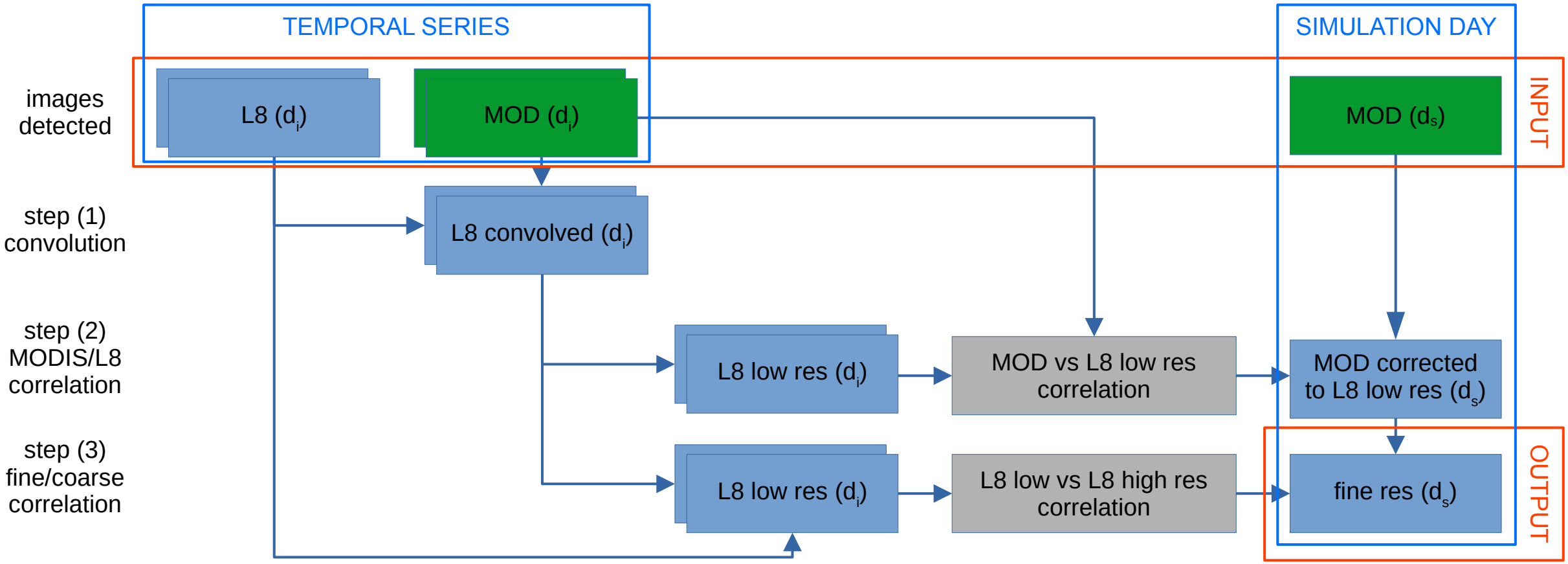
Total variance σ^2 vs *i*-th group of pixels local variance σ_i^2 and local mean μ_i

$$\sigma^2 = \mathbb{E}[\sigma_i^2] + \mathbb{E}[(\mu_i - \mathbb{E}[\mu_i])^2]$$

image variance | mean of local variances | coarse resolution variance

Linear Regression Based Downscaling (LRBD) algorithm proposed in this work:

- does not need a fine resolution image in input as reference
- investigates the linear correlations between MODIS and L8
- attemps to account for the change in the local variance
- studied on both energy (radiance) and LST downscaling



Piccardo M. *et al.*, *An Effective Linear Regression Based Downscaling Strategy for Fine Resolution Land Surface Temperature Estimation*, in preparation

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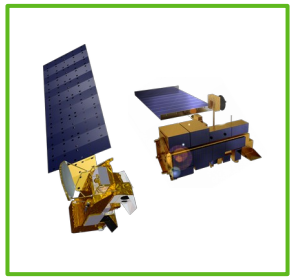
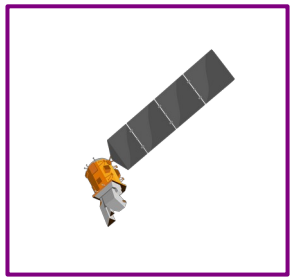
Simulated fine resolution LST on Madrid:

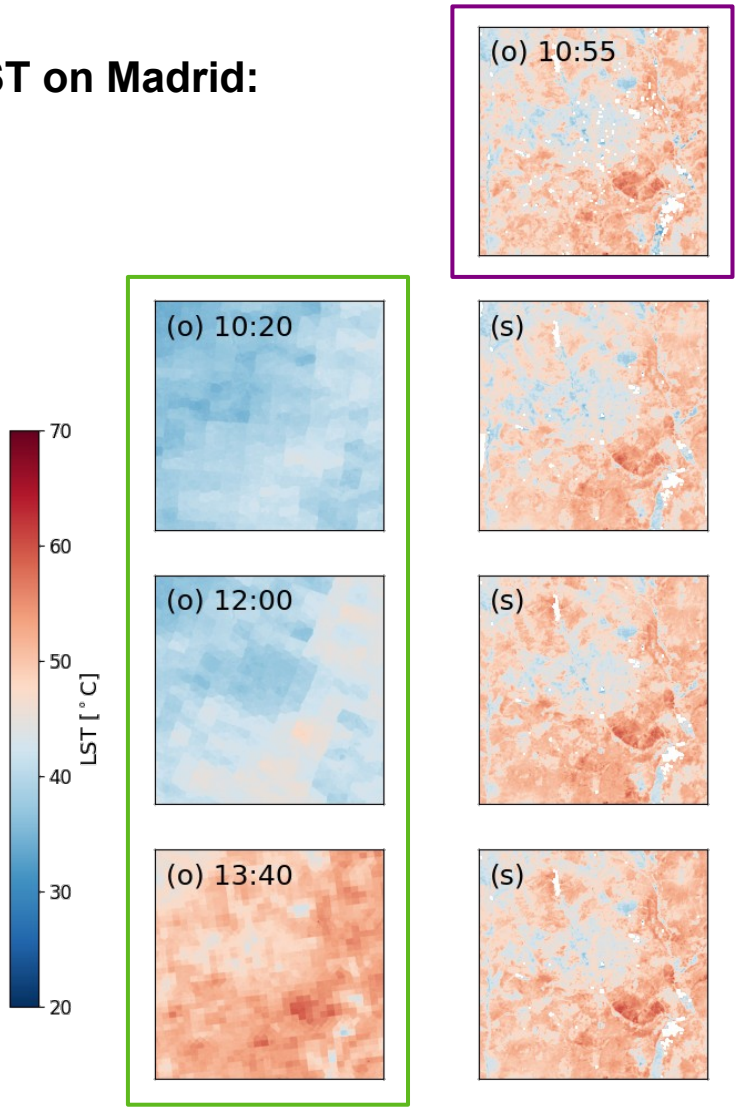
- by radiance downscale
- training set 2014 to 2019
- simulation day 04/07/2020

MODIS





LANDSAT 8



(o) observed
(s) simulated
(d) (s) – (o)

(e) (s) vs (o)
(h) image pixels distribution
(f) (s) – (o) pixels distribution

L8 TIRS-1 radiance from collection 2 level 1
MODIS band 31 radiance from M[O,Y]D021KM

LST by single channel algorithm, atmospheric corrections and emissivity from L8 collection 2

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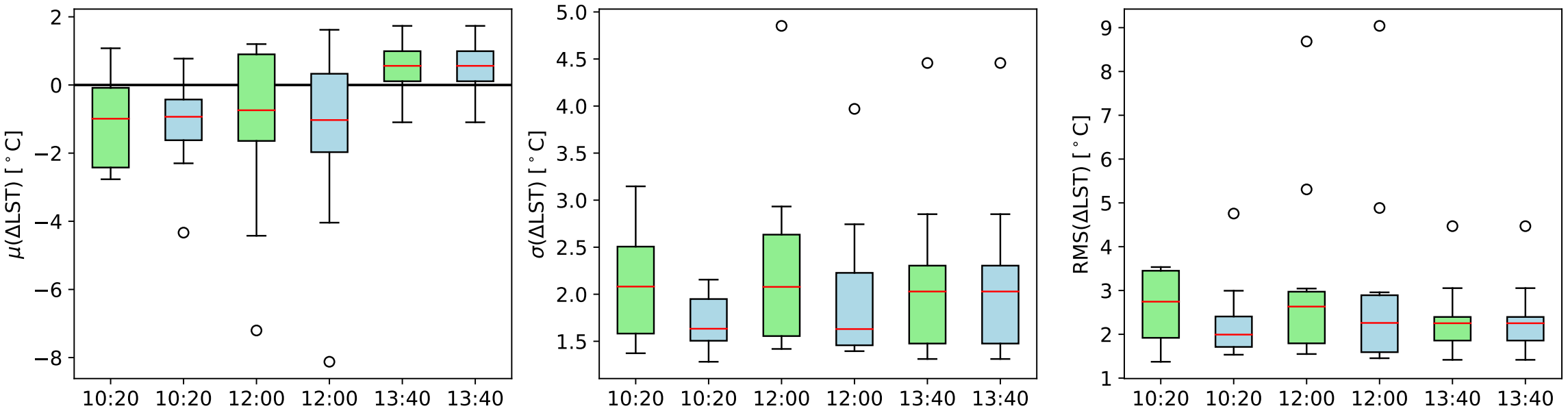
LRBD method testing on images set:

- training set 2014 to 2019
- by **radiance** (green) and **LST** (lightblue) downscale
- test set 2020 and 2021 (10 valid L8/MODIS images pairs)



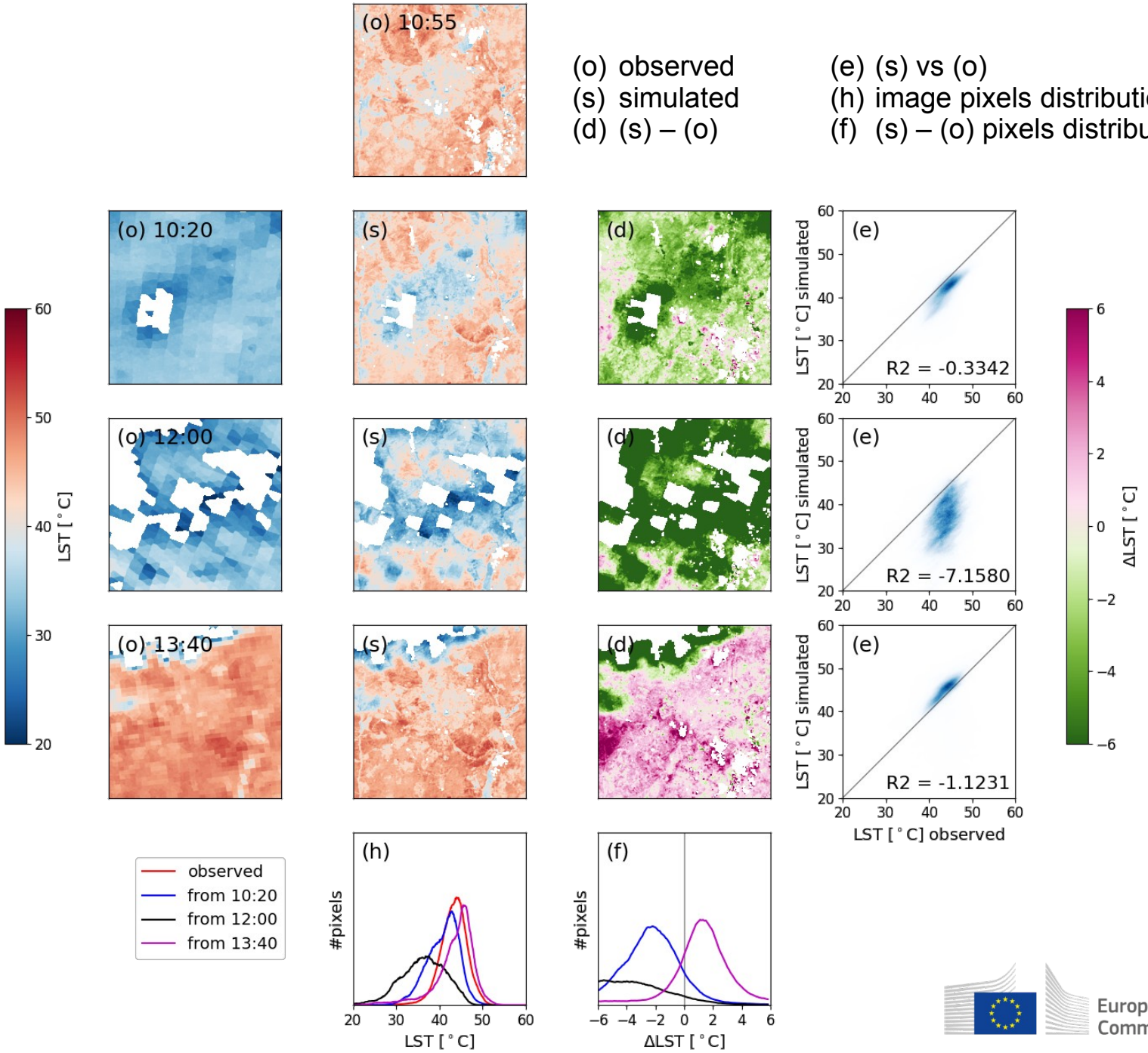
LST errors statistics for LRBD simulations

Unreliable simulation:

- by radiance downscale
- training set 2014 to 2019
- simulation day 21/07/2021

σ(L8 observed) = 3.0 °C
σ(MOD observed at 12:00) = 3.9 °C

Invalid MOD(d_s) images:
→ clouds disturbances



L8 TIRS-1 radiance from collection 2 level 1
MODIS band 31 radiance from M[O,Y]D021KM

LST by single channel algorithm, atmospheric corrections and emissivity from L8 collection 2

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Conclusions:

- LRBD method:
  → reconstruction of fine resolution LST image over an area of interest from a coarse resolution MODIS image at prediction day and the L8/MODIS images time series

- L8 vs MODIS correlation:
  → L8 and MODIS TIR and LST data show reliable linear correlations when properly aggregated

- LST daily change:
  → the differences due to the different acquisition times are relevant

- Future developments:
  → LRBD methodology could be used in the constellation composed of Sentinel-3 SLSTR and the future Copernicus LSTM mission

ESA Copernicus LSTM

Thank you

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