# Land Surface Temperature estimates from infrared and microwave sensors

Ana C. Pires, Isabel F. Trigo, Sofia L. Ermida, João P. A. Martins

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Yerevan, Armenia, 18 - 20 September 2017

# Outline

- Towards a global harmonised LST product:
  - merging geostationary sensors and polar sensors;
  - calibrating all as if only one sensor is observing Earth;
  - correcting LST estimates for angle dependency.

- Towards an operational all-weather LST product:
  - infrared LST is clear-sky only;
  - methods for obtaining LST estimates in cloudy conditions:
    - . microwave LST (see talk by Carlos Jimenez next!);
    - . surface model-derived skin temperature.

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# LST merged product

**Objective**

To produce global LST as if measured
by the same sensor from the same point of view

ipma

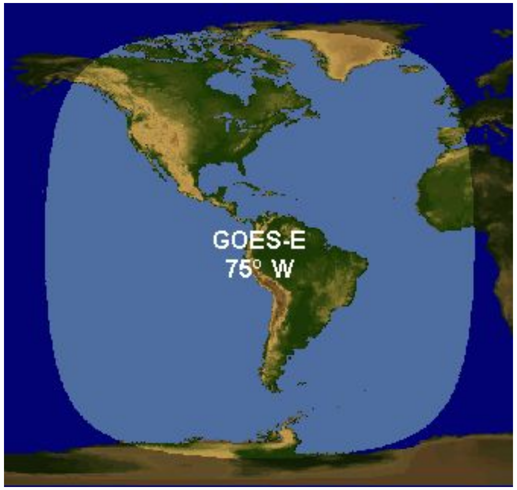
# LST merged product

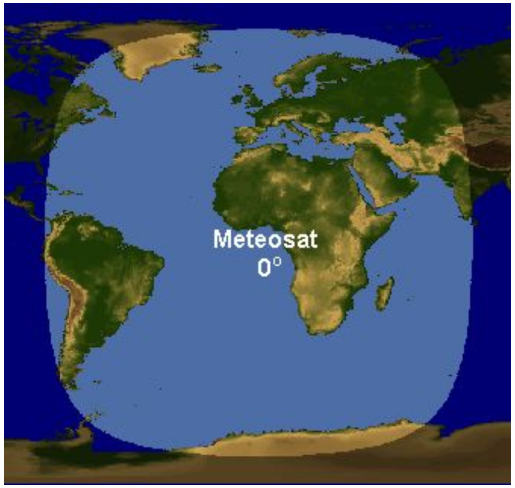
## Geostationary Satellites (GEOs)

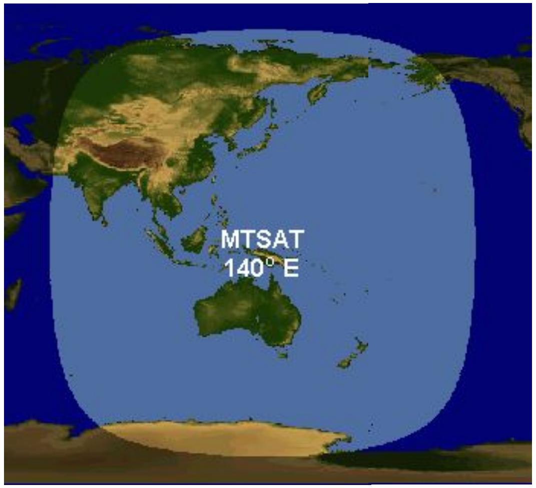
> **MSG** – Meteosat Second Generation (Eumetsat)
  SEVIRI *(Spinning Enhanced Visible and Infrared Imager)*

> **MTSAT-2** – Multi-function Transport Satellite (JMA) > now HIMAWARI-8!
  JAMI *(Japanese Advanced Meteorological Imager)*

> **GOES-East** – Geostationary Operational Environmental Satellites (NASA)




*Source: http://www.ssec.wisc.edu/mcidas/doc/learn_guide/2007/sat-1.html*

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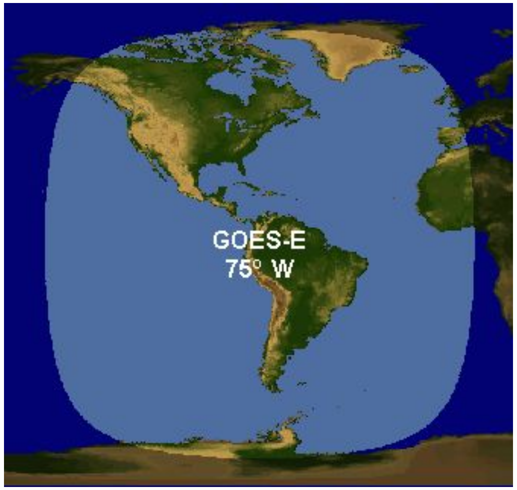


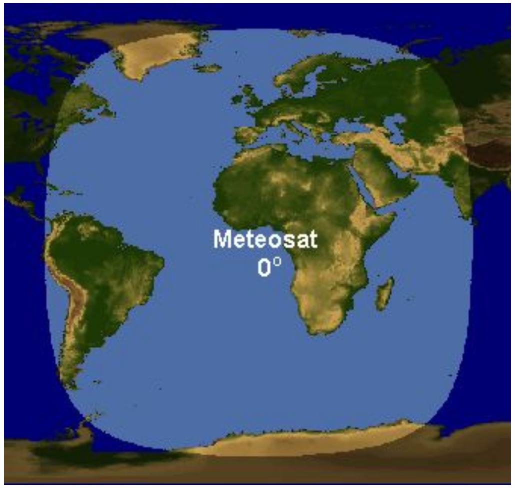


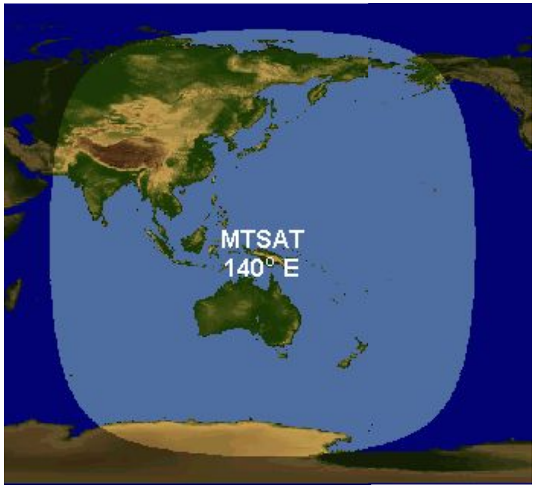


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## Low-Earth Orbit Satellites (LEOs)

> **Aqua & Terra** (NASA)
> MODIS *(Moderate Resolution Imaging Spectroradiometer)*
> **AATSR** (Envisat)
> *Advanced Along Track Scanning Radiometer*

# LST merged product

## Objective

To produce global LST as if measured
by the same sensor from the same point of view

## Challenges

> different sensor characteristics

. mono- or dual-channel in the thermal infrared
. different sensor spectral functions
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. different retrieval formulations (both LST and cloudmask)

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. stamp time can refer to beginning, middle or end of scan

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dealt with through calibration, although not every issue is perfectly solved

# LST merged product

## Methodology

> Taking **SEVIRI** (LSA SAF product) as reference (robust and reliable)
> Using **MODIS** as the common denominator because it has a wider range of viewing angles, necessary for computing the angular correction
> Using **AATSR** in the LEO+GEO product

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**CALIBRATION**

Removing the bias between sensors

> by removing the systematic differences between sensors, we attenuate the differences due to different sensor characteristics, input data, and LST retrieval methods

> Linear regressions:

$LST_{GEO} = m*LST_{SEVIRI} + b$

$LST_{AATSR} = m*LST_{SEVIRI} + b$

where $LST_{SEVIRI} = m*LST_{MODIS} + b$

> Computation by groups of landcover (cluster analysis)

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### ANGULAR CORRECTION

Bringing the calibrated sensors to nadir view

> adds directional correction on top of bias correction
> viewing and illumination angles as input
> **Kernel Model:** computation by groups of landcover (cluster analysis)

$$T(\theta_v,\theta_i,\Delta\varphi)/T_0 = 1 + \boldsymbol{A}\Phi(\theta_v) + \boldsymbol{D}\Psi(\theta_v,\theta_i,\Delta\varphi)$$

- $\theta$, $\varphi$: zenith, azimuth angles
- v, i: viewing, illumination angles
- $\Phi(\theta_v)$: emissivity kernel (observation angle anisotropy)
- $\Psi(\theta_v,\theta_i,\Delta\varphi)$: solar kernel (spatial inhomogeneity of surface heating and shadowing – landcover)
  $\Psi = 0$ in night-time

Vinnikov et al. (2012): Angular anisotropy of satellite observations of land surface temperature. (Geophys. Res. Lett.)

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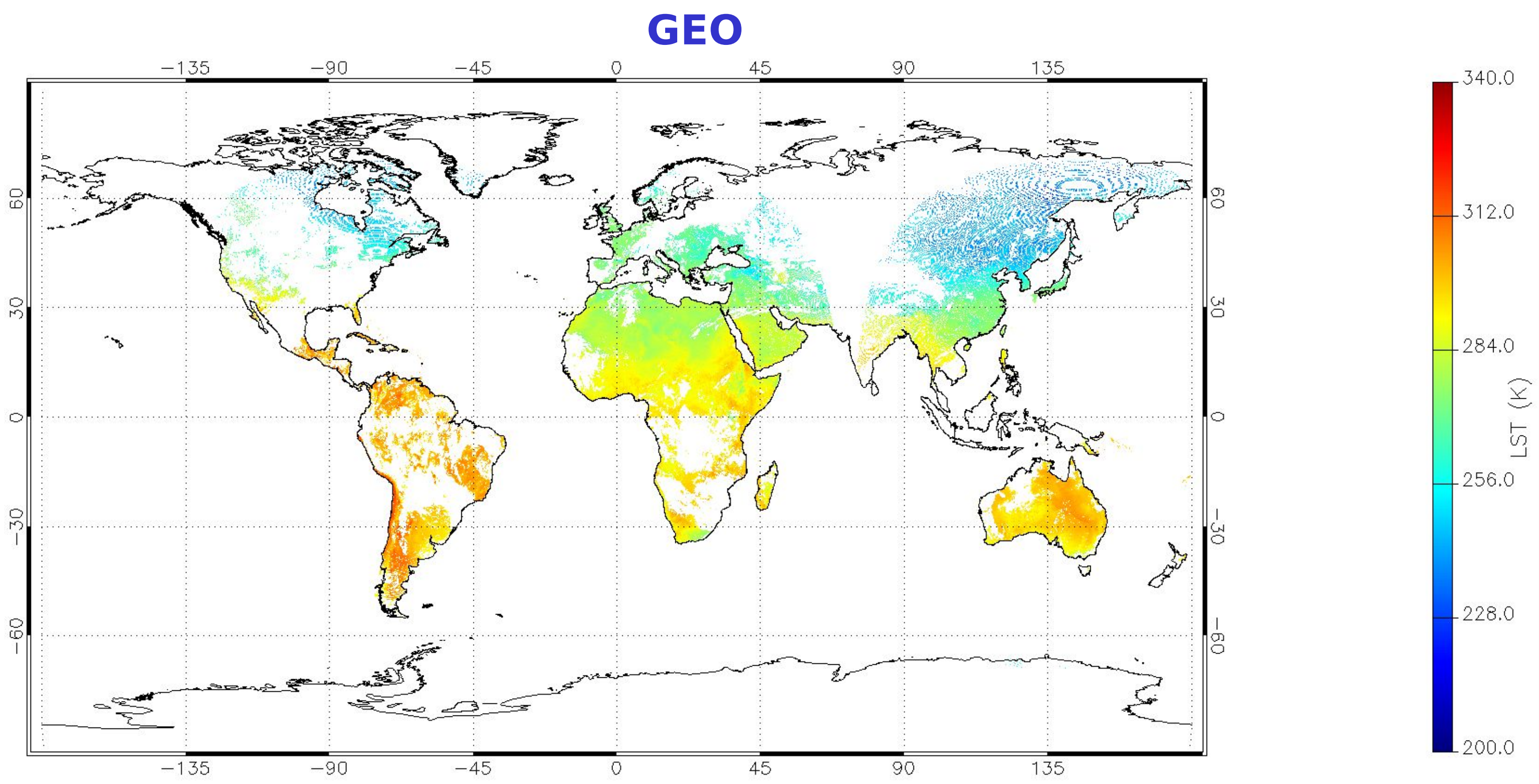
Ermida et al. (2017): Modelling directional effects on remotely sensed land surface temperature (Rem. Sens. of Envioronm.)

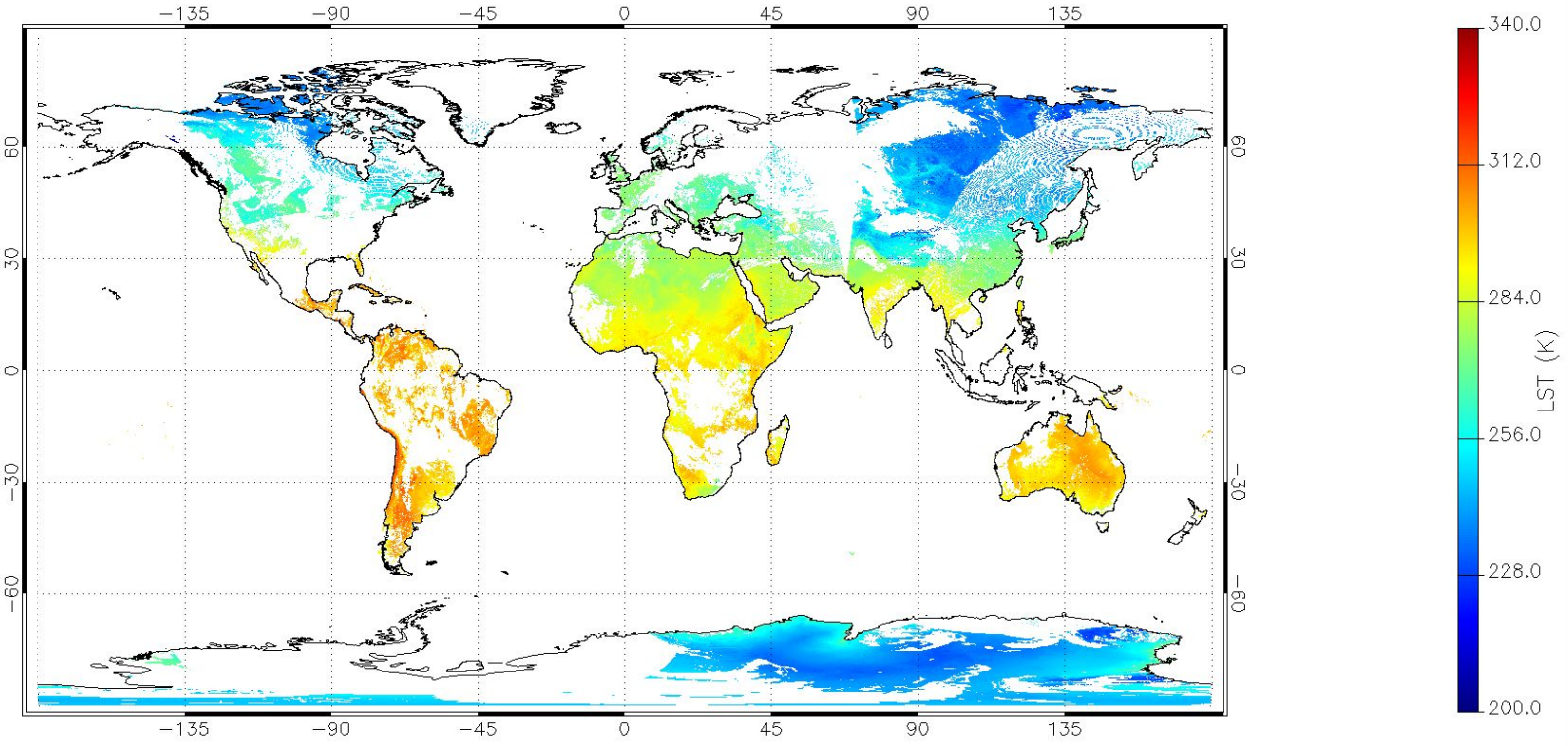
# LST merged product




**1st Jan 2013 at 21:00 UTC**

# LST merged product

**GEO + LEO**

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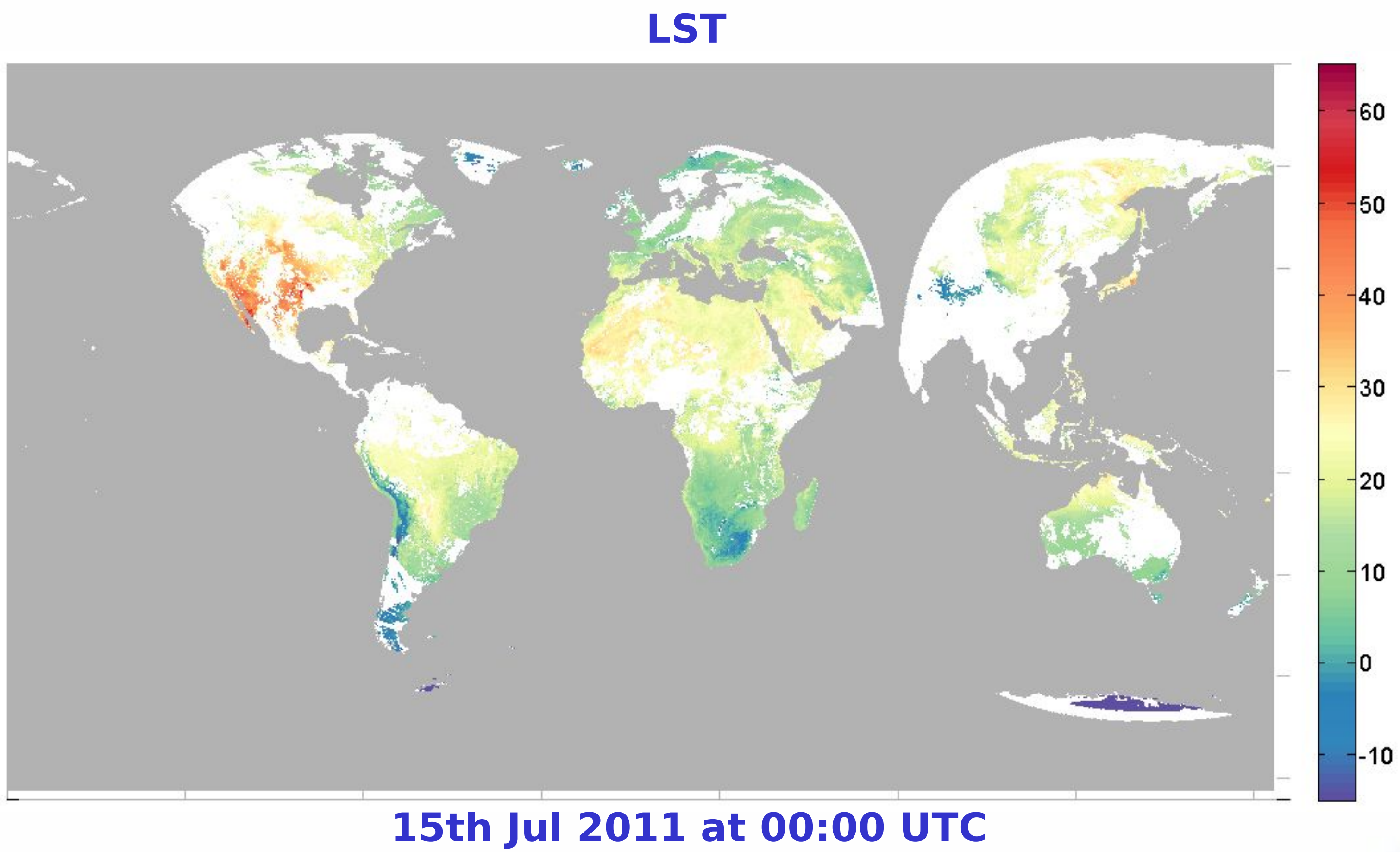
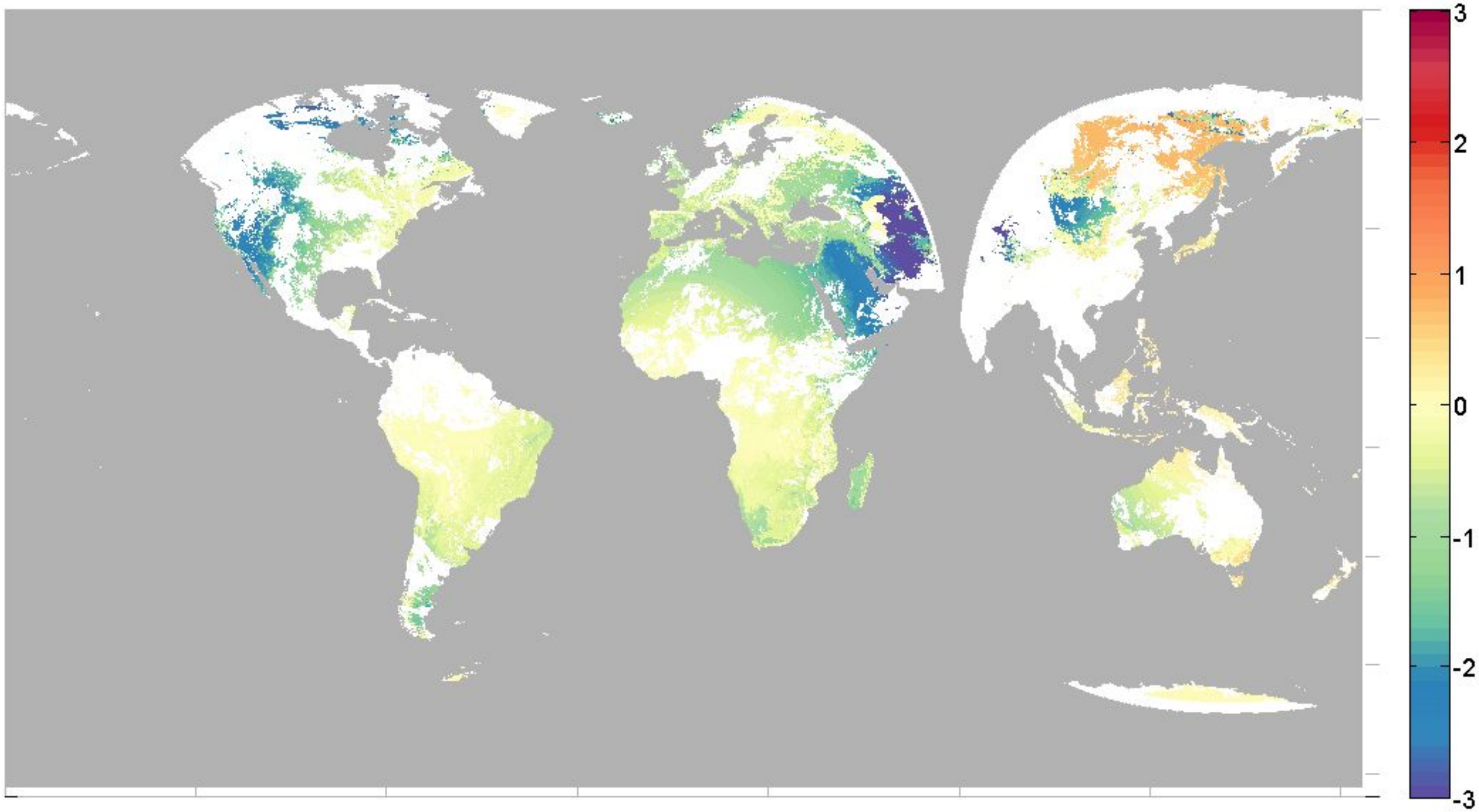


# LST merged product

**angular adjustment (ΔLST)**




**15th Jul 2011 at 00:00 UTC**

# LST merged product

**Highlights**

Global LST data which resolve the diurnal cycle

> Combined GEO+LEO 3-hourly product at UTC

> Merged geostationary (GEO) and low earth orbit (LEO) data giving high spatial resolution, sub-diurnal sampling; estimates of cloud-bias.

> Intercalibrated LST using Land-SAF SEVIRI as a reference sensor

> Estimates of what LST should be if always measured at nadir (angular dependency removed)

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Operational

> Future implementation of the angular correction as an extra layer of the LSA-SAF LST product

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The EUMETSAT Network of Satellite Application Facilities
LSA SAF
Land Surface Analysis

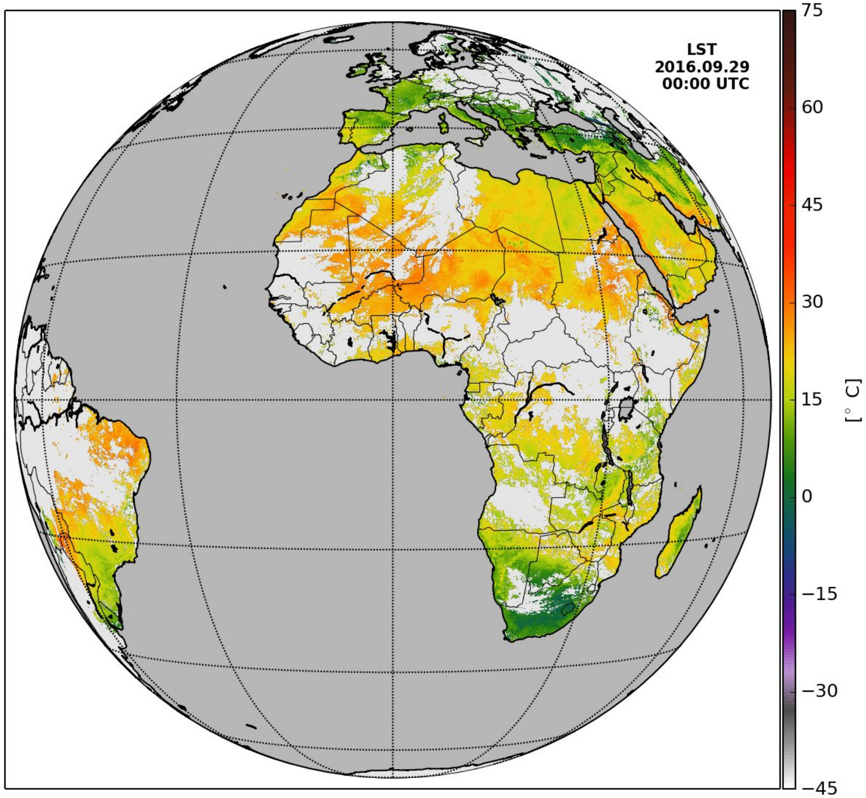
# All-weather LST

## Motivation

- Land Surface Temperature (LST) products based on remote infrared (IR) measurements are **clear-sky** only.
- Some applications would benefit of LST produts with less “gaps” due to clouds
- Ways to provide all-weather LST:

  > **surface models**

  > **microwave** (MW) **measurements**
- The LSA-SAF already has an algorithm that produces evapotranspiration which also produces skin temperature as a byproduct.



# All-weather LST

## Infrared LST (clear-sky)

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Generalized Split-Windows (Wan and Dozier, 1996; Freitas et al, 2010)

$$LST = \left(A_1 + A_2 \frac{1-\epsilon}{\epsilon} + A_3 \frac{\Delta\epsilon}{\epsilon^2}\right) \frac{T_{IR1} + T_{IR2}}{2} + \left(B_1 + B_2 \frac{1-\epsilon}{\epsilon} + B_3 \frac{\Delta\epsilon}{\epsilon^2}\right) + C$$

- $\boldsymbol{A_i}$, $\boldsymbol{B_i}$ and $\boldsymbol{C}$ – model coefficents. Determined by classes of **viewing angle** and **total column water vapor** (retrieved from ECMWF forecasts)
- $\boldsymbol{\epsilon}$ and $\boldsymbol{\Delta\epsilon}$ surface emissivity (IR1 and IR2 average and difference). Determined by the Vegetation Cover method (Trigo et al., 2008) as an average of bareground and vegetation emissivities, weighted by the **FVC** (produced by LSA-SAF).
- $\mathbf{T_{IR1}}$ and $\mathbf{T_{IR2}}$ – infrared brightness temperatures

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〉State of the art, takes advantage of both MSG TIR channels (used at LSA-SAF)

〉Clear-sky only

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# All-weather LST



## Cloudy sky LST (ET model)

Surface energy balance equation (*tile i*)

$$Rn_i = H_i + LE_i + G_i$$

Net radiation

Sensible Heat

Latent Heat

Ground heat (conduction)

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Shortwave

Longwave

$$Rn_i = (1-\alpha)S_{\downarrow} + \epsilon\left(L_{\downarrow} - \sigma T_{sk,i}^4\right)$$

Skin Temperature (byproduct)

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›All-weather

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Skin Temperature (byproduct)

› Problems in the representation of diurnal cycle in some locations

›All-weather

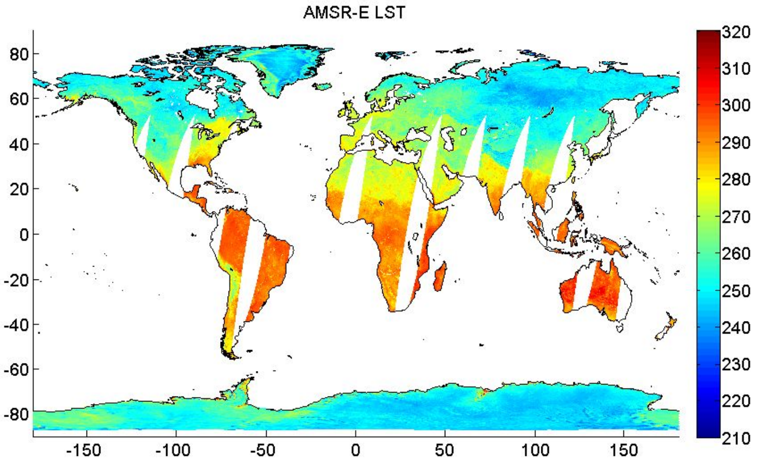
### Model inputs
(mostly from remote sensing but also NWP)

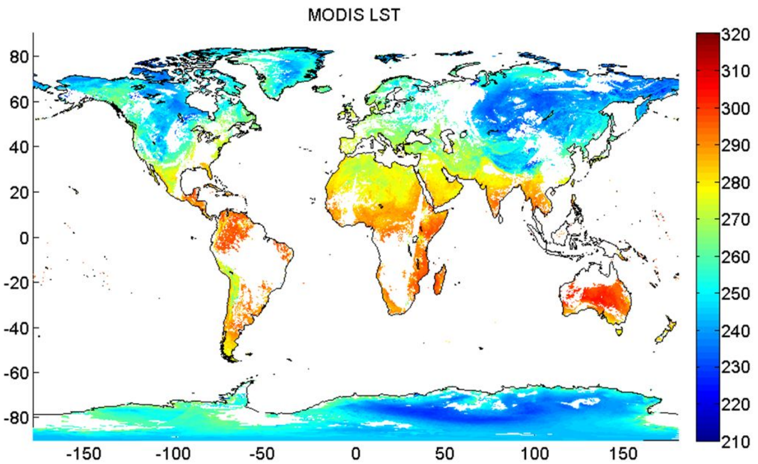
| Input | Variable | Source | Provider | Frequency |
|---|---|---|---|---|
| Radiative forcing | $S$ **(DSSF)** | SRS | **LSA-SAF** | 30 min |
| | $L$ **(DSLF)** | | **LSA-SAF** | 30 min |
| | **(AL-BB-BH)** | | **LSA-SAF** | 1 day |
| | FRP **(FRP-Pixel)** | | **LSA-SAF** | 15 min |
| Meteorological fields | $T_a$, $q_a$, $P_a$, $U_a$ | NWP | ECMWF IFS | 3 hours |
| Land cover | Tile % | SRS | ECOCLIMAP-I | Static |
| | Snow (SC2) | SRS | H-SAF | 1 day |
| Biophysical parameters | LAI, $F_V$ **(LAI, FVC)** | SRS | **LSA-SAF** | 1 day |
| Soil moisture | $_k$ | NWP | ECMWF IFS | 3 hours |
| | [ $_k$ (SM-DAS-2) | SRS | H-SAF | 1 day] |
| | LST **(LST)** | SRS | **LSA-SAF** | 15 min |

# All-weather LST

## Cloudy sky LST (MW)

- Passive MW measurements less affected by **clouds** than IR observations
- Microwave **emissivities** have large variability (soil moisture, vegetation cover, presence of snow)
- Spatial **resolution** of the MW observations is typically lower than IR measurements
- MW radiation can emanate from the **subsurface, not from the surface skin**



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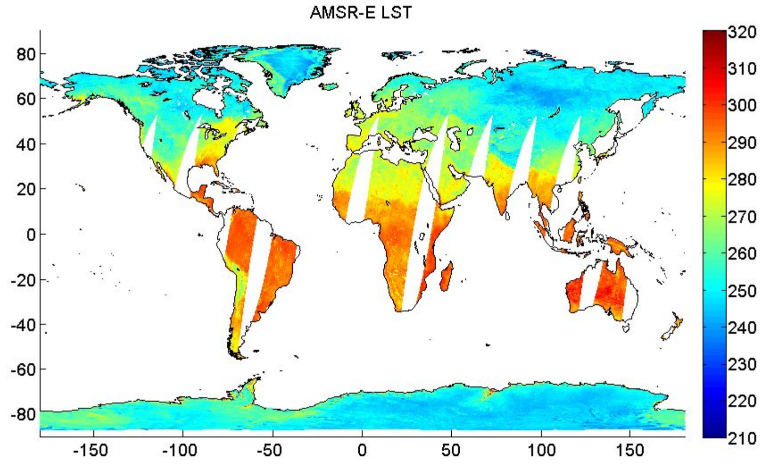
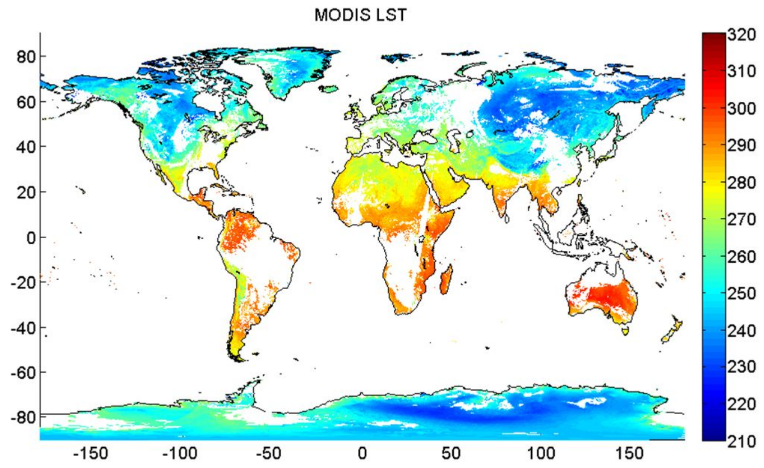



〉application

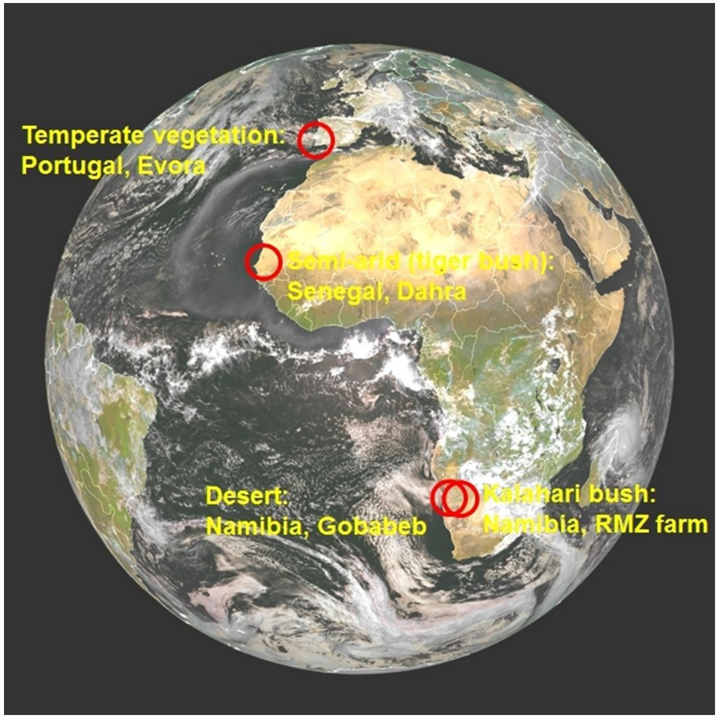
- LST estimated from passive MW imagers: NASA's **AMSR-E** (Aires et al., 2001), with a spatial resolution of 0.125º x0.125º, twice daily.

  **-〉 see Carlos Jimenez talk next!**

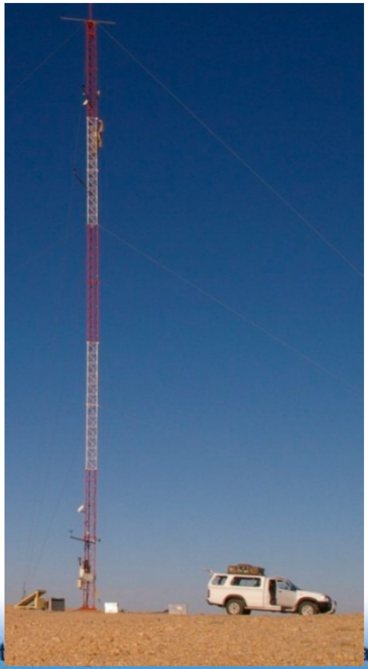
# All-weather LST

Evora

**In-situ LST**

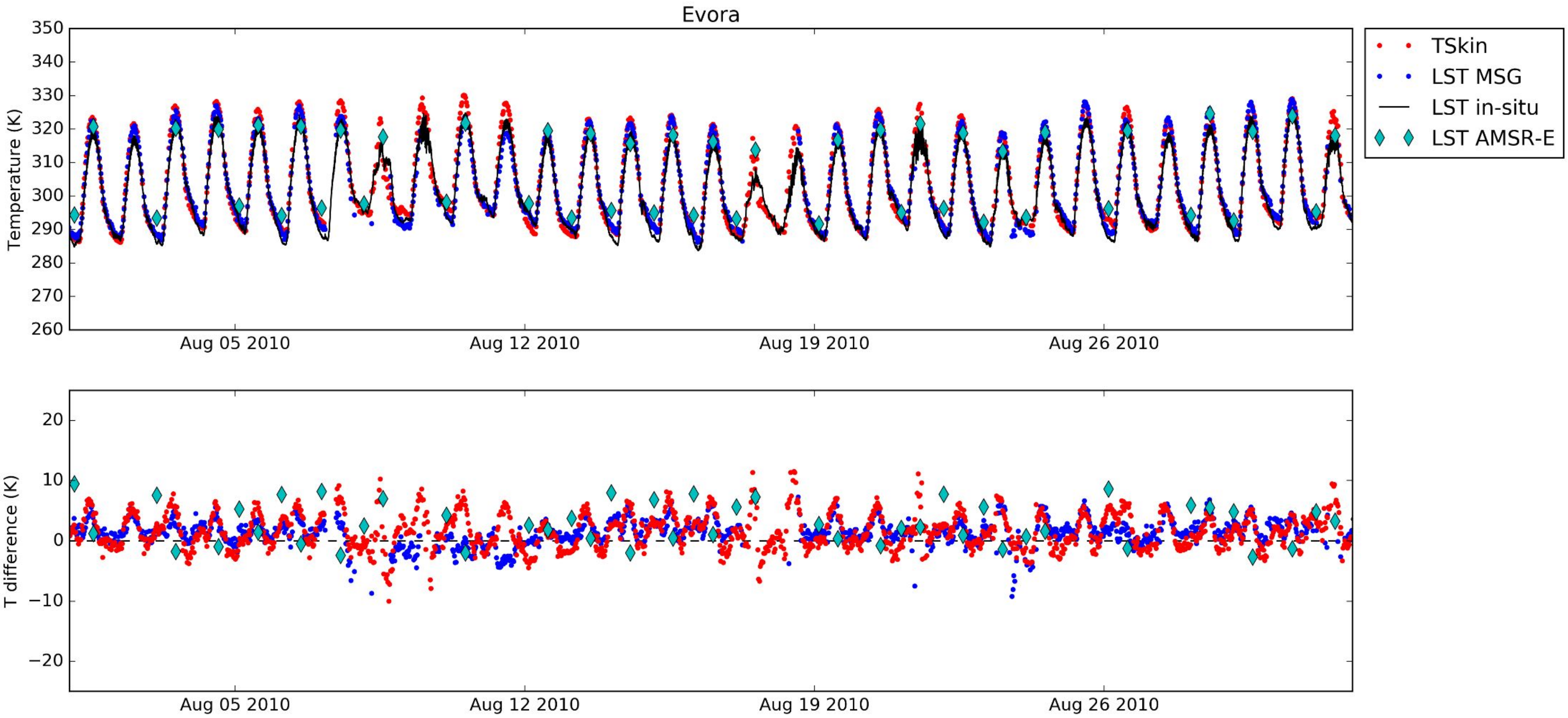



Kalahari



Gobabeb

# All-weather LST

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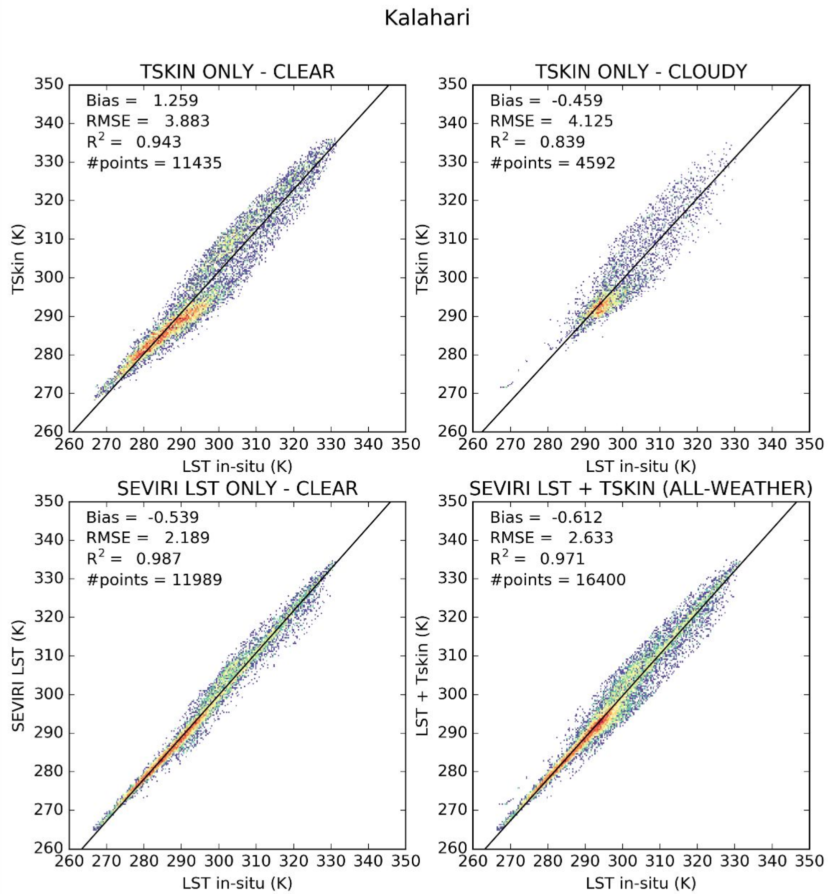
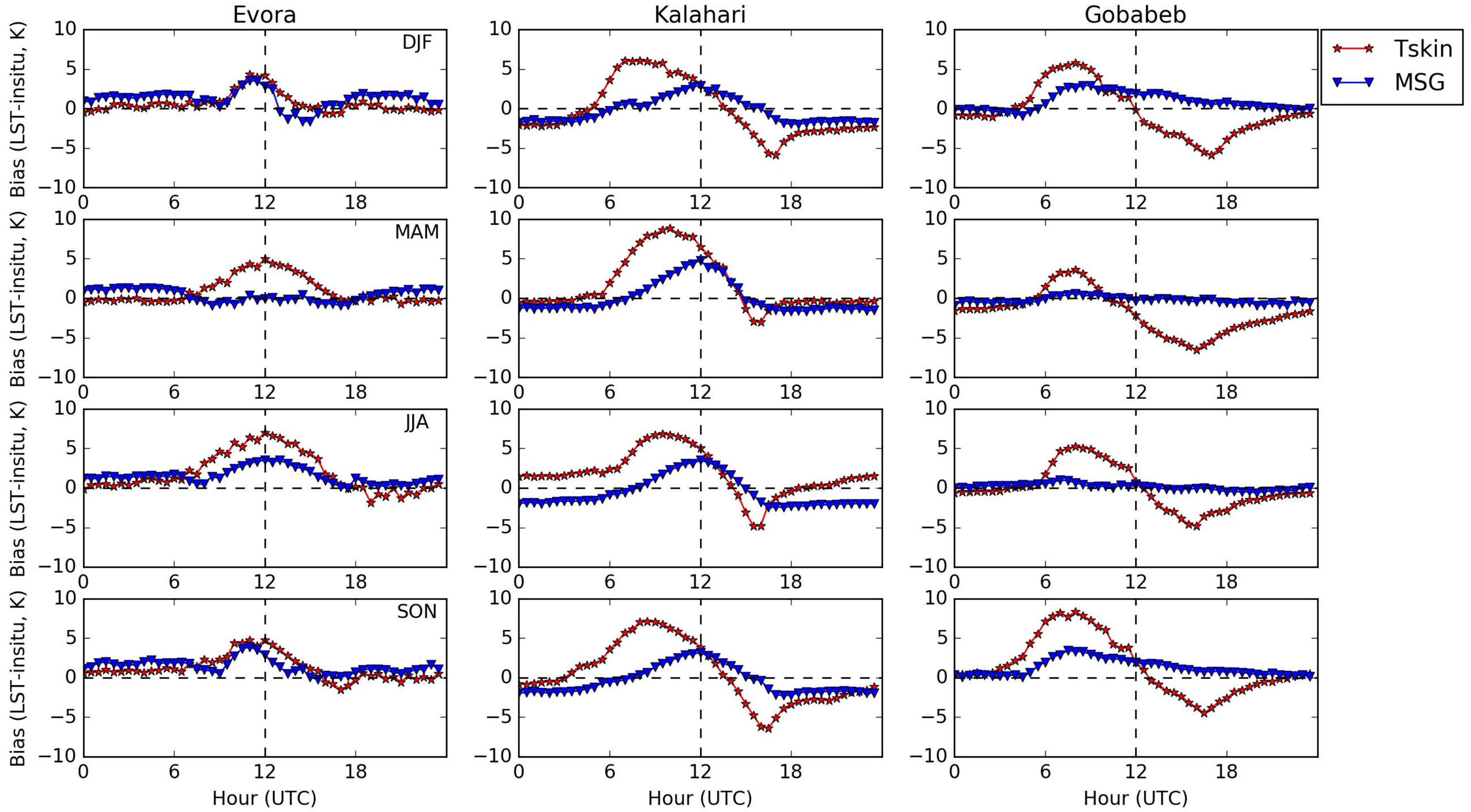
# All-weather LST

## Comparison of SEVIRI LST, and Skin Temp from the ET model with in-situ LST. Data from 2010. No outliers (3σ-filter)



# All-weather LST

## Diurnal/Seasonal Cycle of error

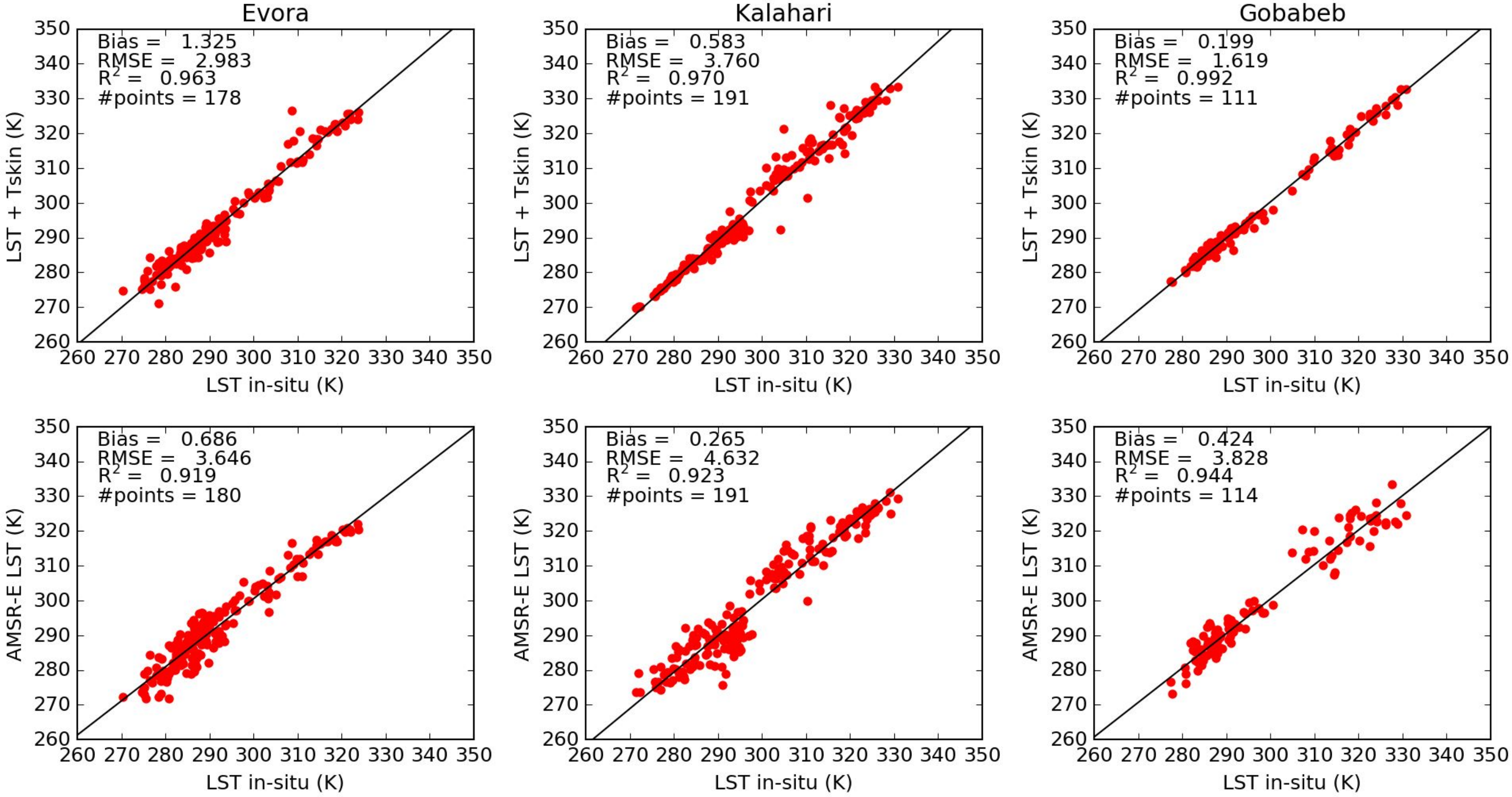



May be related to the G term

# All-weather LST

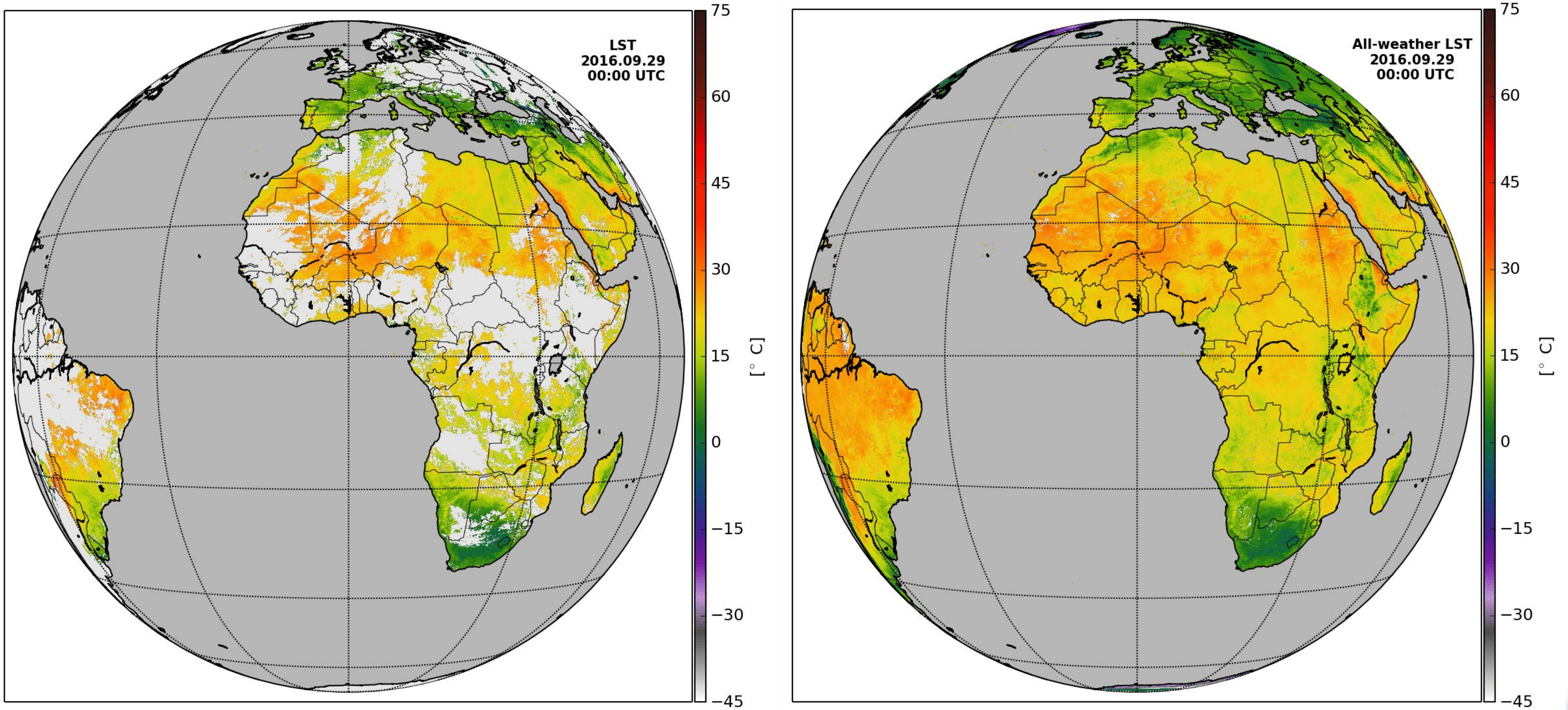
All-weather LST

MW LST



# All-weather LST

## Example of final product (prototype)





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# All-weather LST

**Highlights**

- A new all-weather LST product is proposed, using IR-based LST for clear-sky and Tskin derived from an evapotranspiration model with mostly remote sensing data as inputs to fill cloudy scenes in the operational Land-SAF LST product.
- This approach is better than the MW approach as it allows a better time-sampling and leads to better error statistics (as estimated by comparison with 3 in-situ stations).
- Still, the diurnal cycle is not well represented by the model in certain locations (overestimation in the late morning and under-estimation in late-afternoon/early-night in less vegetated areas).
- The new product still does not allow full coverage:
  - in some pixels algorithm convergence is not achieved
  - unavailable inputs (radiative fluxes,etc.)

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**THANK YOU FOR YOUR ATTENTION!**