The EUMETSAT Satellite Applications Facility on Land Surface Analysis

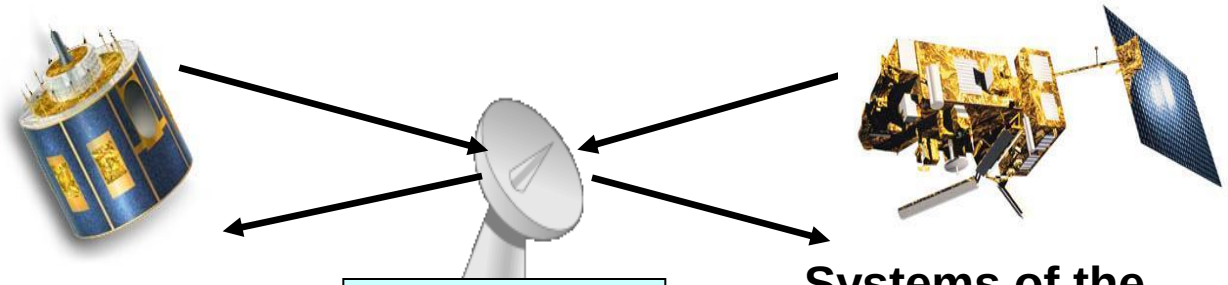
Continuous Development of Remote Sensing Products

Isabel Trigo

Outline

- The EUMETSAT LSA SAF
  - Current Products and Services
  - Applications
  - Training & Outreach
- Land Surface Temperature
  - Algorithm
  - Validation
  - On-going work
- NEXT

EUMETSAT Application Ground Segment



EUM Geostationary Systems

Data Acquisition and Control

Data Processing EUMETSAT HQ

Systems of the EUM/NOAA Cooperation

Other data sources

Application Ground Segment

Meteorological Products Extraction EUMETSAT HQ

Archive & Retrieval Facility (U-MARF) EUMETSAT HQ

Satellite Application Facilities (SAFs)

Centralised processing and generation of products

Decentralised processing and generation of products

USERS

Objectives

Objectives of the SAF Network:

- Improve EUMETSAT's Member States exploitation of satellite data
- Encourage the utilisation of existing skills and infrastructure in Member States and Cooperating States
- Cost-effective exploitation: Services are distributed in the most appropriate way
- Foster development of cooperation with non-Member States and other organisations

LSA SAF

EUMETSAT Satellite Applications Facility on Land Surface Analysis

- Part of EUMETSAT Ground Segment
- Aims to develop algorithms that allow an effective use of MSG and Metop data related to
  - LAND
  - LAND-ATMOSPHERE Interactions
  - BIOSPHERIC Applications
- Generates, Archives & Distributes **Satellite Products** in Near Real Time (up to 3h after last obs) and Off-line
- Consortium – 8 Institutes / 6 countries

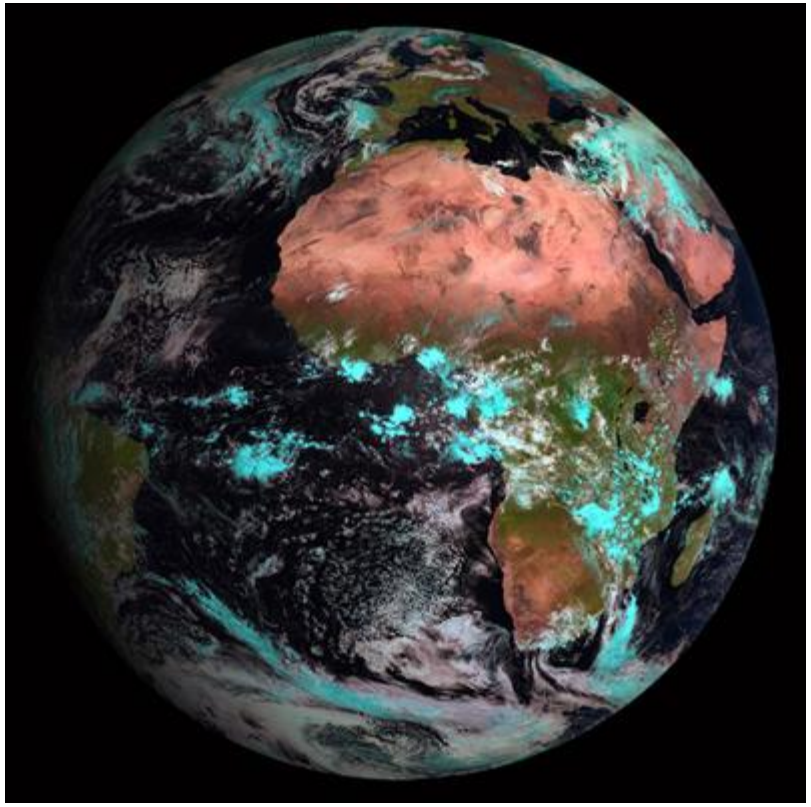
- Reviewed (~annually) by technical and scientific panels

Trigo et al., 2011 in *Int. J. Remote Sens*., DOI: 10.1080/01431161003743199

EUMETSAT Satellites - GEO

Meteosat Second Generation

- Geostationary orbit
- Nominal sub-satellite point at 0º long



Instruments

Spinning Enhanced Visible and Infrared Imager - SEVIRI

Geostationary Earth Radiation Budget - GERB

- visible-infrared radiometer for Earth radiation budget studies
- 2 broad-band channels (0.32 – 4 μm and 0.32 – 30 μm)
- sub-satellite point at ~45 km; temporal sampling - 15 min

EUMETSAT Satellites - GEO

SEVIRI - Spinning Enhanced Visible and Infrared Imager

11 Channels:

3 km sampling distance at sub-satellite point

15 minutes

High Resolution VIS channel:

1km sampling distance at sub-satellite point

15 minutes

Channel 1 VIS	0.6 μm
Channel 2 VIS	0.8
Channel 3 NIR	1.6
Channel 4 MIR	3.9
Channel 5 WV	6.2
Channel 6 WV	7.3
Channel 7 IR	8.7
Channel 8 IR/O_3	9.7
Channel 9 TIR	10.8
Channel 10 TIR	12.0
Channel 11 IR/CO_2	13.4
Channel 12	HRV

EUMETSAT Satellites - GEO

Meteosat First Generation

- Geostationary orbit
- CURRENT: Nominal sub-satellite point at 57º E
- 0º images available since 1982

(CDRs: Albedo and LST)

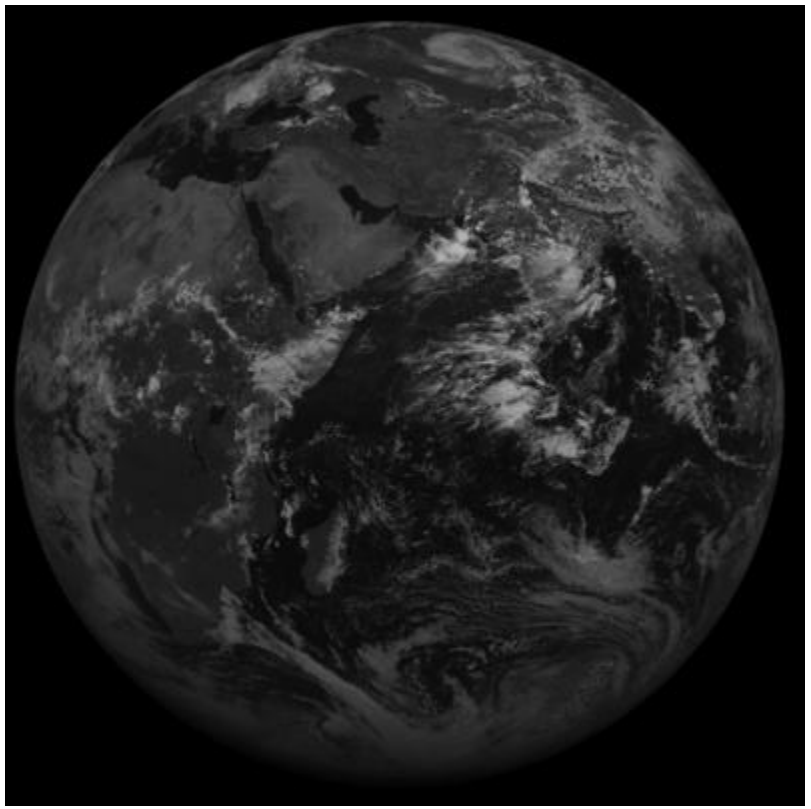
3 Channels:

5 km sampling distance at nadir

30 minutes

Channel VIS	0.45 – 1.0 μm
Channel WV	5.7 – 7.1
Channel TIR	~ 11.0 μm

Meteosat-7

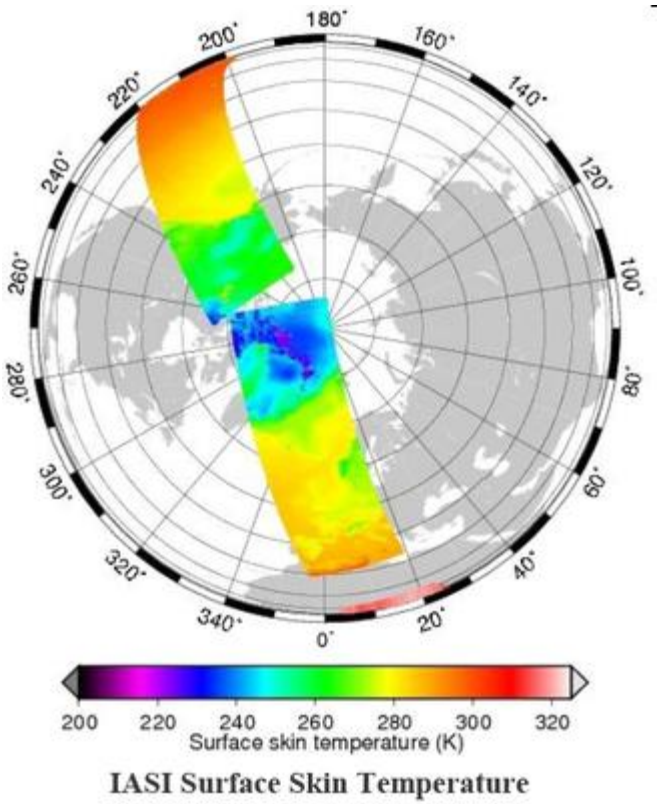


EUMETSAT Satellites - LEO

Metop (Polar-Orbit) – Playload:

- AVHRR
- HIRS
- AMSU-A
- MHS
- IASI
- ASCAT
- GOME-2
- GRAS

IASI



IASI Surface Skin Temperature

http://www.eumetsat.int

AVHRR

1 km at sub-satellite point

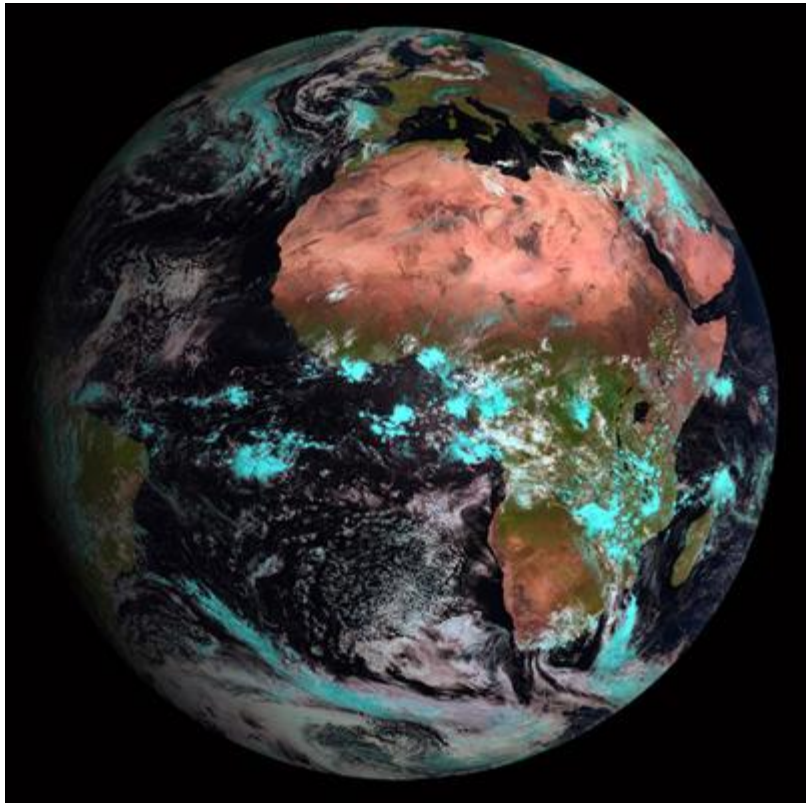
≥ 2 observations / day

Channel 1	0.58 – 0.68 μm
Channel 2	0.725 – 1.0 μm
Channel 3	~ 1.6 (day) / ~3.8 μm (night)
Channel 4	11.3 – 11.3 μm
Channel 5	11.5 – 12.50 μm

EUMETSAT Satellites - GEO

Meteosat Second Generation

- Geostationary orbit
- Nominal sub-satellite point at 0º long



Main focus of LSA SAF until present

Spinning Enhanced Visible and Infrared Imager - SEVIRI

- explore 96 observations /day (every 15 min) ...
- 12 channels ...
- at 3 km at nadir

LSA SAF – Family of Products

Surface Radiation

- LST
- ↓LongWave Flux
- ↓ShortWave Flux
- Albedo

Vegetation

State

- Fraction Veg Cover
- LAI
- fAPAR
- NDVI

Water stress

- Evapotranspiration
- Reference Evapot

Wild fires

- Fire Detection
- Fire Radiative Power
- Fire Risk (Europe)

MSG & Metop platforms

LSA SAF Products

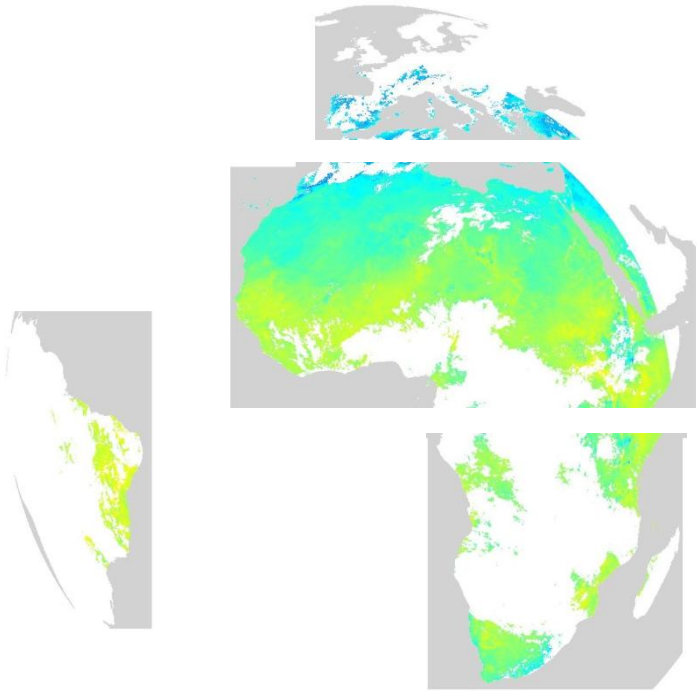
All products have a quality flag and/or error bar field associated

All products have an ATBD, a Product User Manual and a Validation Report

Full MSG disk
- Europe
- Northern Africa
- Southern Africa
- Southern America

SEVIRI Spatial resolution

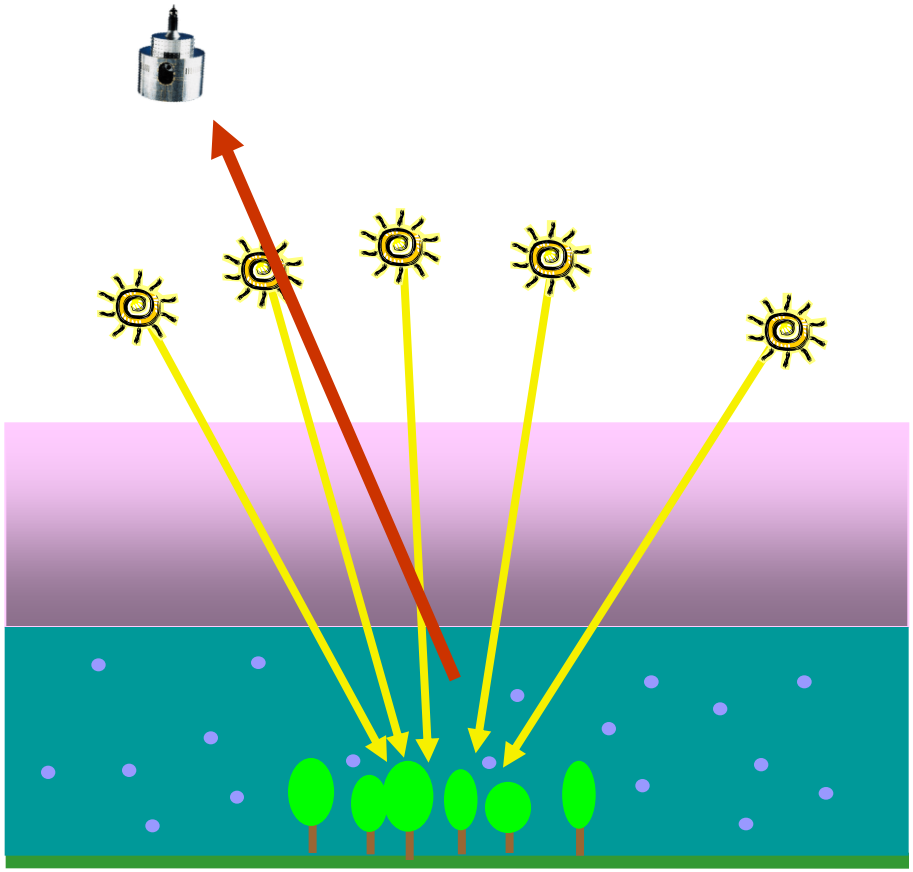
Generation Frequency
- 15 min
- 30 min
- Daily
- 10-daily



BRDF

SEVIRI 15 min clear sky obs within VIS & NIR channels ⇒ characterise the sfc BRDF:

$$R(\theta_{in},\theta_{out},\varphi) = k_0 + k_1\ f_1(\theta_{in},\theta_{out},\varphi) + k_2\ f_2(\theta_{in},\theta_{out},\varphi)$$



Anisotropic surface

- k_0 – Isotropic reflectance
- K_1 – geometric scattering processes
- k_2 – volumetric scattering processes

Albedo

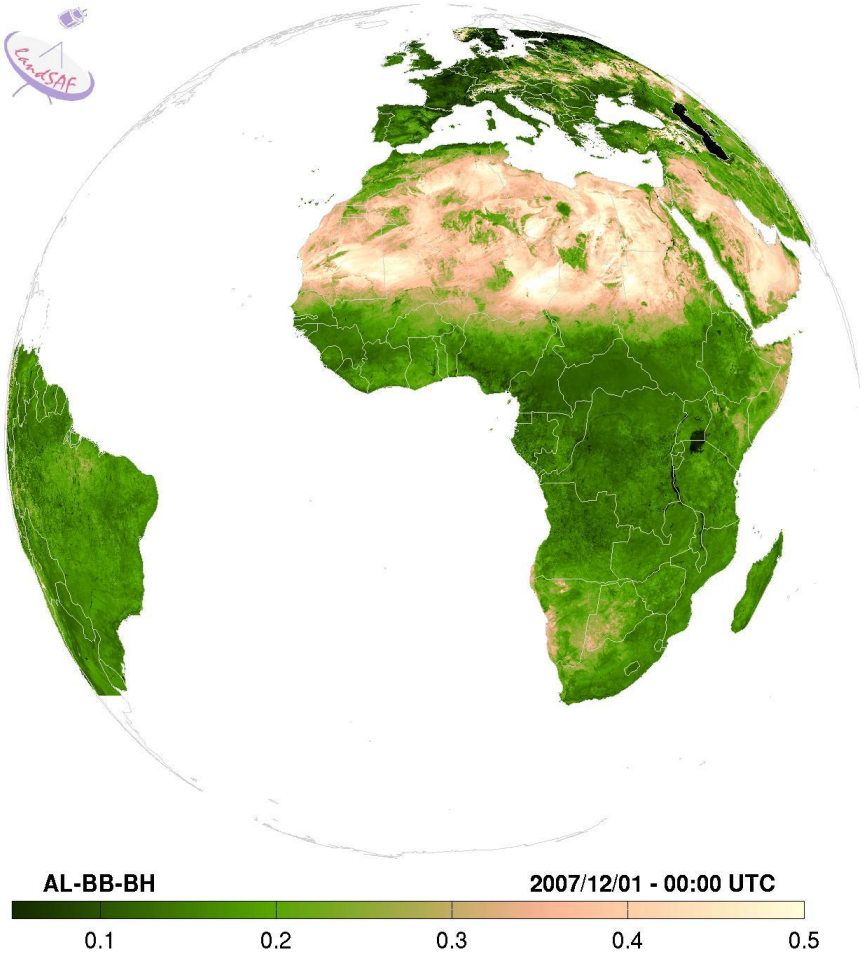
Black Sky AL
White Sky AL

Vegetation Parameters

FVC
LAI
FAPAR

ALBEDO

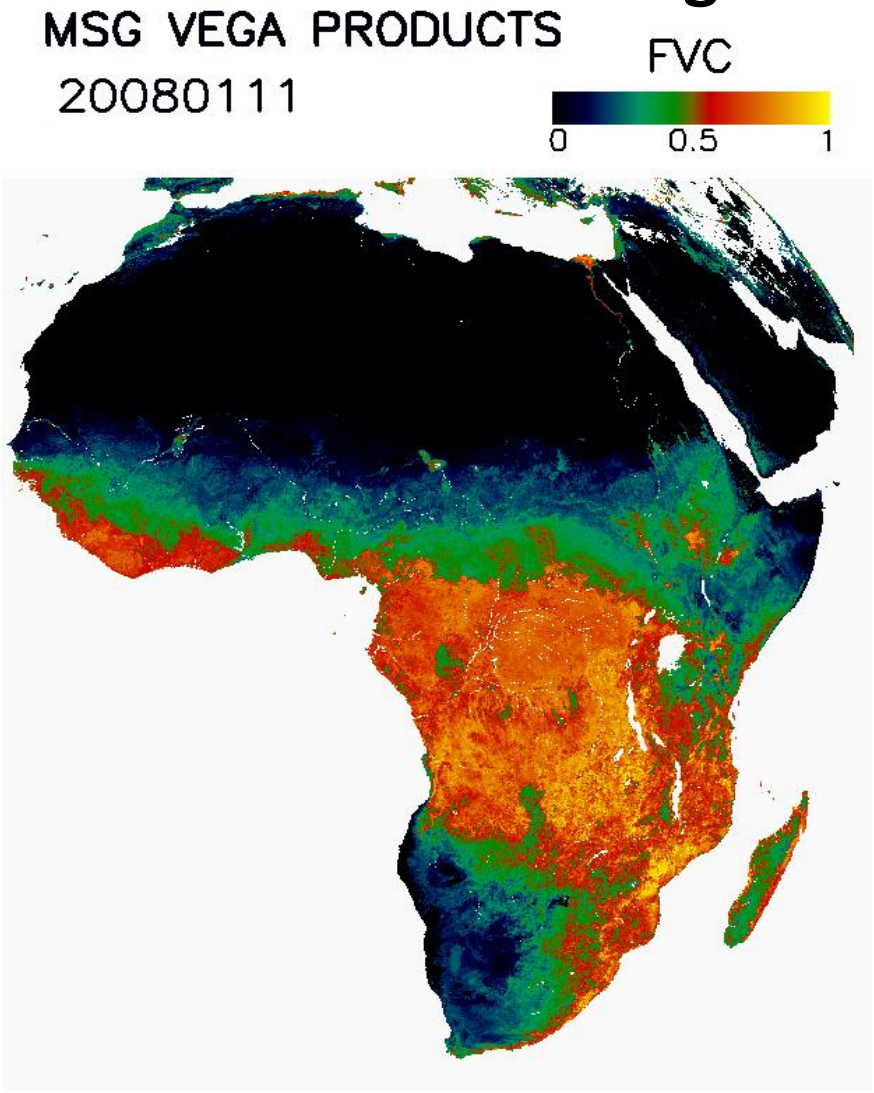
- *Spatial Resolution:*
SEVIRI original resolution
3 km at nadir
- *Temporal Resolution:*
Daily & 10-daily
- *Area Coverage:* SEVIRI disk
- *Error bars*
- *Available since:*
2005



Developer: LSA SAF / Meteo-France

Geiger et al. (2008) in *IEEE Trans Geosc Remote Sens*, DOI:10.1109/TGRS.2008.2001798
Carrer et al. (2010) in *IEEE Trans Geosc Remote Sens,* DOI: 10.1109/TGRS.2009.2034530.

Vegetation



- Fraction of Vegetation Cover **(FVC)**
- Lead Area Index **(LAI)**
- Fraction of Absorbed Photosyinthetically Active Radiation **(FAPAR)**

✓ Daily and 10-daily products

✓ 3 km at sub-satellite point

✓ NRT (EUMETCast)

✓ Off-line

Developer: LSA SAF / University of Valencia

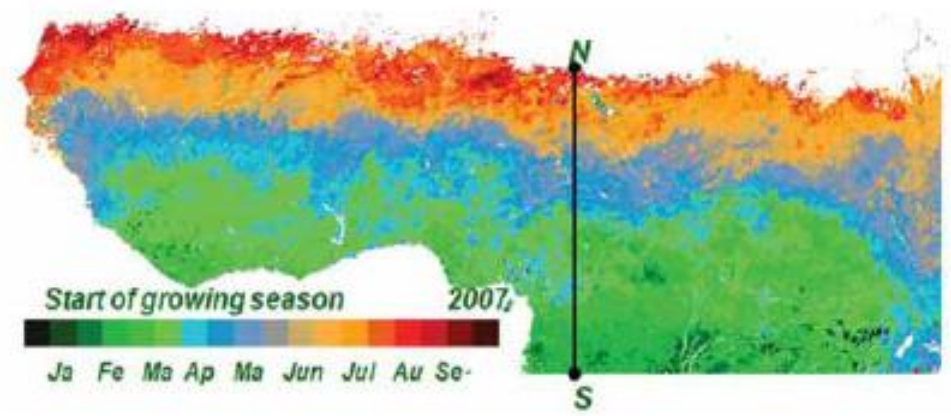
Verger et al. (2009) in *Remote Sens Environ.*, DOI:10.1016/j.rse.2009.06.009

Martínez et al. (2013) in *Int J App Earth Obs Geoinf*, DOI: 10.1016/j.jag.2012.06.010

Vegetation Parameters

SEVIRI

Phenology parameters



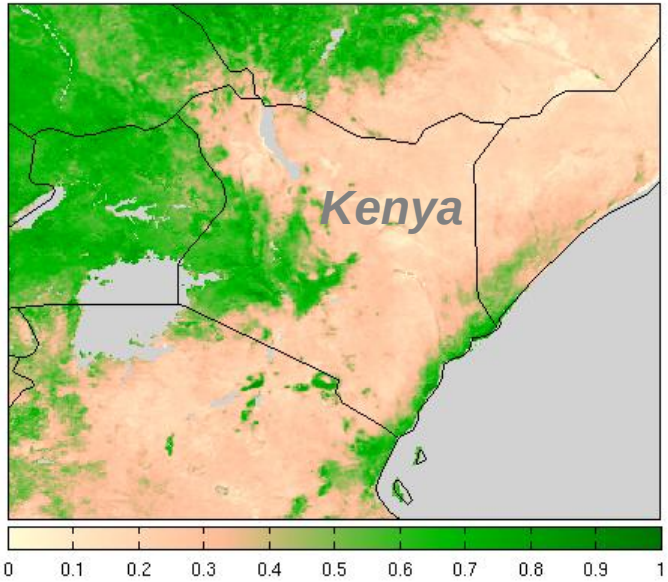
High number of observations leads to relatively **smooth time-series –** good for Phenology

Start of the Growing Season

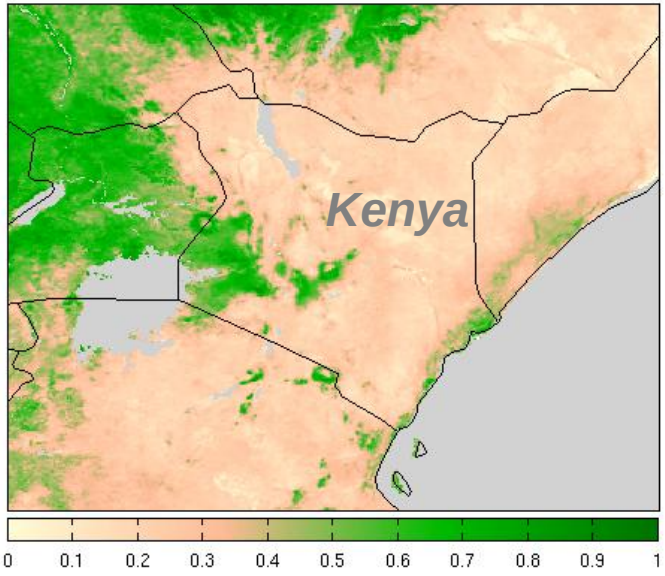
2007

Kenya – Drought 2009

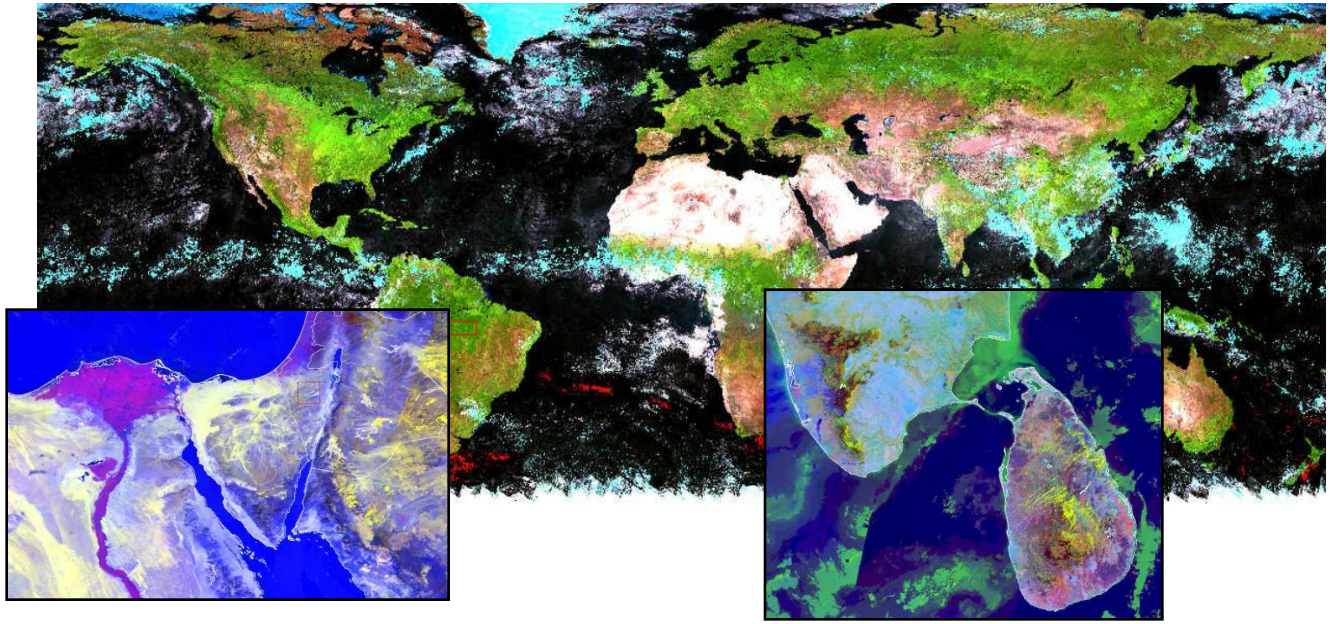
20070927



20090927



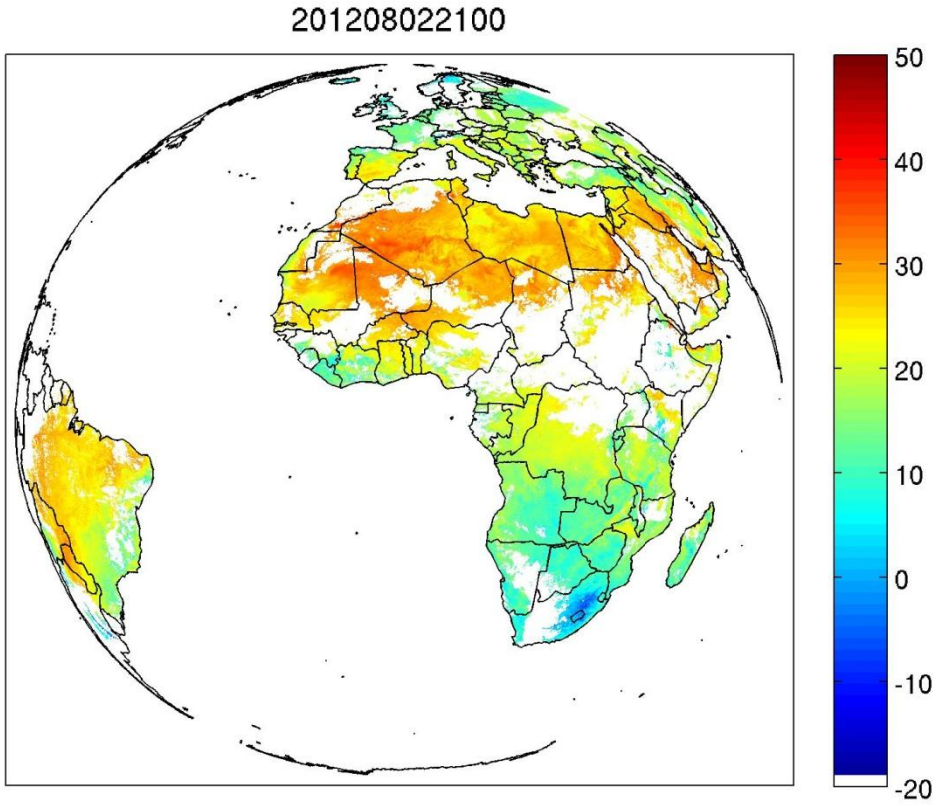
MetOp
10-day NDVI from AVHRR/Metop



Example of a Global S10-composite derived from METOP-AVHRR, with zoom on two regions: the Nile delta and Sri Lanka

Developer: LSA SAF / VITO

Land Surface Temperature

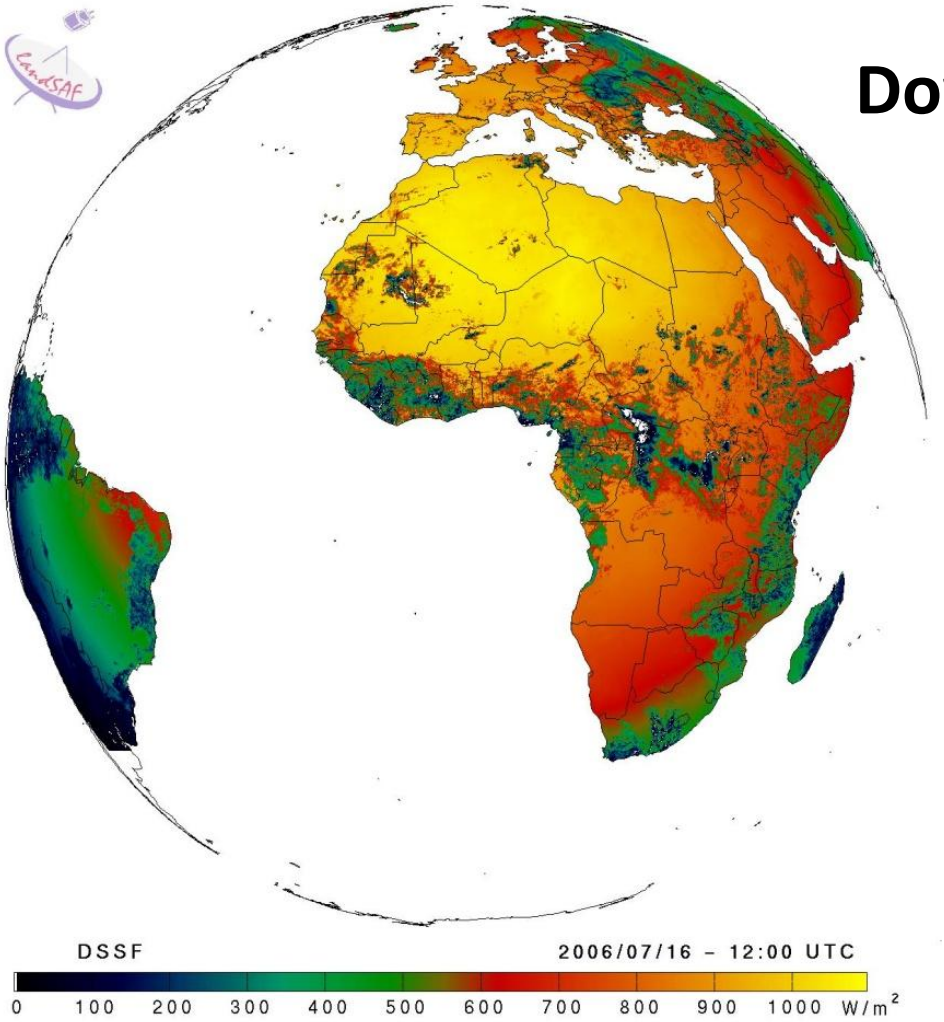


- ✓ 15-min
- ✓ 3 km at sub-satellite point
- ✓ clear sky pixels
- ✓ NRT (EUMETCast)
- ✓ Off-line

Developer: LSA SAF / IPMA

Trigo et al. (2008) in *J. Geophys. Res.*, DOI:10.1029/2008JD010035

Freitas et al. (2010) in *IEEE Trans Geosc Remote Sens,* DOI: 10.1109/TGRS.2009.2027697.

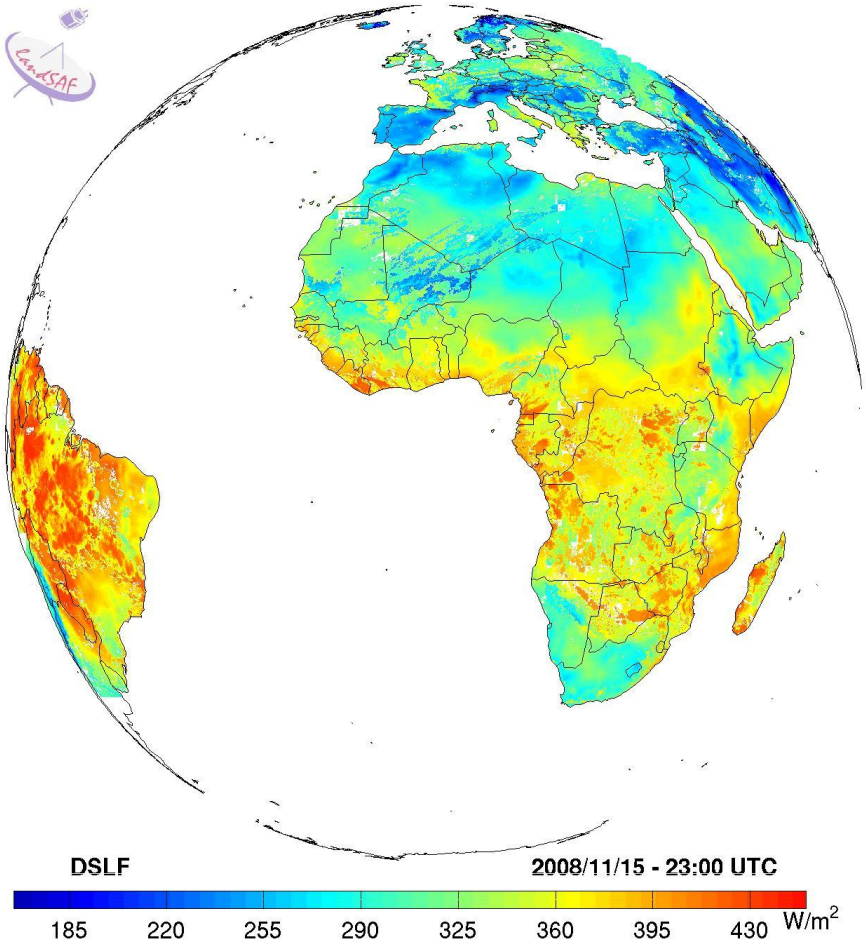


Downward Short-wave (solar) radiation at the surface

- ✓ 30-min and daily products
- ✓ 3 km at sub-satellite point
- ✓ NRT (EUMETCast)
- ✓ Off-line

Developer: LSA SAF / Meteo-France

Geiger et al. (2008) *in Meteorol. Appl.*, DOI: 10.1002/met.84
Carrer et al. (2012) in *J. Hydrometeor.*, DOI: 10.1175/JHM-D-11-059.1.



Downward Longwave-wave radiation at the surface

- ✓ 30-min and daily products
- ✓ 3 km at sub-satellite point
- ✓ NRT (EUMETCast)
- ✓ Off-line

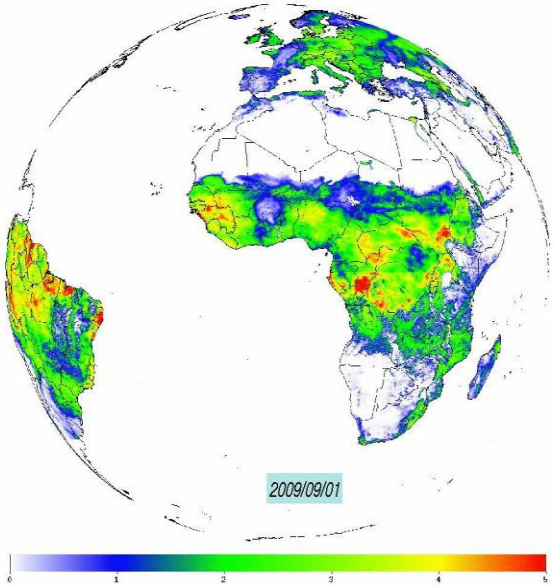
Developer: LSA SAF / IPMA

Trigo et al. (2011) *in J. Geophys. Res.,* DOI:10.1029/2010JD013888
Carrer et al. (2012) in *J. Hydrometeor.*, DOI: 10.1175/JHM-D-11-059.1.

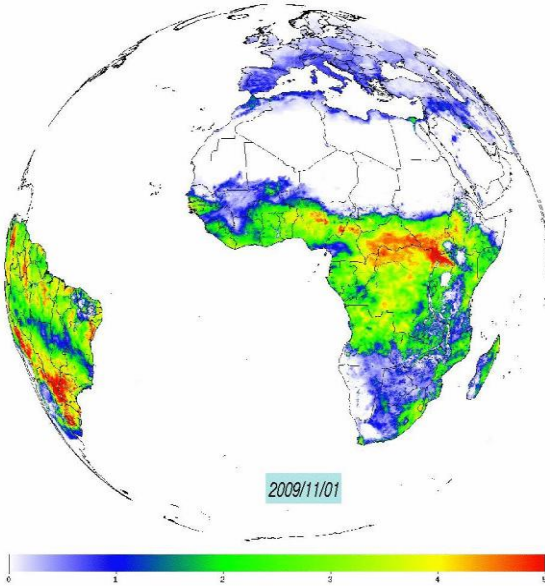
Evapotranspiration

Based on Sfc Energy Balance with Radiation products and VEGA from LSA SAF

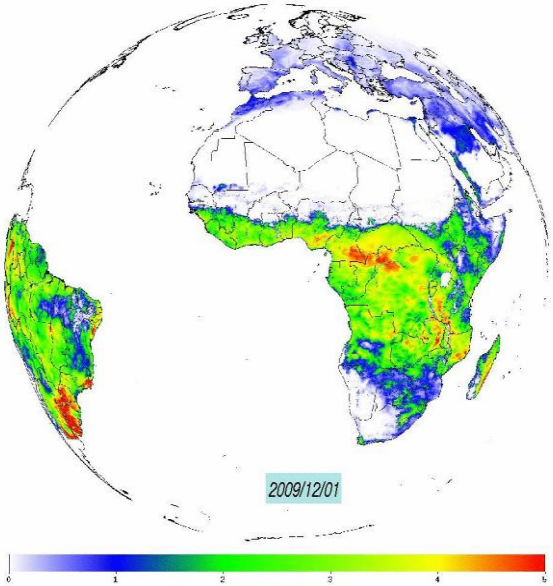
September 2009



November 2009



December 2009



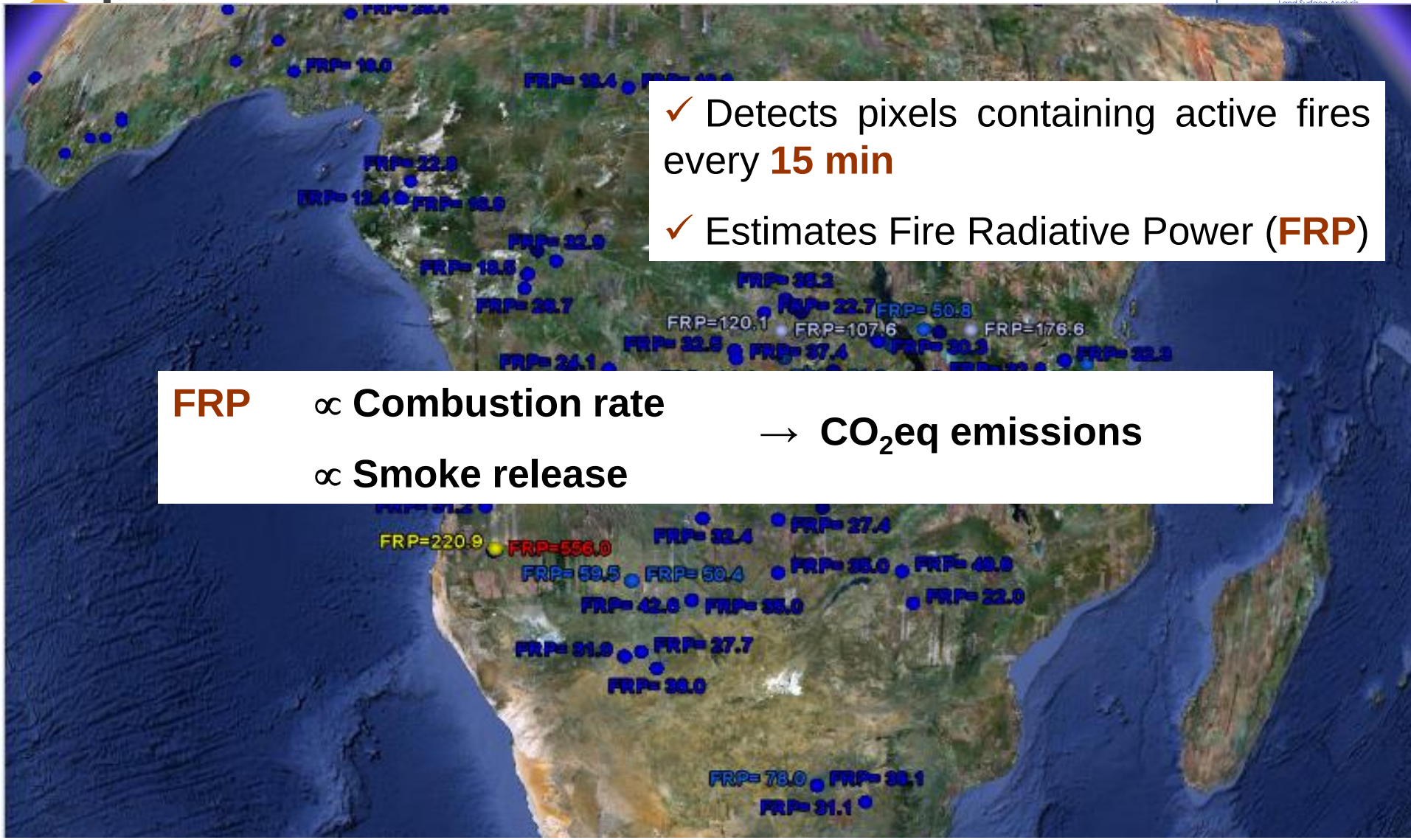
- ✓ 30-min and daily products
- ✓ 3 km at sub-satellite point
- ✓ NRT (EUMETCast)
- ✓ Off-line

Developer: LSA SAF / RMIB

Ghilain et al. (2011) *in* Hydrol. Earth Syst. Sci., DOI: 10.5194/hess-15-771-2011

Ghilain et al. (2012) *in* Hydrol. Earth Syst. Sci, DOI: 10.5194/hess-16-2567-2012.

Fire Products



Developer: LSA SAF / King's College London, University of Lisbon

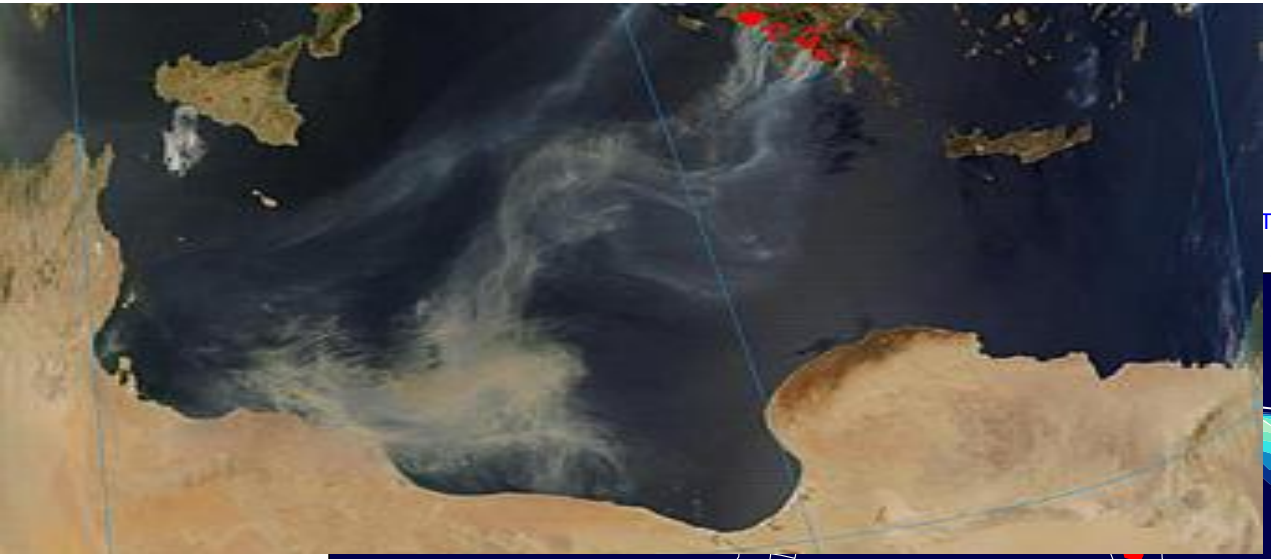
Freeborn et al. (2009) *in Remote Sens. Environ.,* DOI: 10.1016/j.rse.2009.03.013

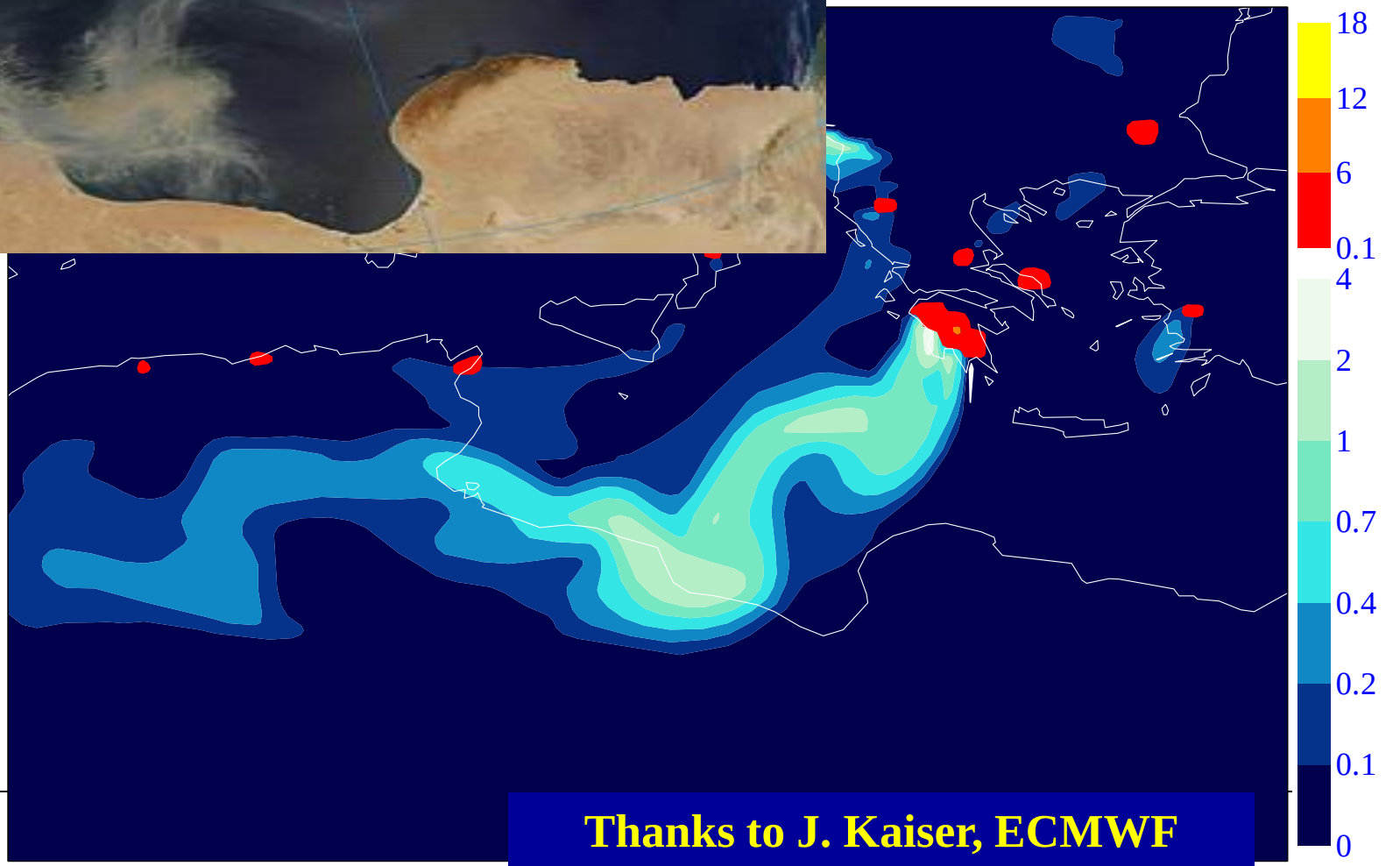
Amraoui et al. (2010) in *Remote Sens. Environ*., doi:10.1016/j.rse.2009.12.019.

Observed LandSAF Fire Radiative Power [W/m2] & Modelled BC+OM Optical Depth [-]

Thanks to J. Kaiser, ECMWF

MODIS 26 August, 0935 UTC

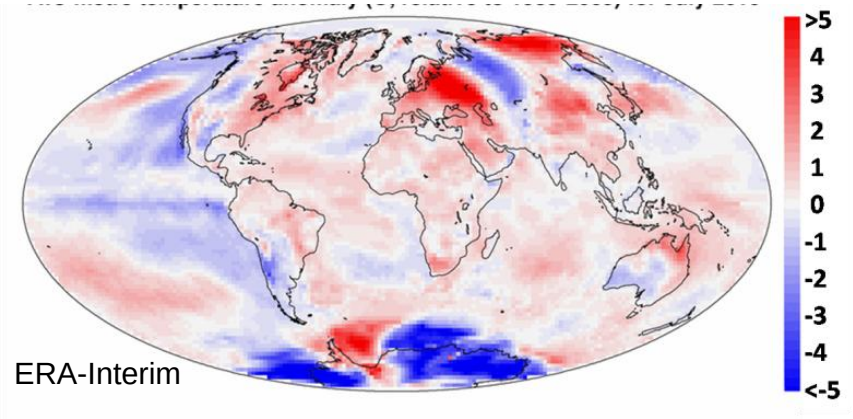




Thanks to J. Kaiser, ECMWF

Fires over Russia July – August 2011

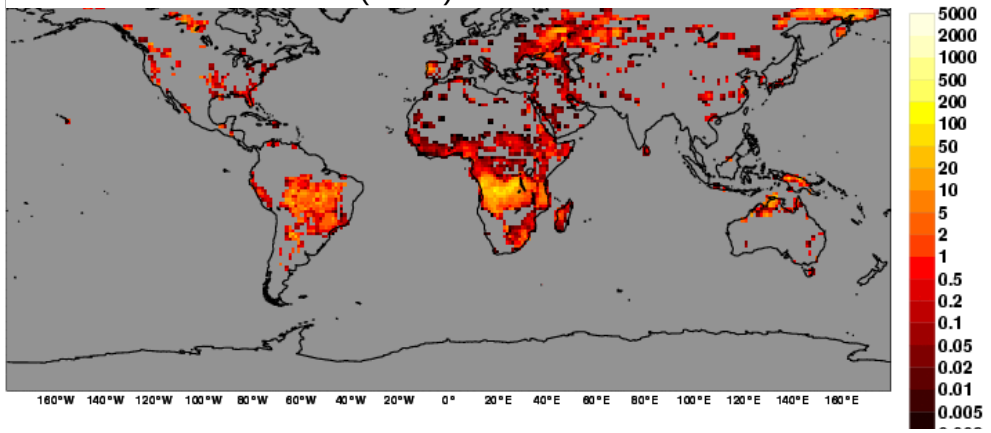
2m temperature anomaly (C) for July 2010

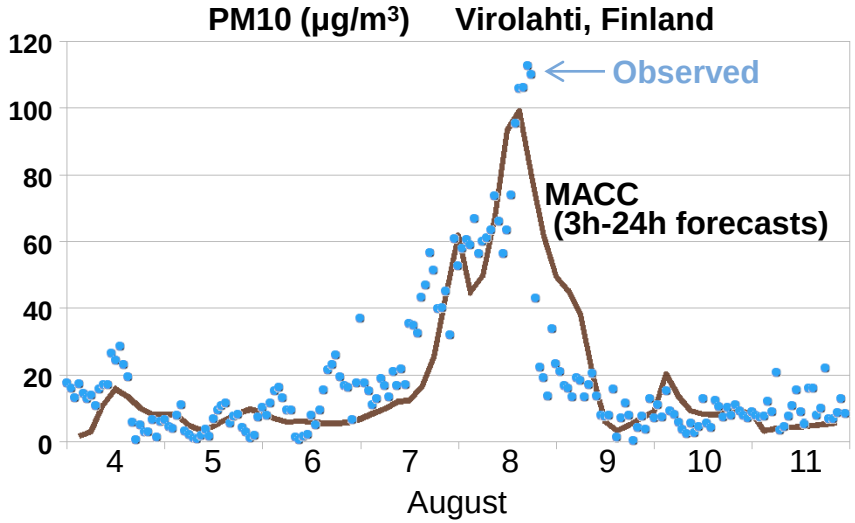


ERA-Interim

MACC Daily Fire Products Monday 26 July 2010
Average of Observed Fire Radiative Power Areal Density [mW/m2]
max value = 0.10 W/m2

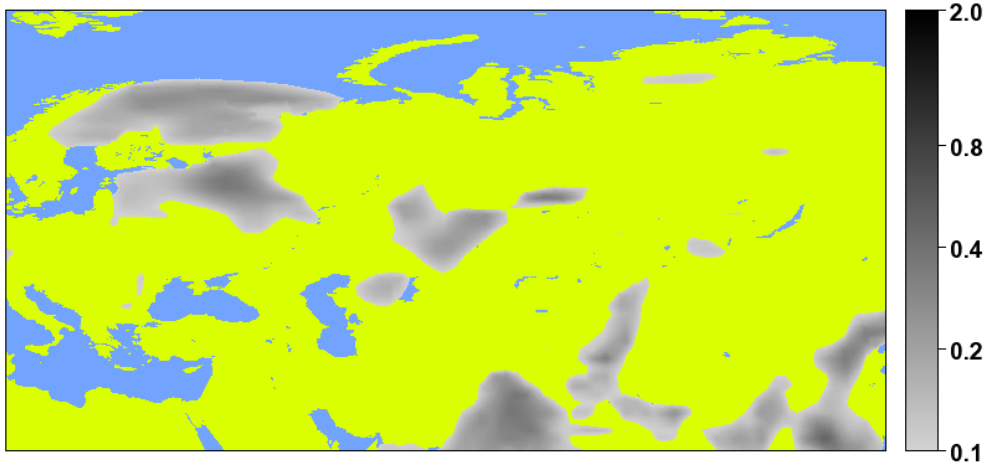
Fire Radiative Power (Wm^{-2}) from SEVIRI and MODIS





2010072603

Aerosol optical depth due to black carbon and organic matter



Successive 24h forecasts initialized using MODIS aerosol data

Thanks to A. Simmons, ECMWF

Outreach & Training

Regular Workshops

- ✓ LSA SAF team presents work on product development & validation
- ✓ Users are invited to report on applications and ...
- ✓ to discuss product/service requirements

Training

- ✓ e-learning modules
  - **http://www.eumetrain.org/data/3/36/index.htm** (Vegetation)
- ✓ Courses (in cooperation with EUMETSAT)
  - (At least) 1 course / year for African Users (in English, French, or Portuguese)
  - Remote Courses in cooperation with EUMETrain

Outline

- The EUMETSAT LSA SAF
  - Current Products and Services
  - Applications
  - Training & Outreach
- Land Surface Temperature
  - Algorithm
  - Validation
  - On-going work
- NEXT

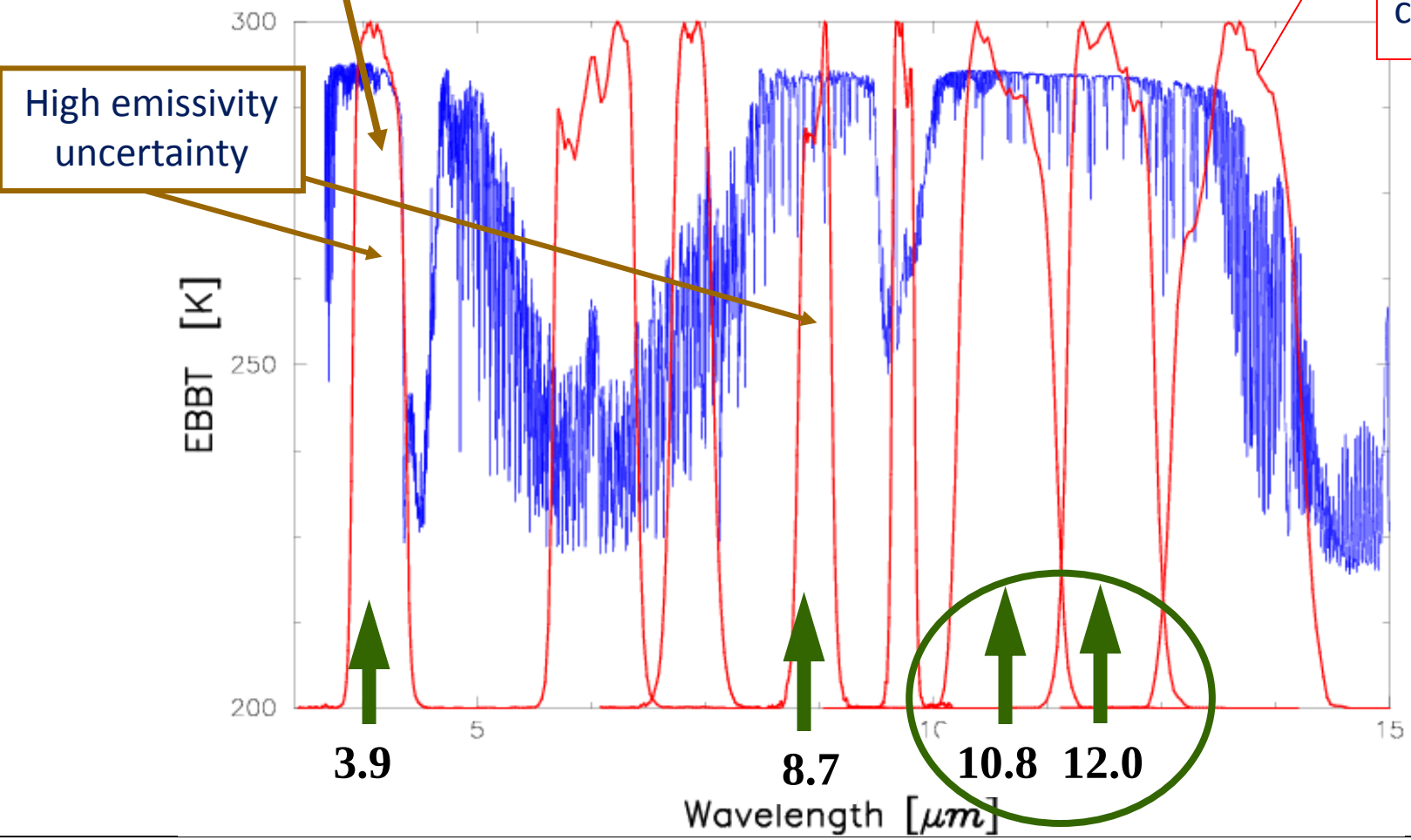
SEVIRI/MSG - LST

SEVIRI/Meteosat channels & LST

Solar contamination

High emissivity uncertainty

Response function of channels 3-11



LST/GEO Algorithm at the LSA SAF

- Maximize the use of available channels, in order to ...
- Minimize the incertainty of the retrievals, and ...
- being Computacionally Efficient.

Split-Windows – Semi-empirical method based on the simplification of the radiative transfer equation:

$$L_i = B(T_{bi}) = \varepsilon_i \, B_i(T_{sfc}) \tau_i + L^{\uparrow}_{atm,i} + (1-\varepsilon_i) \, L^{\downarrow}_{atm,i} \, \tau_i$$

TOA obs Sfc

- ✓ 2 adjacent channels, *i*, within the atmospheric window
- ✓ + Taylor expantion of the Planck function, B(T)

SEVIRI/MSG - LST

Generalised Split-Window → 10.8μm and 12.0μm (Wan & Dozier, 1996)

Trained using CLEAR SKY synthetic SEVIRI/MSG data

$$T_s = (A_1 + A_2 \frac{1-\varepsilon}{\varepsilon} + A_3 \frac{\Delta\varepsilon}{\varepsilon^2}) \frac{T_{10.8} + T_{12.0}}{2} + (B_1 + B_2 \frac{1-\varepsilon}{\varepsilon} + B_3 \frac{\Delta\varepsilon}{\varepsilon^2}) \frac{T_{10.8} - T_{12.0}}{2} + C$$

GSW parameters depend on:

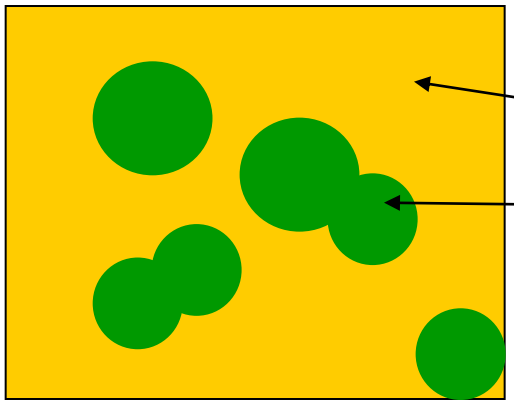
- total column water vapour (ECMWF forecasts)
- viewing angle

Channel Emissivity → Fraction Vegetation Cover

Emissivty

VEGETATION COVER METHOD

Pixel MSG



$$\varepsilon = \varepsilon_{veg}\,FVC + \varepsilon_{ground}\,(1\text{-}FVC) + \delta\varepsilon$$

LSA SAF Product

↑

Sfc Reflectances VIS

- Non-accounted effects (multiple reflections at sfc)
- Variability of bare ground/ vega within pixel

Emissivty – Vega/Ground

Band Emissivity for VEGETATION / SOIL classes

Emissivity at λ ←(Spectral Libraries)

$$\varepsilon_{c\text{-}VEGA/SOIL} = \frac{\int_{\lambda 1}^{\lambda 2} f_\lambda \varepsilon_\lambda B_\lambda \, d\lambda}{\int_{\lambda 1}^{\lambda 2} f_\lambda B_\lambda \, d\lambda}$$

Channel response function

SEVIRI/Meteosat Channels
- IR 3.9
- IR 8.7
- IR 10.8
- IR 12.0

Broad Band

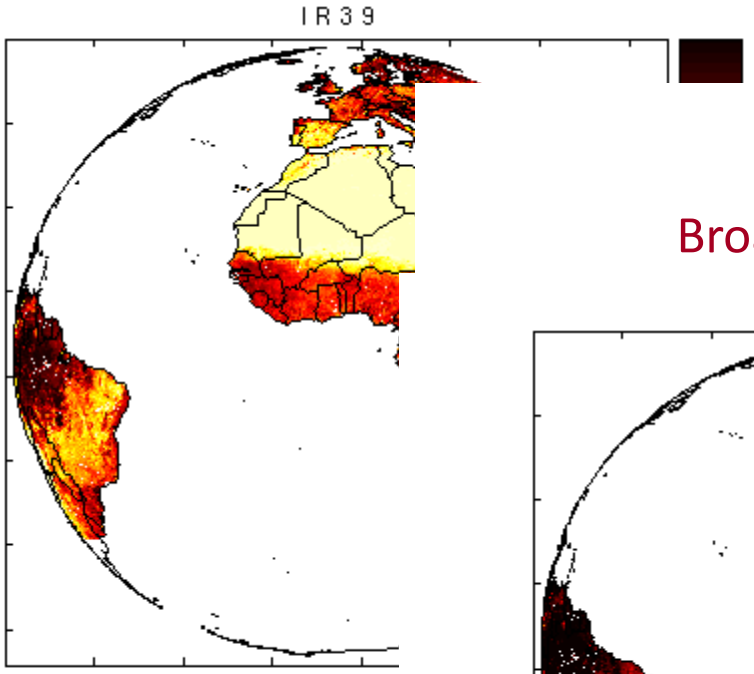
$\lambda 1 = 3\ \mu m$; $\lambda = 14\ \mu m$

($f_\lambda = 1$)

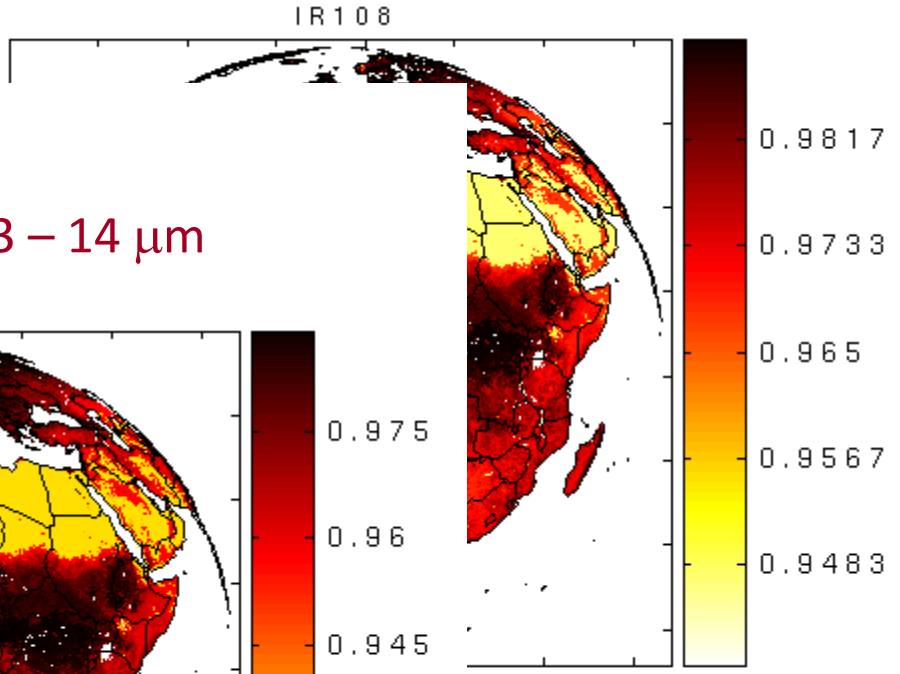
Trigo et al. (2008) in *IEEE Trans Geosc Remote Sens.*, Doi: 10.1109/TGRS.2007.905197

Emissivty

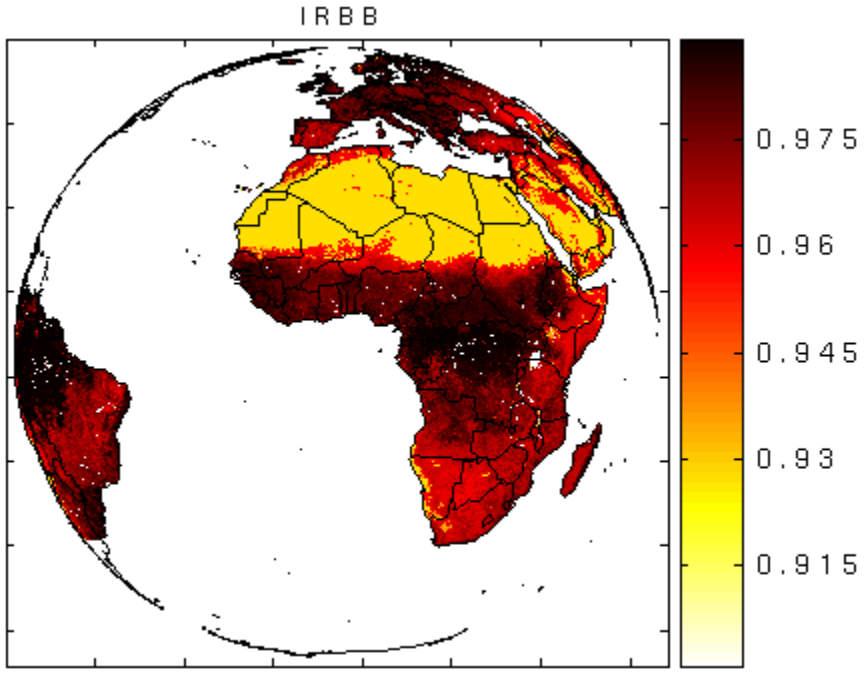
SEVIRI IR3.9



SEVIRI IR10.8



Broad-Band 3 – 14 μm



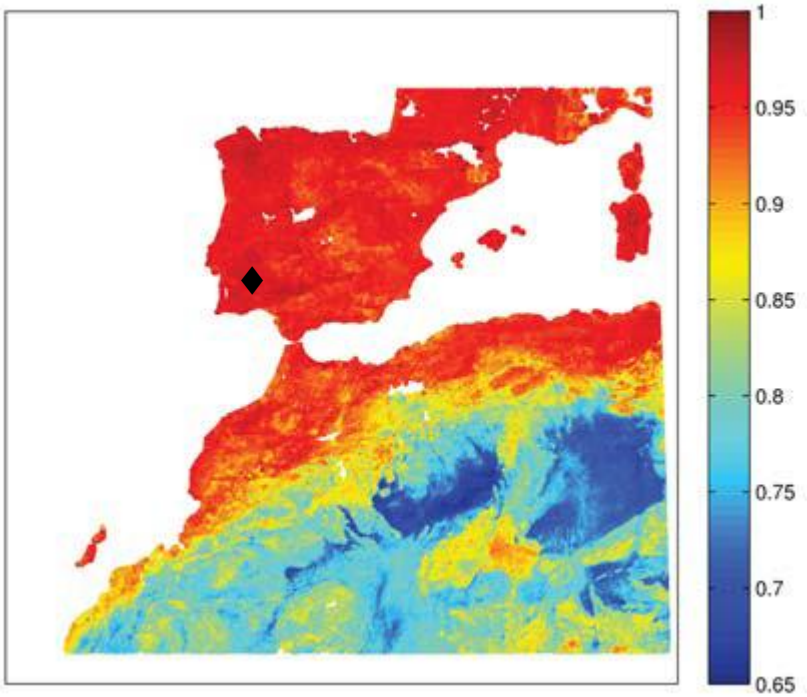
Updated Daily

Trigo et al. (2008) in *IEEE Trans Geosc Remote Sens,* Doi: 10.1109/TGRS.2007.905197

Emissivty

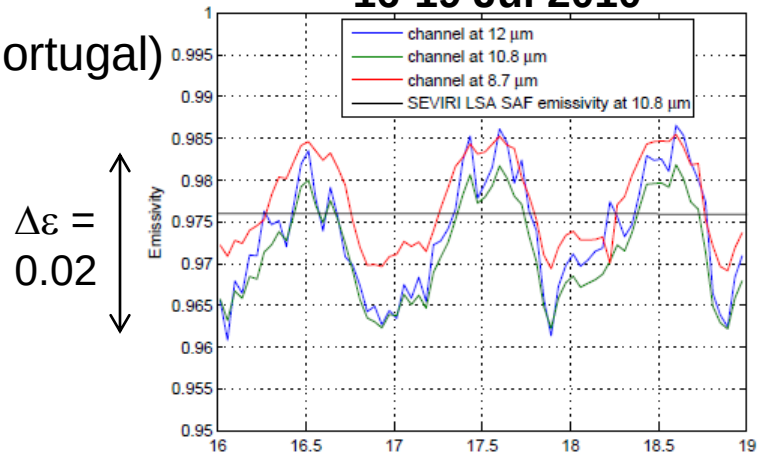
Under Testing: Kalman Filter approach to exploit the high temporal sampling
Channels **8.7, 10.8 and 12.0μm** ⇒ **Emissivity** & LST

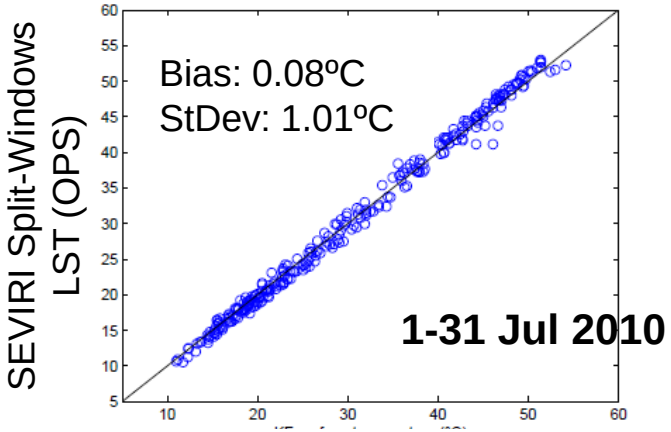
1-31 Jul 2010
EMISSIVITY 8.7μm



Evora ♦
(Southern Portugal)

16-19 Jul 2010





Marsiello et al. (2013) in *Atmos. Meas. Tech,* DOI: 10.5194/amt-6-3613-2013

SEVIRI/MSG - LST

Generalised Split-Window → 10.8μm and 12.0μm (Wan & Dozier, 1996)

Trained using CLEAR SKY synthetic SEVIRI/MSG data

$$T_s = (A_1 + A_2 \frac{1-\varepsilon}{\varepsilon} + A_3 \frac{\Delta\varepsilon}{\varepsilon^2}) \frac{T_{10.8} + T_{12.0}}{2} + (B_1 + B_2 \frac{1-\varepsilon}{\varepsilon} + B_3 \frac{\Delta\varepsilon}{\varepsilon^2}) \frac{T_{10.8} - T_{12.0}}{2} + C$$

GSW parameters depend on:

- total column water vapour (ECMWF forecasts)
- viewing angle

Channel Emissivity → Fraction Vegetation Cover

Operational LST Product

SEVIRI/MSG – LST: Product Uncertainty

$$S_{LST}^2 = \sum_i \left(\frac{\partial f}{\partial X_i} \right)^2 \sigma_{X_i}^2 + \sum_j \left(\frac{\partial f}{\partial \theta_j} \right)^2 \sigma_{\theta_j}^2 + \Delta LST^2$$

Input errors

↓

Sensor noise; emissivity

Algorithm uncertainty

↓

Retrieval conditions

Model parameters/ Implicit input variables

↓

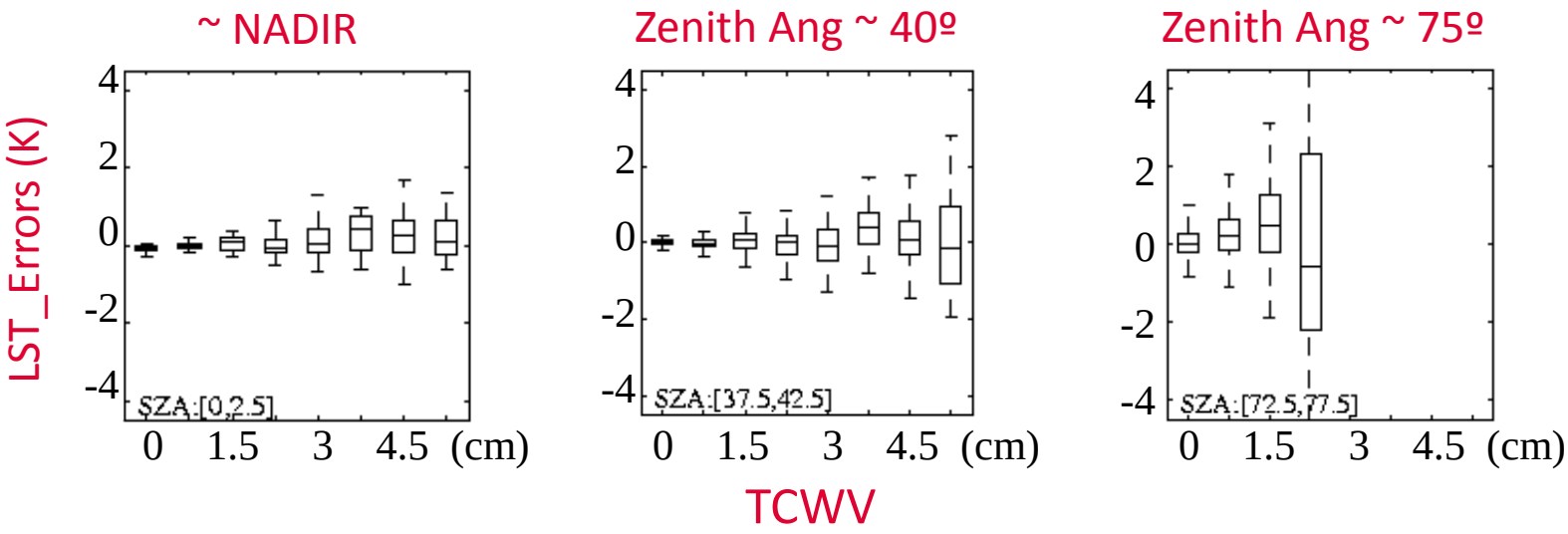
TCWV (ECMWF); view angle

SEVIRI/MSG – LST: Product Uncertainty

Generalised Split-Window

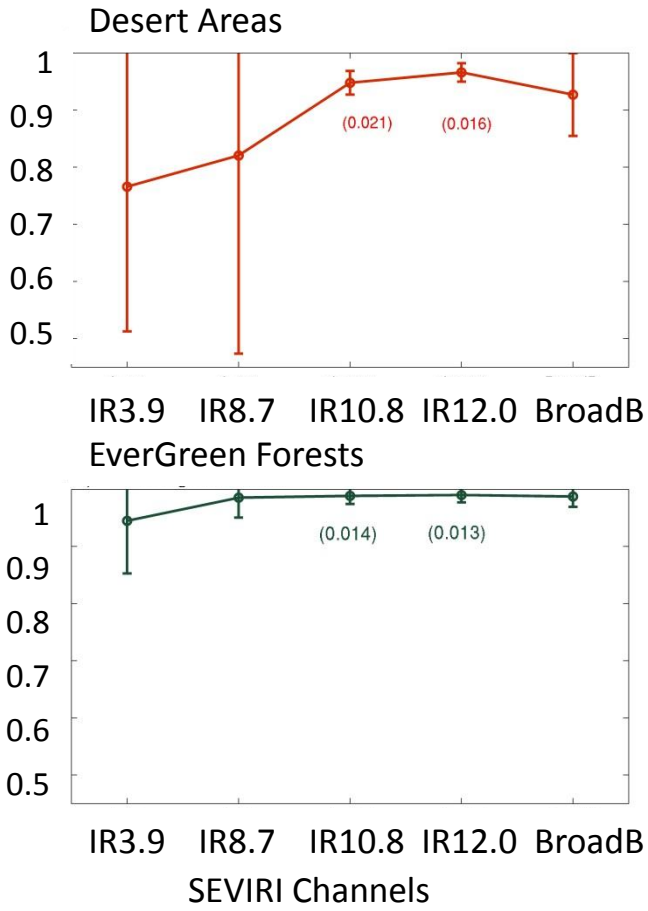
- Trained using CLEAR SKY TOA Tb's - MODTRAN
- Verified against independent dataset (~ 15 700 profiles).

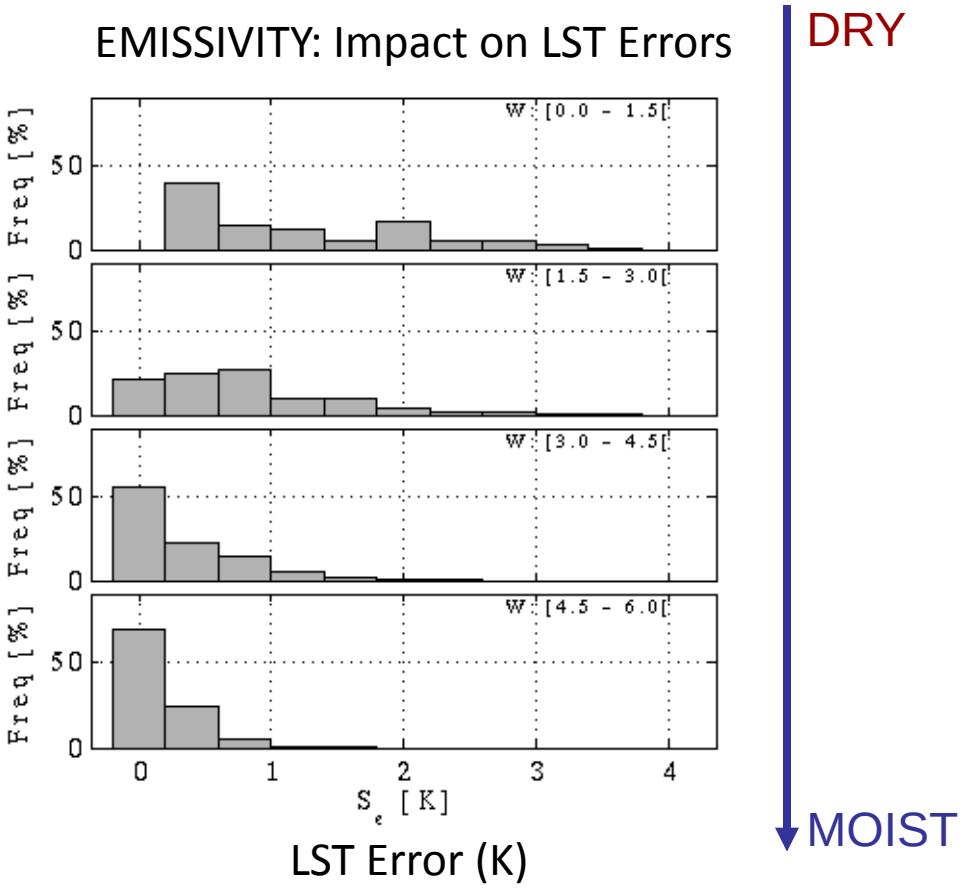
Algorithm uncertainty estimated through comparison with Verification dataset.



SEVIRI/MSG – LST: Product Uncertainty

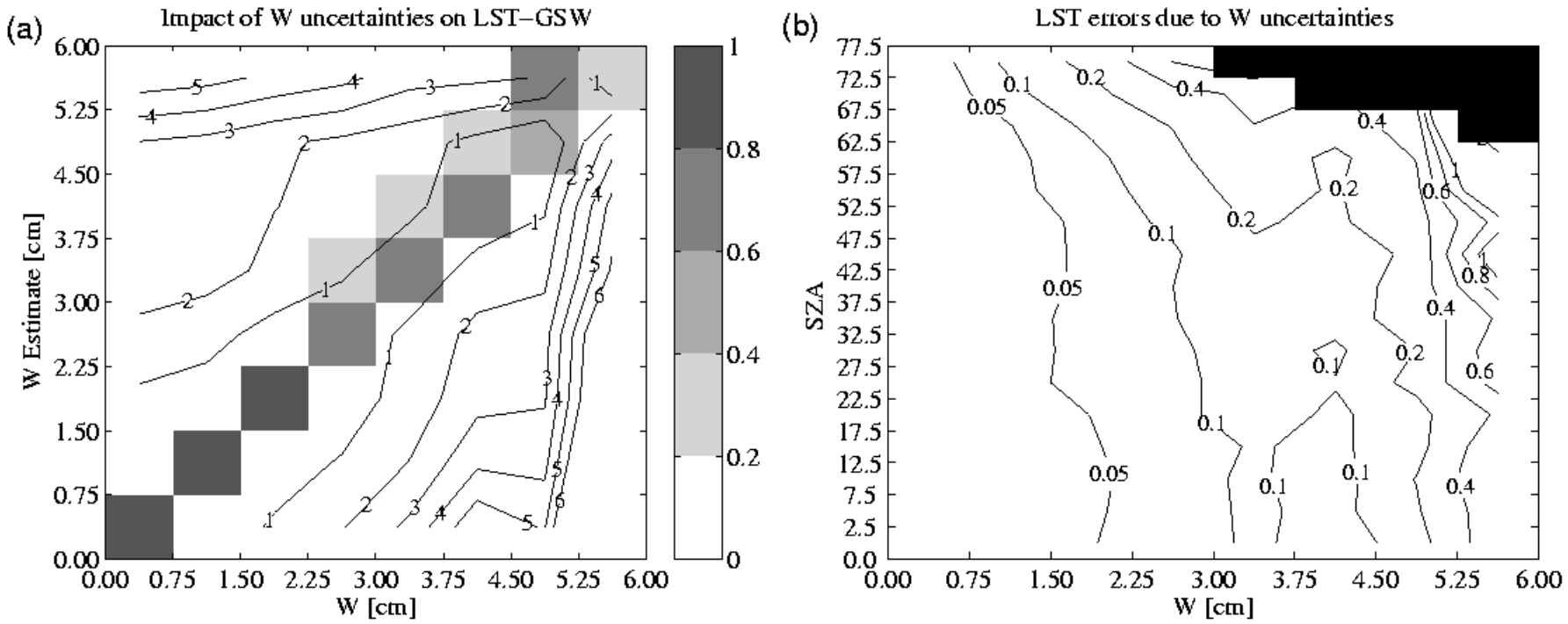
Emissivity uncertainty





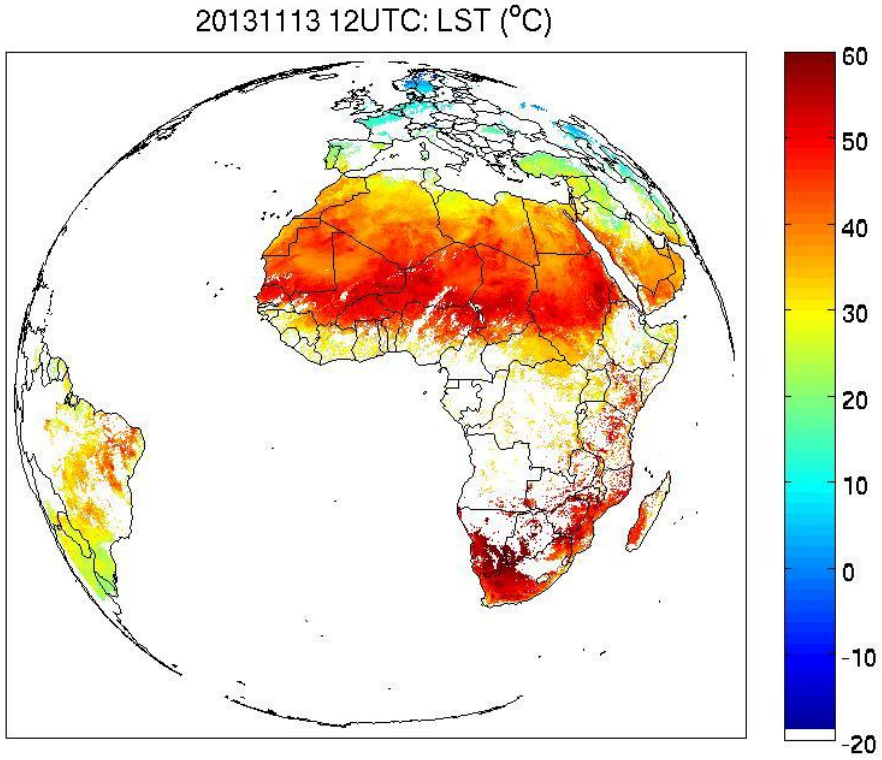
SEVIRI/MSG – LST: Product Uncertainty

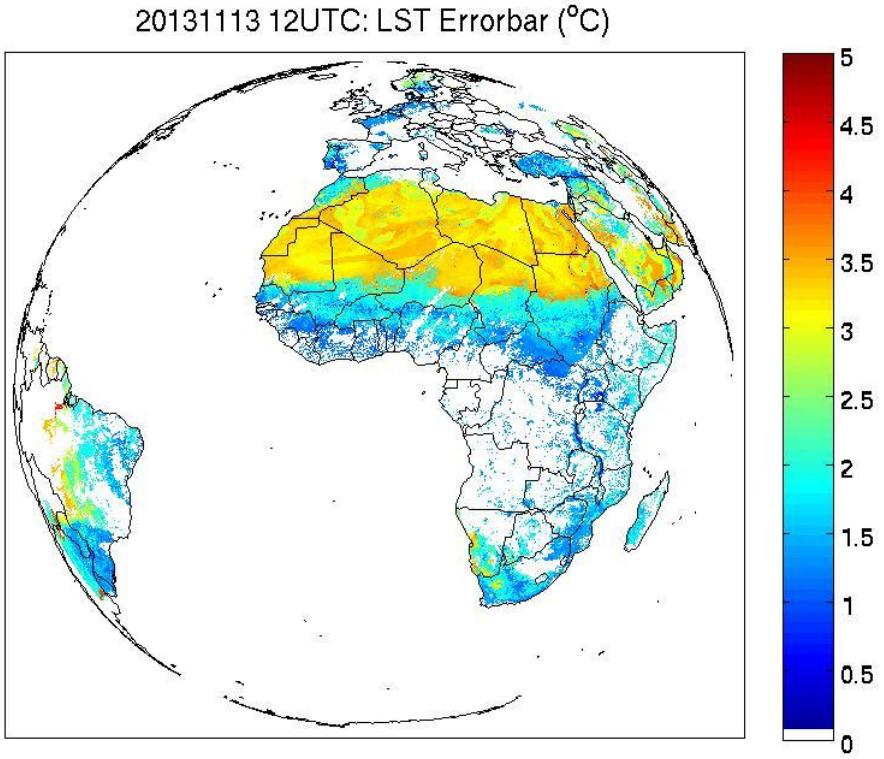
Total Column Water Vapour uncertainty



Freitas et al. (2010) in *IEEE Trans Geosc Remote Sens*, DOI: 10.1109/TGRS.2009.2027697.

SEVIRI/MSG - LST





- 15 minutes
- Geostationary Projection (3 km sub-satellite)
- HDF5 format; NRT & Off-line distribution
- Standardized set of documentation (ATBD, VR, PUM)

LSA SAF – Product Validation

GENERAL APPROACH

- Validation: Information on products compliance with user requirements
- Intercomparison with other satellite derived similar products
  - ✓MODIS
  - ✓AATSR
  - ✓CERES
  - ✓...
- Comparison with Ground Observations
  - LSA SAF/ KIT sites (Southern Portugal; Namibia; Senegal)
  - Established Networks (e.g., BSRN, Fluxnet)
  - Field Campaigns (e.g., AMMA)
- Comparison with Model fields

LSA SAF – Product Validation

LST

- Intercomparison with other satellite derived similar products
  - Consistency Analysis

- Validation against ground observations - Portugal (Évora), Namibia (Gobabeb, Kalahari), Senegal (Dahra)
  - As an Indenpendent Reference

SEVIRI - MODIS Intercomparison

LST

MODIS Daily LST (MOD11A1)

- 2 obs per day (day & night)
- 1 km spatial resolution

SEVIRI LST

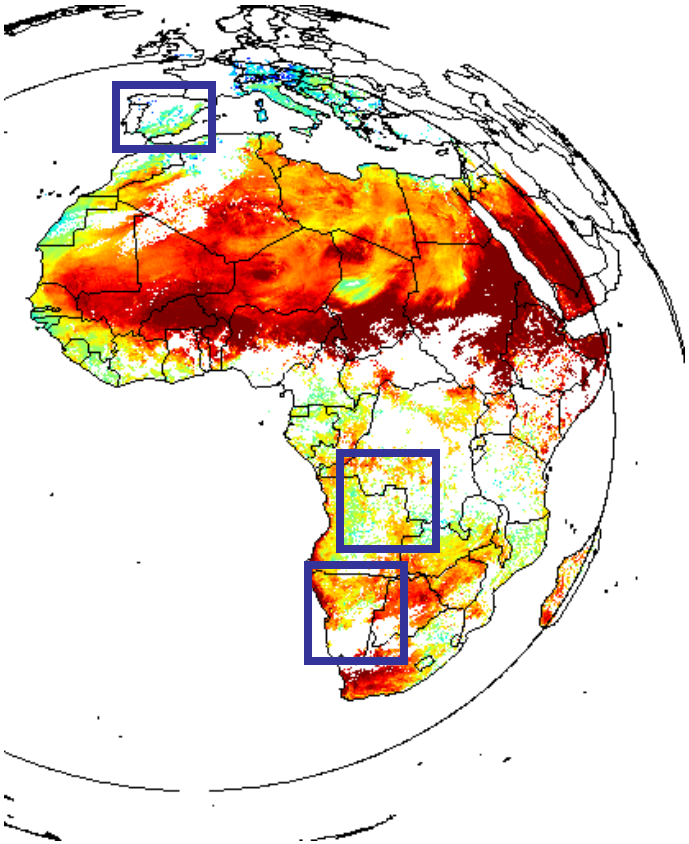
- 15 minutes
- 3 km at nadir

Both collocated in space & time

- 2 obs per day (day & night)
- 0.05º x 0.05º regular grid

SEVIRI - MODIS Intercomparison

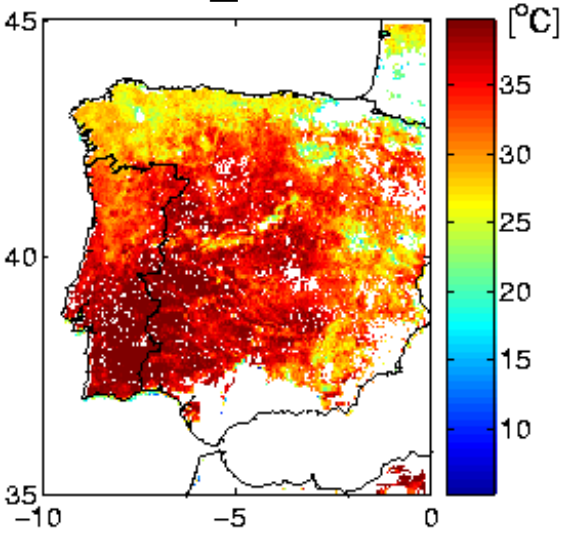
LST



- ✓ 3 AREAS 10º x 10º
- ✓ 6 weeks
- ✓ July 2005 to May 2006

SEVIRI - MODIS Intercomparison

LST _SEVIRI

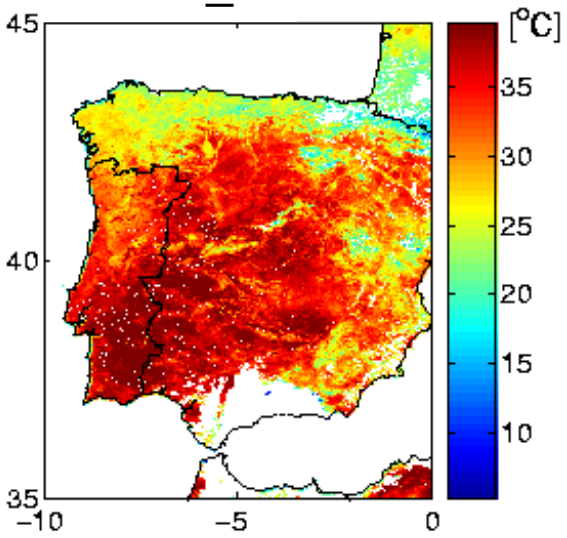


DAYTIME

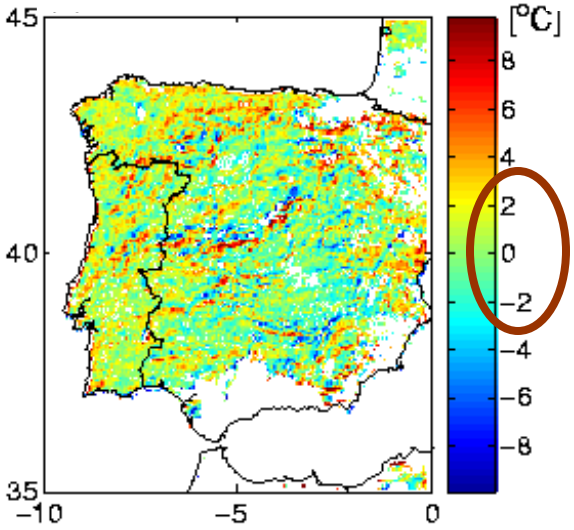
~ 11 UTC

14 Sep 2005

LST _MODIS

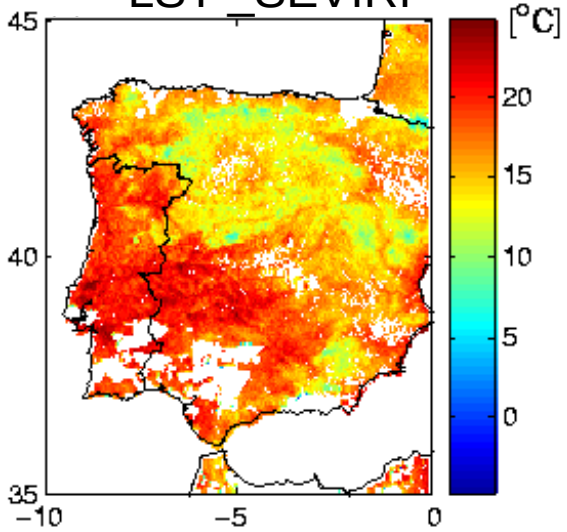


SEVIRI - MODIS



SEVIRI - MODIS Intercomparison

LST _SEVIRI

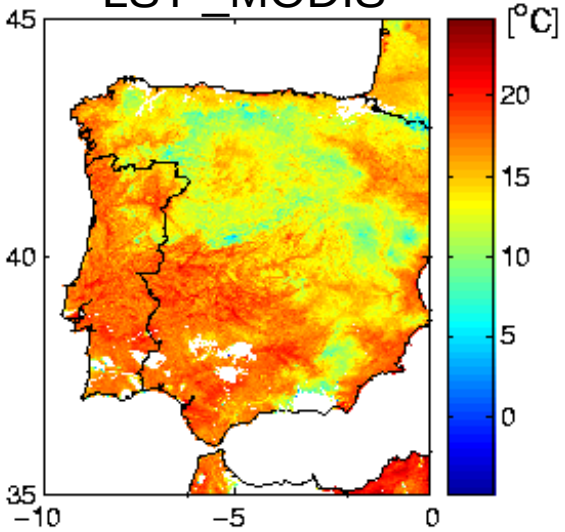


NIGHT-TIME

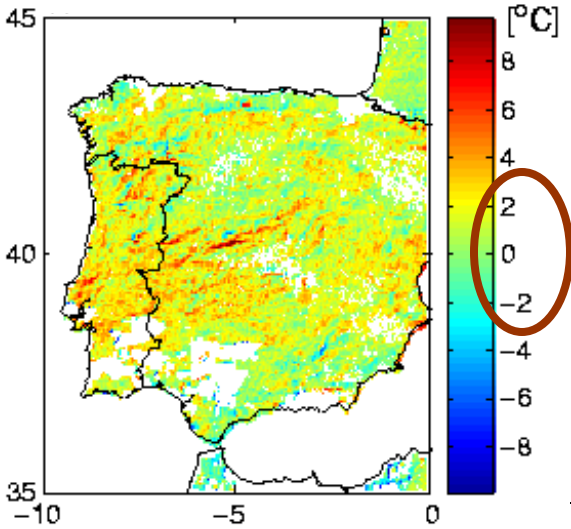
~ 22 UTC

14 Sep 2005

LST _MODIS



SEVIRI - MODIS



SEVIRI - MODIS Intercomparison

LST

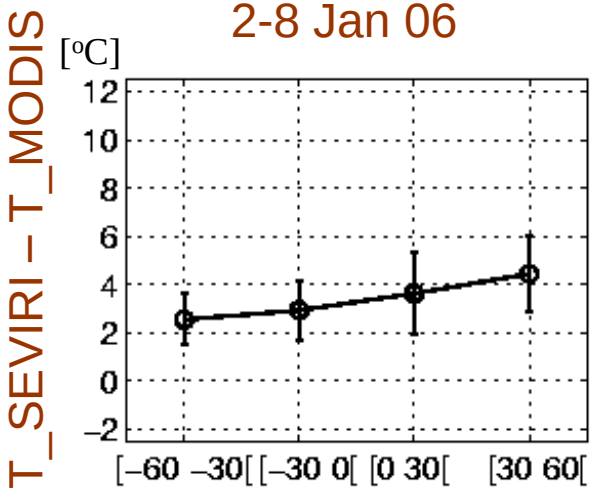
MODIS Zenith Angle:

< 0 view from East

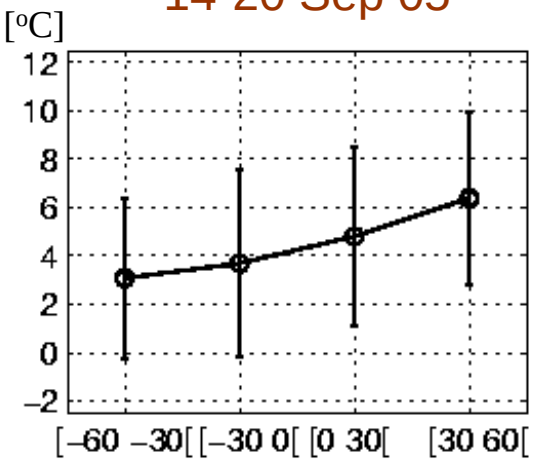
> 0 view from West

Morning MODIS passage:

2-8 Jan 06



14-20 Sep 05



MODIS Zenith Angle

Trigo et al. (2008) in *J. Geophys. Res.*, DOI:10.1029/2008JD010035

SEVIRI - MODIS Intercomparison

LST

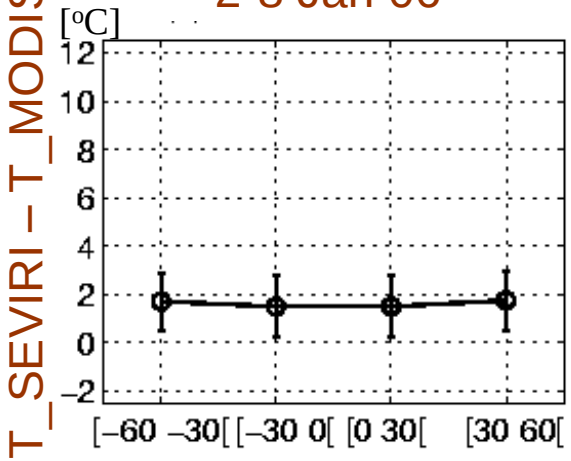
MODIS Zenith Angle:

< 0 view from East

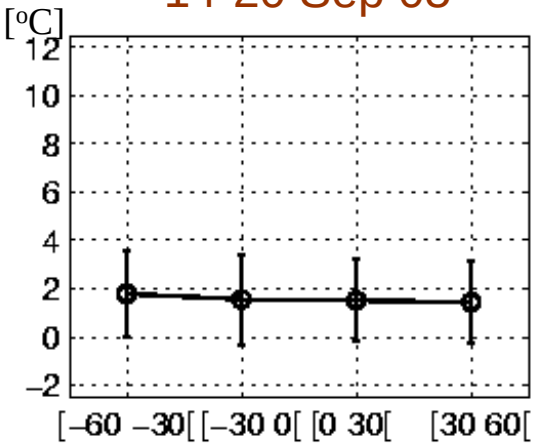
> 0 view from West

Evening MODIS passage:

2-8 Jan 06



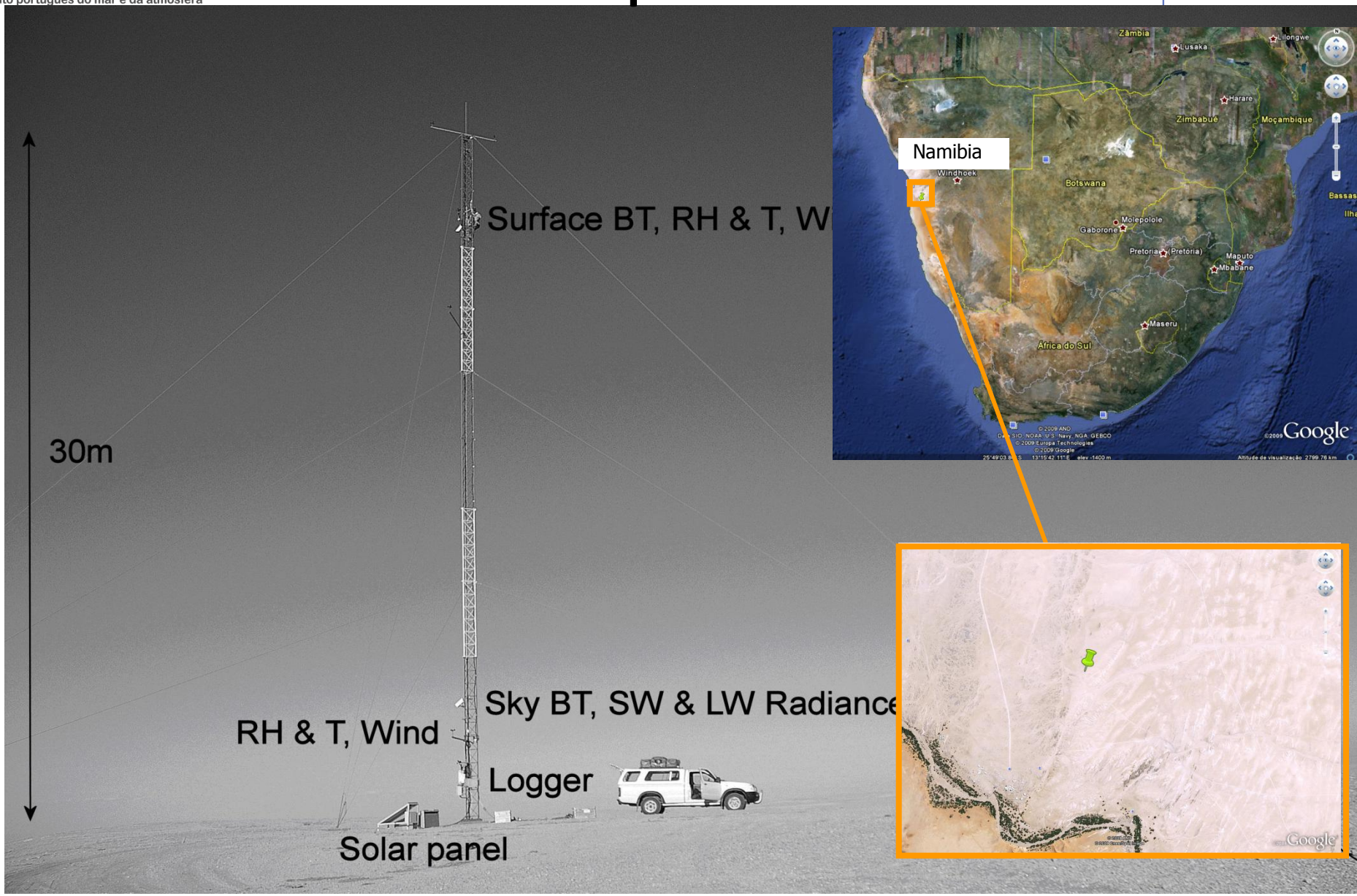
14-20 Sep 05



MODIS Zenith Angle

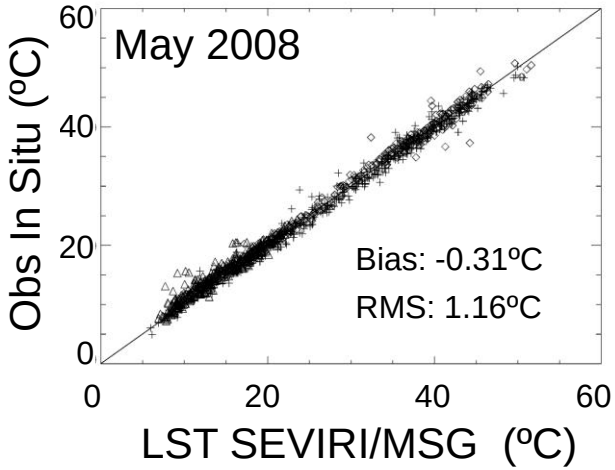
Trigo et al. (2008) in *J. Geophys. Res.*, DOI:10.1029/2008JD010035

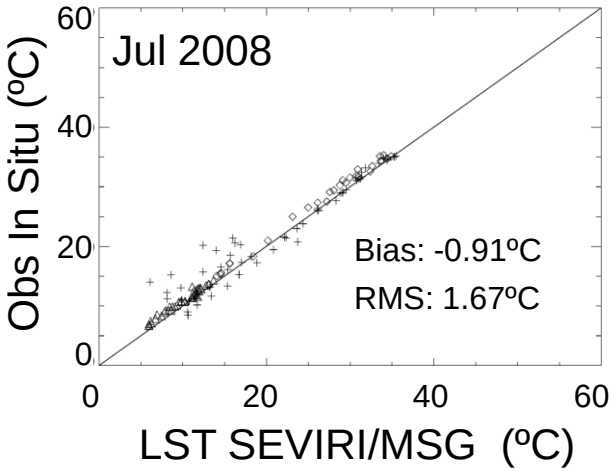
Land Surface Temperature – Validation

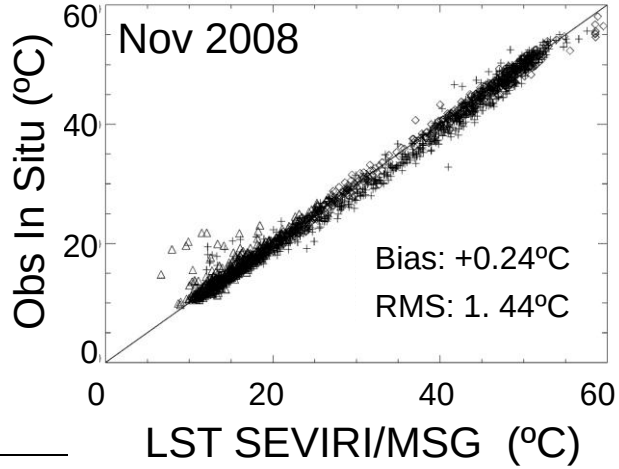


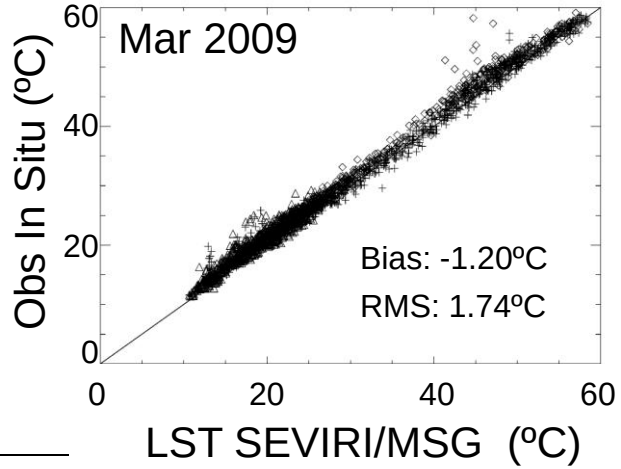
Land Surface Temperature – Validation

T_{sup} MSG/SEVIRI (Land-SAF) versus *in situ* T_{sup}



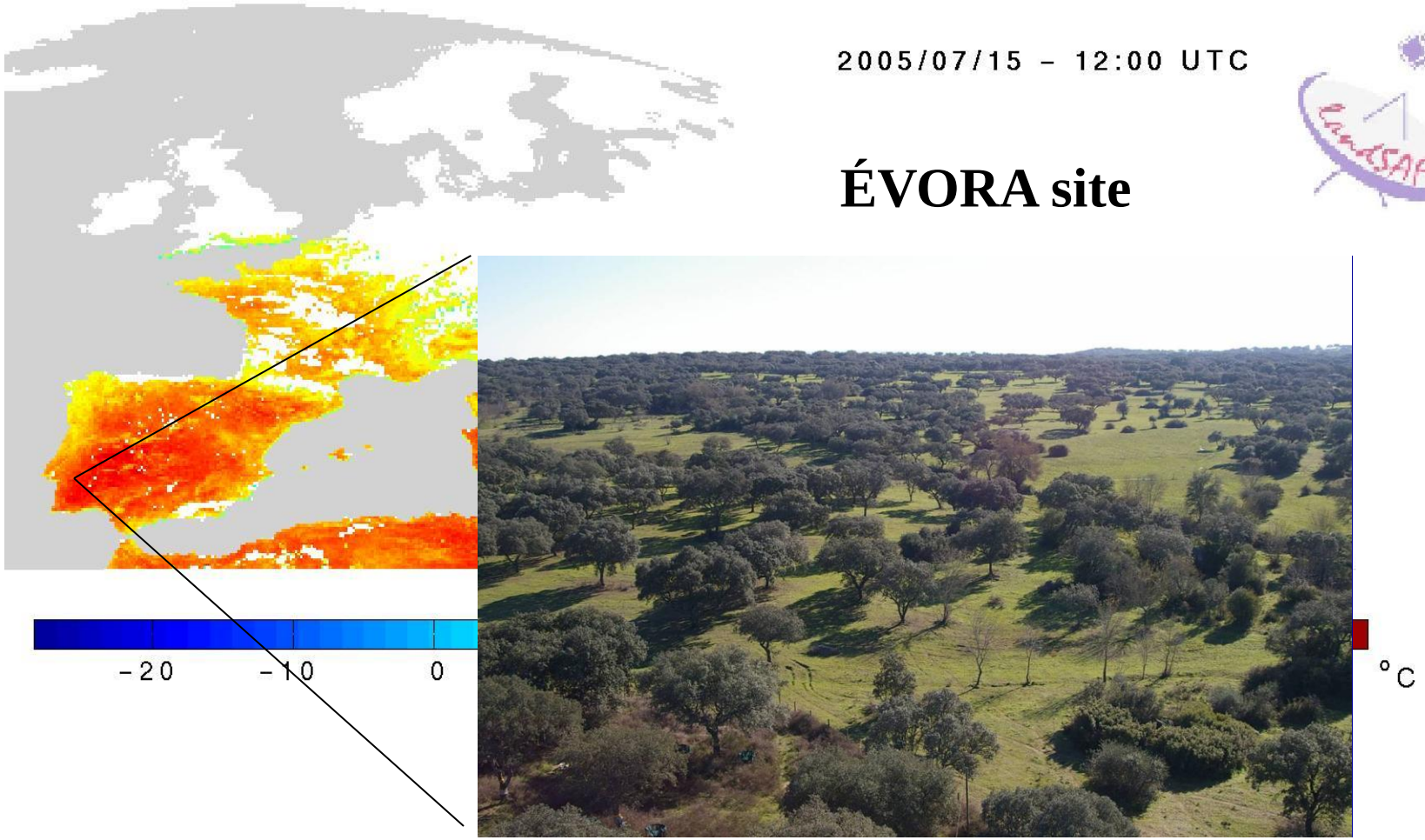






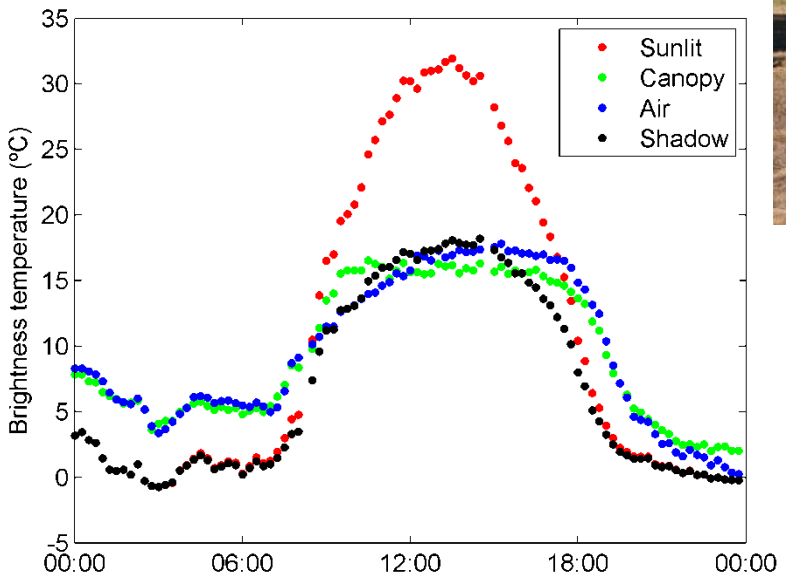
In Situ Observations

LST - permanent site with ground measurements in Southern Portugal



In Situ Observations

LST - Evora

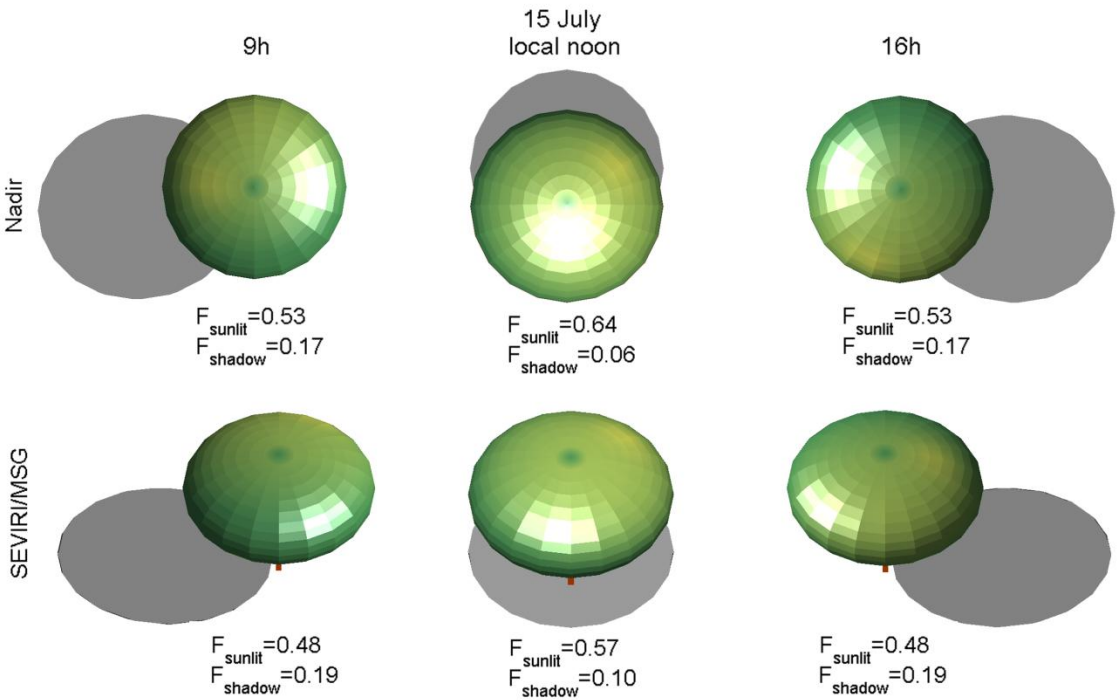


Intercomparison LEO - SEVIRI

Directional Effects on LST

Idealized single tree view at Évora:

Nadir & SEVIRI view at different local times in July



Geometric Model – estimate shapes of objects seen by the sensor

Boolean model – derive overlap probabilities and the actual fraction of each end-member

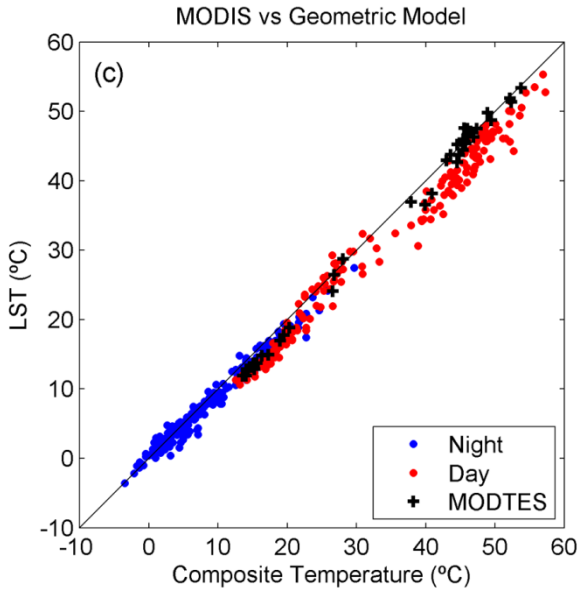
Different Viewing Angles

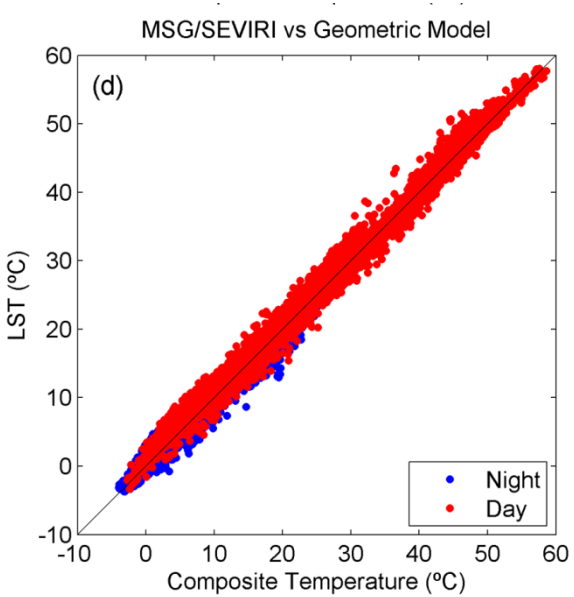
⇓

Different LST

Intercomparison LEO - SEVIRI

LST versus in situ T_{sfc}





Direction effects at Évora

Without Geometric Correction

	Day	Night
MODSW (MOD11)	-5.0/3.1	-0.6/1.2
MODTES (MOD21)	-2.5/1.4	
SEVIRI	-1.2/2.2	-0.1/1.2

With Geometric Correction

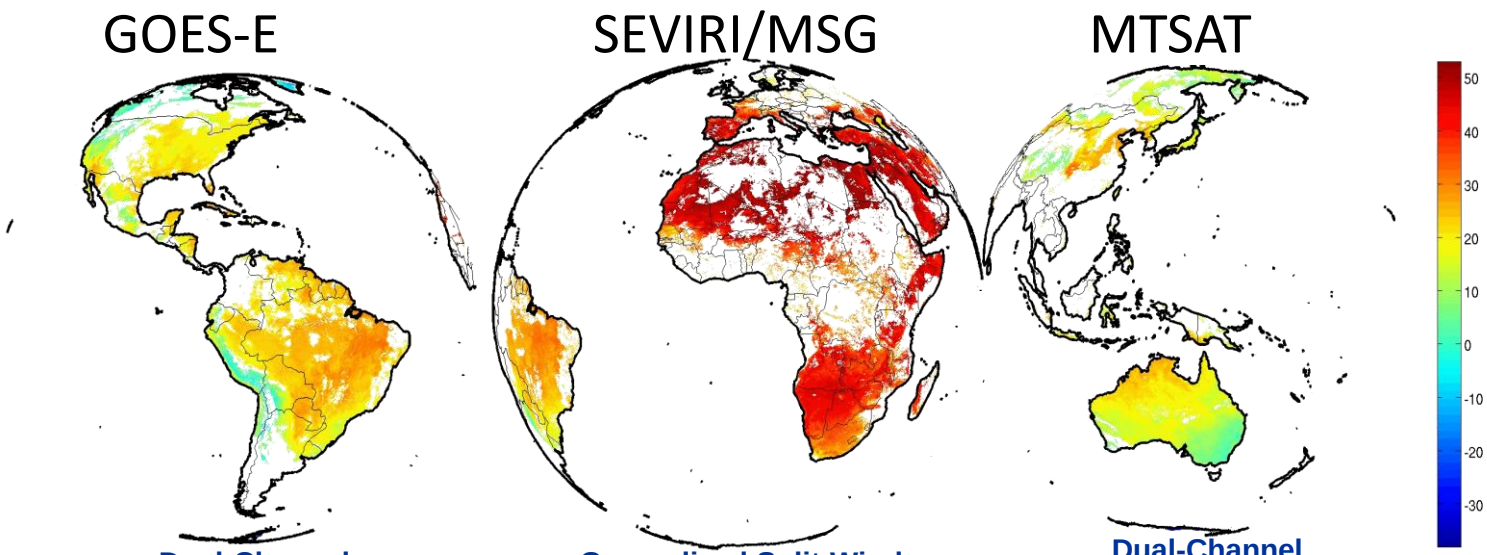
	Day	Night
MODSW (MOD11)	-2.7/1.9	-0.7/1.2
MODTES (MOD21)	-0.8/1.3	
SEVIRI	0.5/1.4	0.1/1.2

(Bias/StDev)

Ermida et al (2014) in *Remote Sens Environ*, DOI: 10.1016/j.rse.2014.03.016

Towards a GEO LST

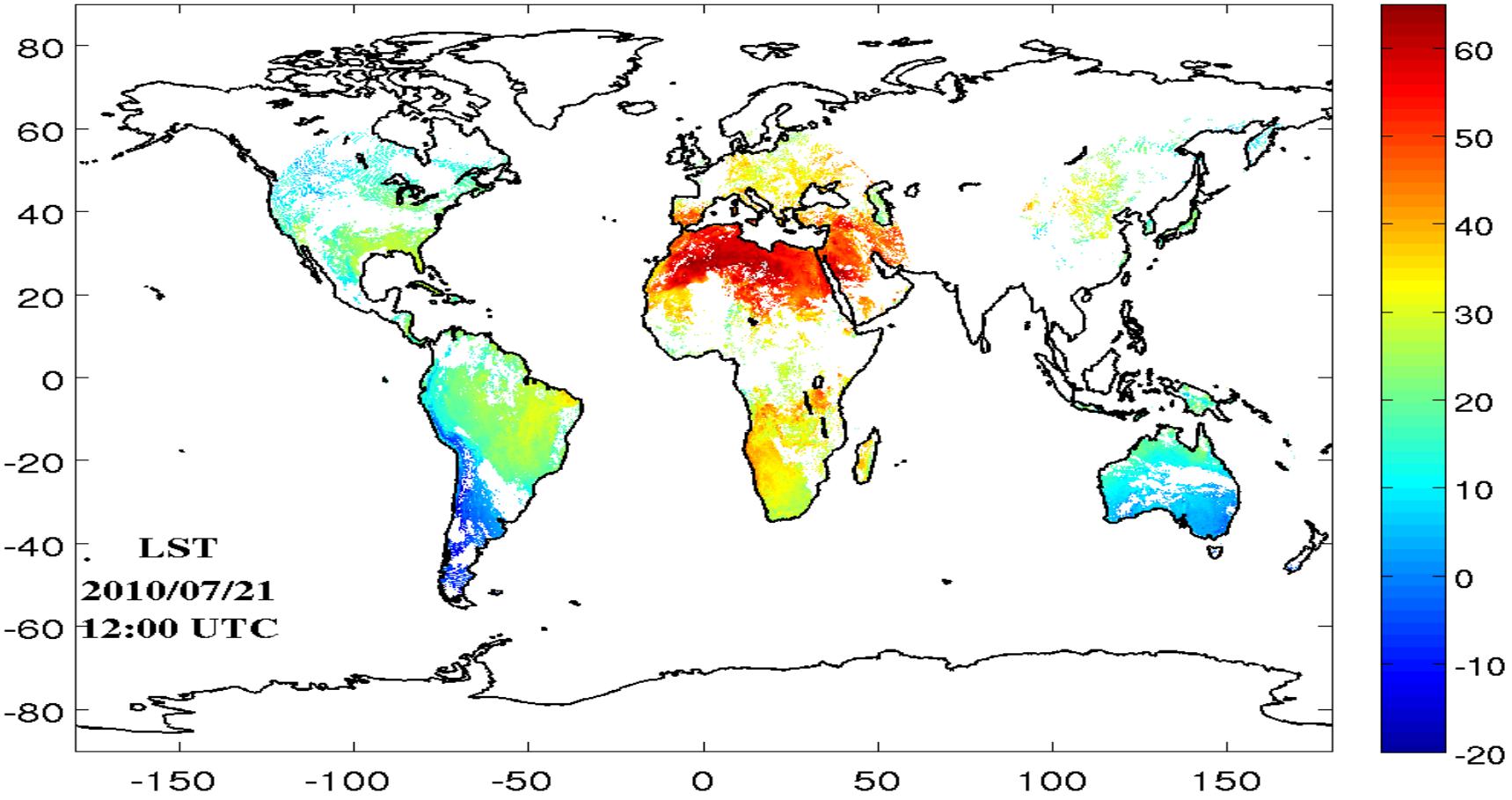
Copernicus – Global Land (NRT)



- LST products are estimated independently for each sensor (pixel-by-pixel; hourly)
- Re-projected to a common (regular 0.05º) grid
- Overlapping areas: LST corresponds to an average of retrieved products; same applies to observation time

Merging LST – Existing Products

Copernicus – Global Land (NRT)

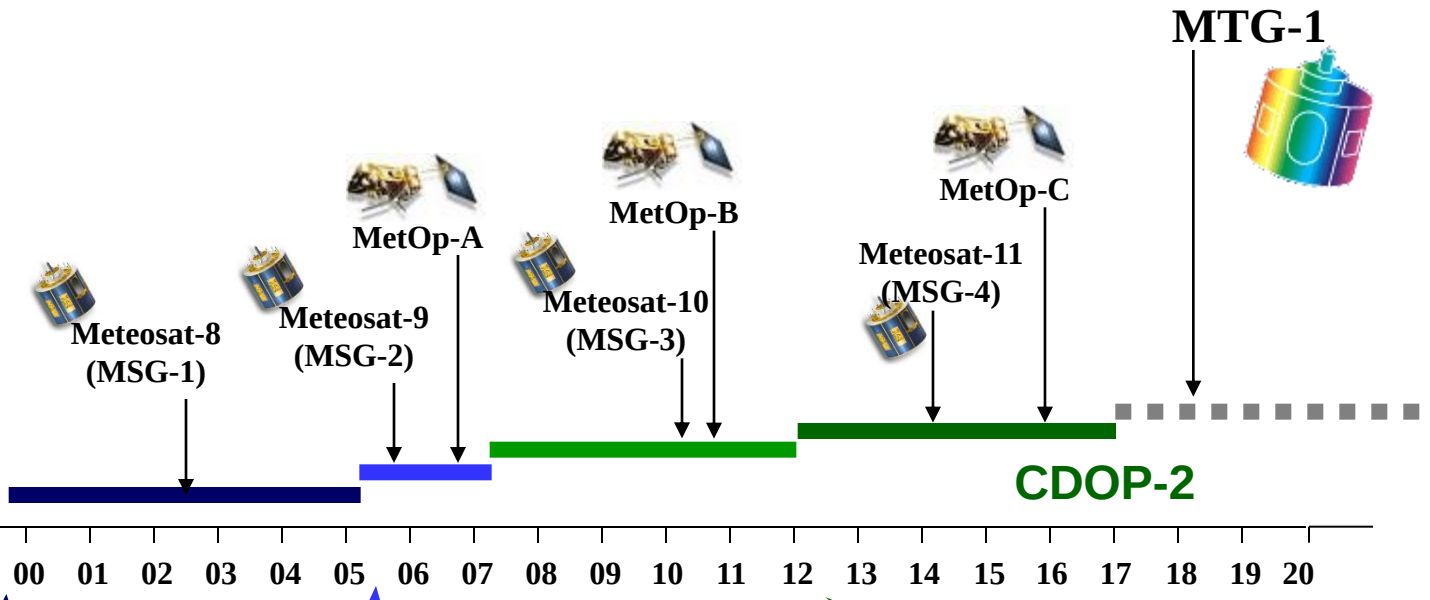


From **2010 onwards**

Outline

- The EUMETSAT LSA SAF
  - Current Products and Services
  - Applications
  - Training & Outreach
- Land Surface Temperature
  - Algorithm
  - Validation
  - On-going work
- NEXT

LSA SAF Chronogram



Development Phase: Sep 99 – Jan 05

Initial Operations Phase: Feb 05 – Feb 07

Continuous Development & Operations Phase - 2: Mar 12 – Feb 17

LSA SAF - NEXT

Near Future (CDOP-2)

- Service Continuity
- Reprocessing Activities (LST, AL, VEGA, FIRE)
- Meteosat First Generation (LST)
- Preparation for new sensors:
  - SLSTR/ Sentinel-3

Preparation for CDOP-3 (2017-2022)

- Next Generation of EUM Satellites
  - Meteosat Third Generation (MTG)
  - EUM Polar System – Second Generation (EPS-SG)

Meteosat Third Generation

Playload will be distributed by 2 satellites

Evolution of SEVIRI – based LSA SAF Products

MTG-I (launch foreseen for 2018)

Flexible Combined Imager (FCI)

16 channels (1km / 2 km; high-resolution 0.5 km)

10 min

Lightning Imager (LI)

Lightning detection (total - cloud-cloud & cloud-ground)

MTG-S (launch foreseen for 2020 - TBC)

Infrared Sounder (IRS)

800 channels LWIR+ 920 channels MWIR – full disk; 4 km

60 min

Ultraviolet, Visible and Near-Infrared Sounding (Sentinel-4)

UV: 305 – 400 nm; VIS: 400 – 500 nm; NIR: 755 – 775 nm

Europe; 60 min

http://landsaf.ipma.pt