Land Surface observations: Requirements for operational NWP in data assimilation and verification

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ECMWF/GLASS Workshop on Land Surface Modelling and Data Assimilation and the implications for predictability, Reading, 9-12 November 2009

Layout

- Overview
- Observations for data assimilation
- Observations for verification
- Land SAF examples: Remote sensing based data for data assimilation and/or verification
- Conclusions

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- **Overview**
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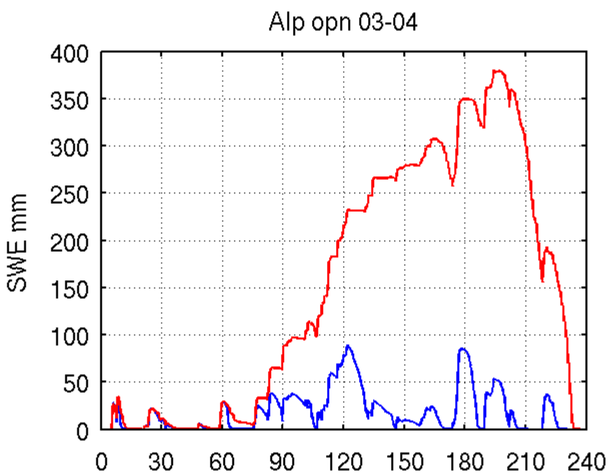
Overview

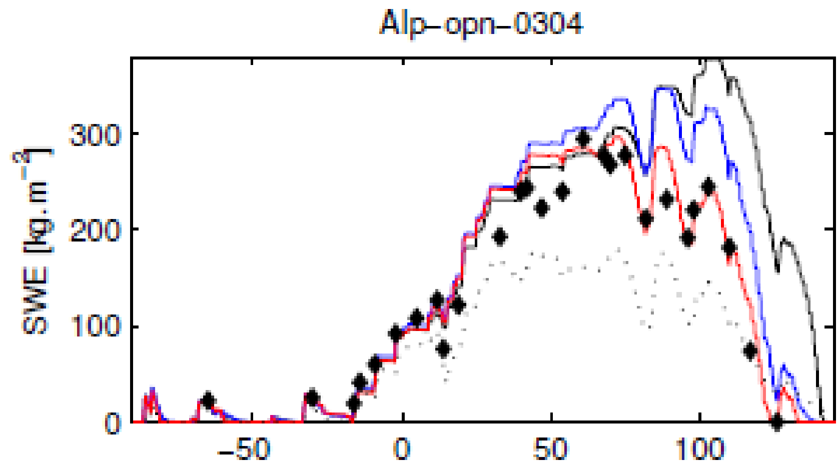
- Potential overlap with other talks, because observations are dealt with in at least:
  - Models and model intercomparison results (Session 1)
    - Observations for model development: Process studies oriented
    - Observations for model validation
    - Observations for “Benchmarking”
  - Data assimilation talks (all of them)
    - They concentrate on data assimilation methods, but also on observations used/needed
  - All talks in session 3

- Scope of the talk: To deal with observations for
  - Data assimilation
  - Verification & monitoring
    - Verification (& monitoring) is a *regular* check of model results against observations in order to have early warning of drifts and build a *representative* sample of model errors
  - *Timeliness* is essential

Observations for model development (1/2)

SWE in Alptal: Open site, 2003-04





TESSEL (BLUE)
HTESSEL (new roughness) (RED)

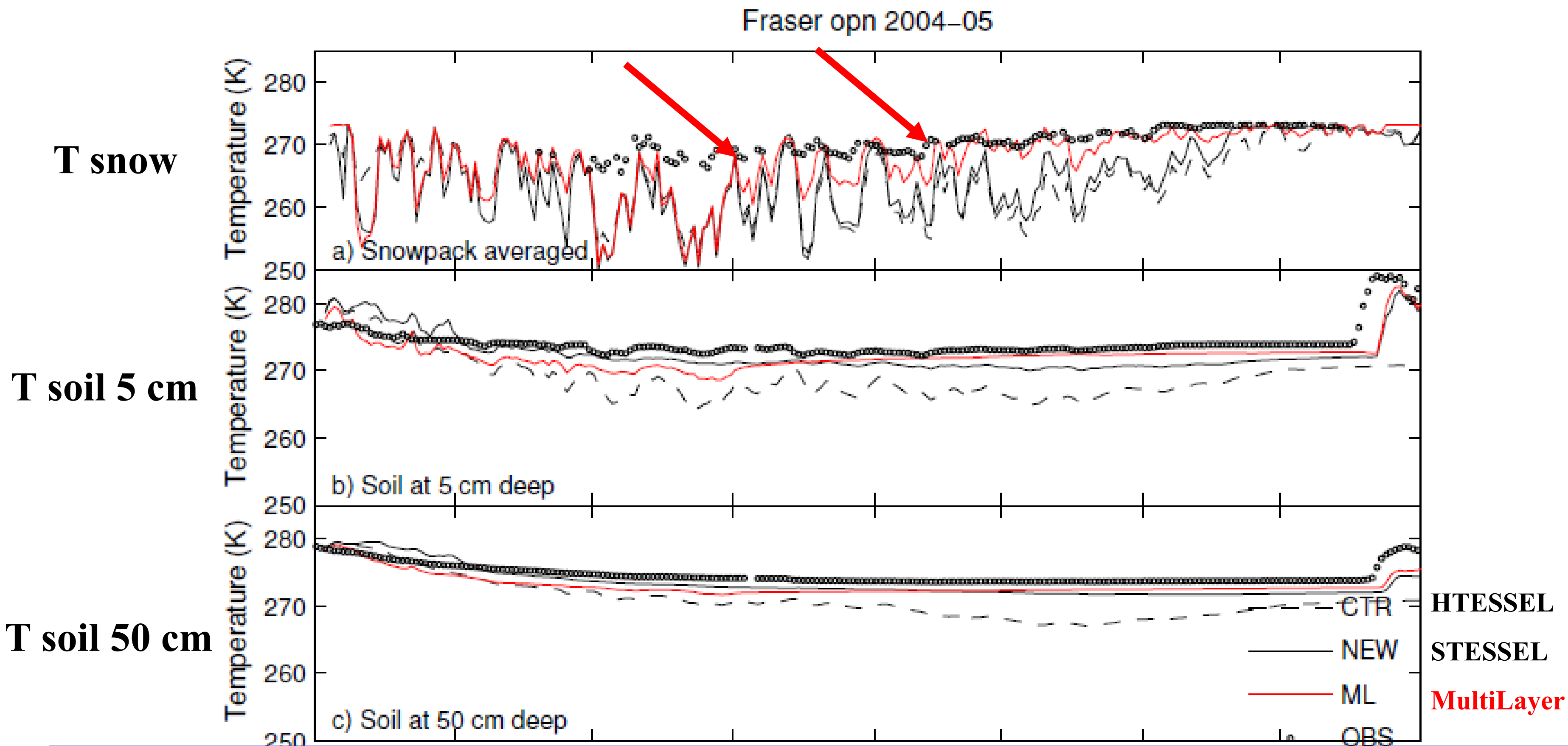
HTESSEL (black)
HTESSEL-new snow(BLUE)
HTESSEL-snow multi-layer (RED)
• Observations
..... Model Median

•TESSEL to HTESSEL reduces the coupling atmosphere-snow (z0) with much less evaporation

•HTESSEL to STESSEL new (lower) albedo in melting conditions favours earlier melting

Observations for model development (2/2)

Snow and soil Temperature in Fraser: Open site



- HTESSEL (CTR) to NEW snow decreases the density, favouring higher soil insulation and less soil cooling
- Multilayer snow model (ML) improves snow temperature and soil T at 5 cm

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General considerations: Seasonal surface budgets

- **Surface data assimilation estimates state variables combining (a) imperfect models forced by imperfect atmospheric forcing with (b) inaccurate and/or proxy data**
- **General evolution equation for state variable X**

  $dX/dt = \Sigma_i F_i$ **F_i are fluxes**

  X = Tsoil , Snow_mass, soil_water, biomass

- **The seasonal variation of X is**

  $dX/dt = 0$ **Tsoil**

  $dX/dt \sim 1/3\ F_i$ **Soil water**

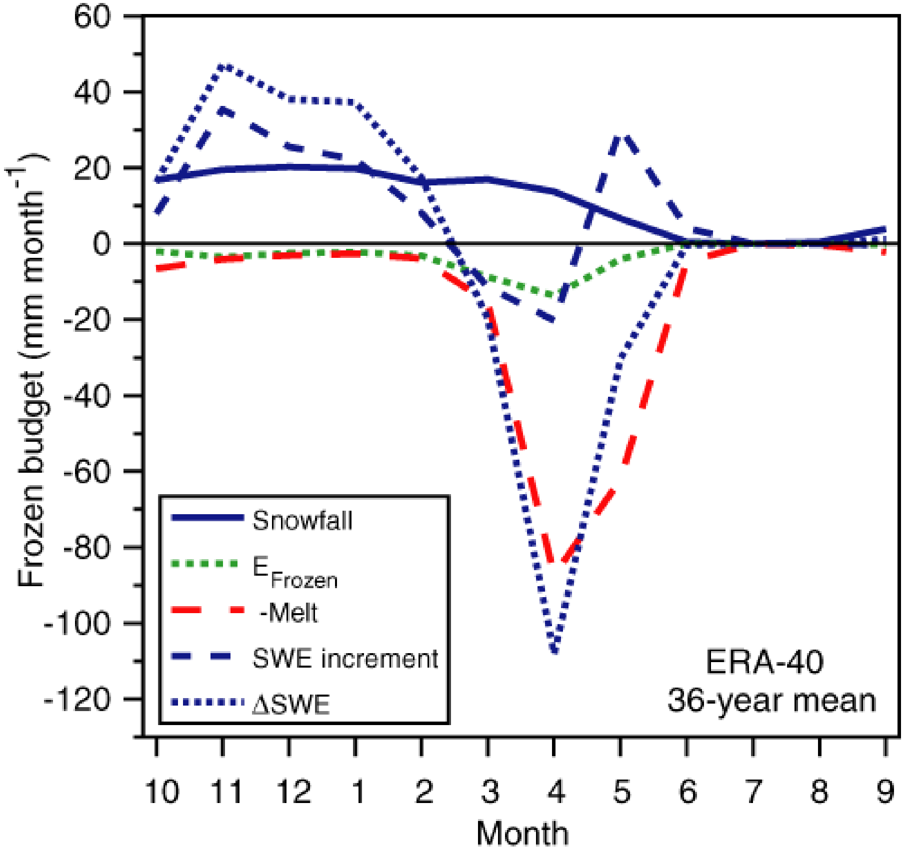
  $dX/dt \sim F_i$ **Snow mass**

  $dX/dt \sim ??$ **Biomass**

- **For soil water and snow mass data assimilation increments are commensurate with the seasonal evolution, creating closure problems in the surface budgets**

Mackenzie river basin era40: Surface snow budget

$$S^a_{n+1} = S^a_n + \sum [F - E_s - M + SWE_{inc}]$$



Surface analysis increments are of the same order of the seasonal evolution of the snow mass budget

Betts et al, 2003: JHM

Synergy of observations (soil moisture)

- **Screen level temperature and humidity** are indirectly linked to soil moisture through evaporative cooling.
- **Microwave brightness temperature** contains more direct information o[illegible] near surface soil moisture and is less dependent on atmospheric [illegible]s.
  - Penetration depth of µw Tb depends on:
    - Soil texture
    - Soil temperature profile
    - Vegetation fraction
    - Vegetation water content
    - Surface roughness
    - LSMEM (Land S[illegible]owave Emissivity Model) for model equivalent of Tb
- **Rate of chang[illegible]al infrared brightness temperature** contains informa[illegible]oil moisture, but
  - [illegible]ky data only;
  - Model Tskin is very sensitive to aerodynamical resistance (surface roughness)
- **Vegetation state (LAI, fAPAR)** contains information on soil moisture, but
  - Clear sky data only;
  - Saturation of LAI and fAPAR at high values

Synergy of observations is essential to avoid over-fitting

Root zone soil moisture: observables and caveats

BL T/RH

- Fair weather spring/summer conditions
- Low wind speed

Vegetation state (LAI, fAPAR)

- Clear-sky data
- Saturation of W=f(LAI)

Root zone Soil moisture

μw Tb
L- and C- band
(d=1-5 cm)

- Low water on vegetation
- C-band limited to non-forest areas

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Observations for verification

- **Verification (& monitoring) is a *regular* check of model results against observations in order to have early warning of drifts and build a *representative* sample of model errors**
- **Order out of caos**
  - **How to extract a model relevant message from a large set of model vs. observations**
    - **Climate/ecosystem/season conditional sampling**
    - **Process oriented thinking (e.g., new snow TESSEL model development)**
- **The importance of a large sample for robust results**
  - **ERA-I**
- **Timeliness**
  - **Any set of observations needs to be available to NWP centres within a few months**

Some examples

- **In-situ data**
  - Surface radiative fluxes
    - From BSRN
    - From remote sensing
  - Fluxnet results
  - COSMOS (cosmic rays for soil moisture)
  - Regional networks in support of SMOS cal/val
  - US SNOWTEL
- **Remote sensing**
  - LST (or radiances from IR (10.9 and 12.4 channels) from geostationary
  - Vegetation results
  - MODIS snow cover fraction
  - MODIS albedo
  - Remote sensing estimates of carbon assimilation (NPP, NEE) can be very useful when NWP models become fully "green"
  - We desperately need a reliable dataset of daily precipitation over land

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LandSAF in a nutshell

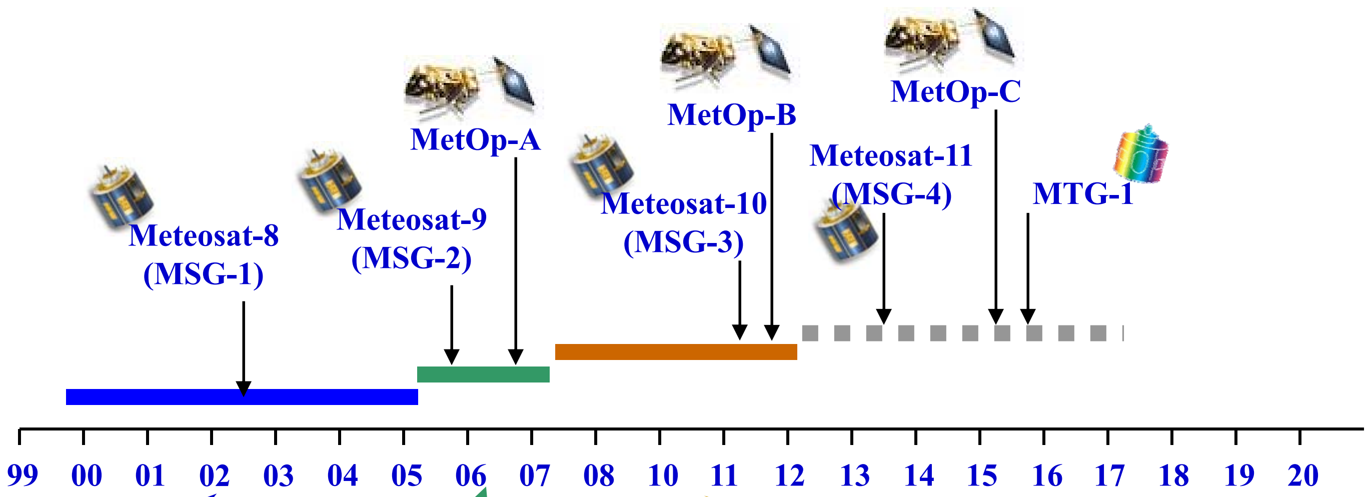
- EUMETSAT Satellite Applications Facility dedicated to algorithm development, validation and operational production of land surface related products (primarily) based on European meteorological satellites (MSG and METOP)
  - 7 Institutes in 6 countries
  - Continuous Development Operational Phase I (2007-2012)
- Real time operations (i.e., some products are available every 15 min, ~2-3 hours after observed)
- An efficient and modular real time operational system, to which new functionalities can be added on demand
- Reviewed (~annually) by technical and scientific review panels
- Most products can be used for verification & monitoring of NWP
- A few products can be used for surface data assimilation

The LandSAF Consortium

- Instituto de Meteorologia (IM), Portugal
- Meteo-France (MF), France
- Royal Meteorological Institute (RMI), Belgium
- Finnish Meteorological Institute (FMI), Finland
- IMK, University of Karlsruhe
- IDL, University of Lisbon
- UV, University of Valencia

- Organisation principles
  - Algorithms developped at one of the participating Institutes
  - Algorithms handed over to IM for integration and production

LandSAF Chronogram

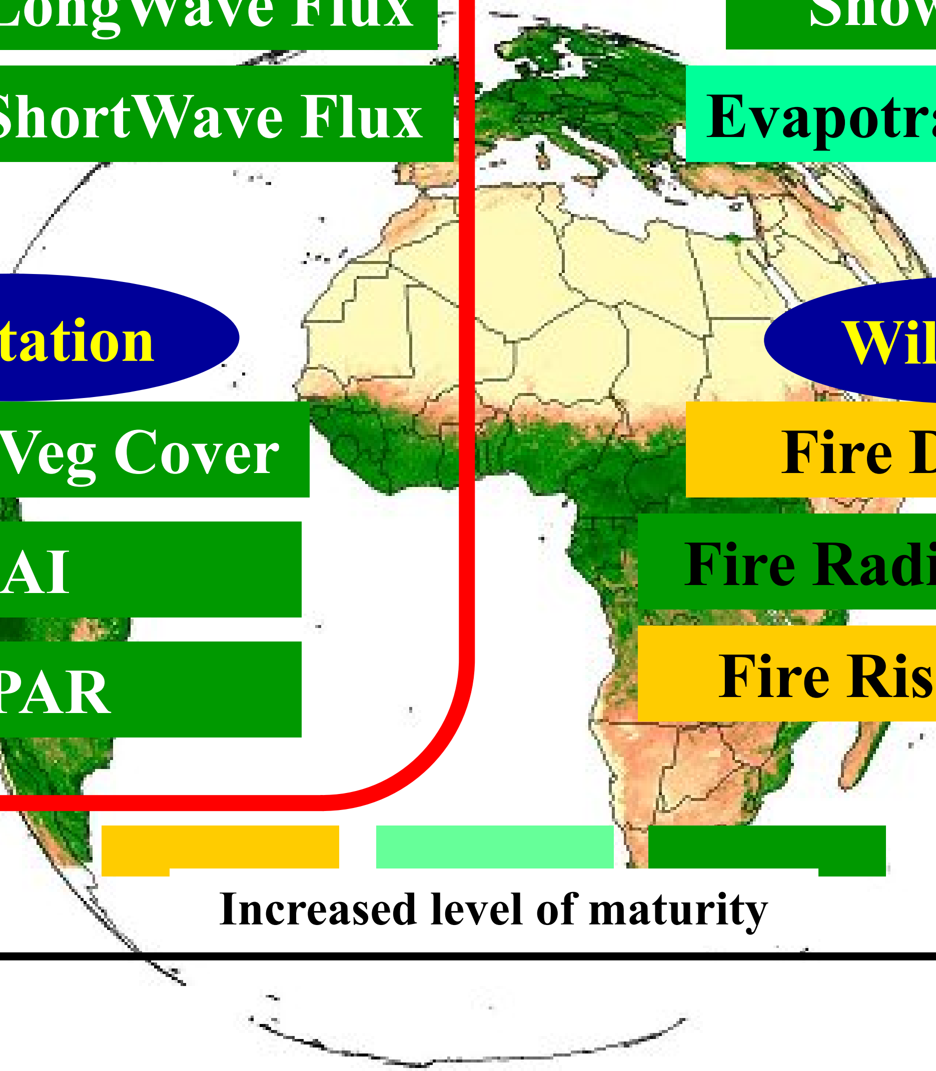


Development Phase: Sep 1999

Initial Operations Phase: Feb 2005

Continuous Development & Operations Phase I: Mar 2007

Land SAF MSG products



Surface Radiation

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

Surface Water Balance

- Snow Cover
- Evapotranspiration

Vegetation

- Fraction Veg Cover
- LAI
- fAPAR

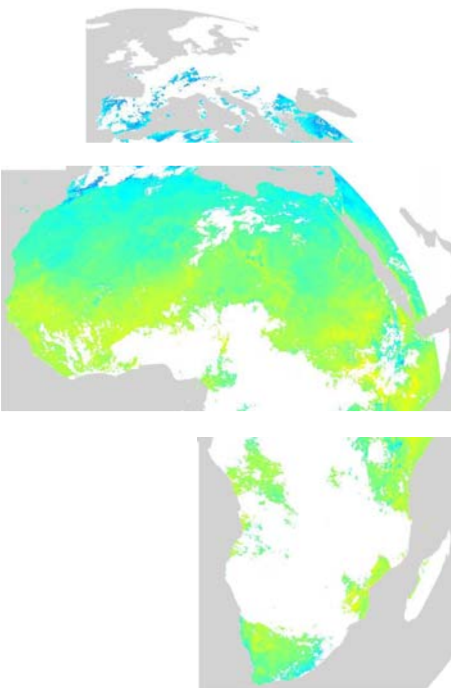
Wild fires

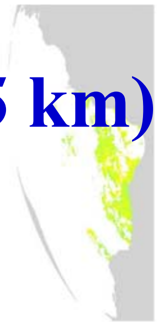
- Fire Detection
- Fire Radiative Power
- Fire Risk (Europe)

Increased level of maturity →

Product characteristics

- **All products have a <u>quality flag (or an error bar)</u> field associated**
- **All products have a Product User Manual and a comprehensive Validation Report**
- **4 production areas for MSG**
  - **Europe**
  - **N. Africa**
  - **S. Africa**
  - **S. America**
- **SEVIRI resolution (3x3 to 3x5 km)**
- **Variable time resolution**
  - **15 min to 10 days**
- **EPS products generation started**

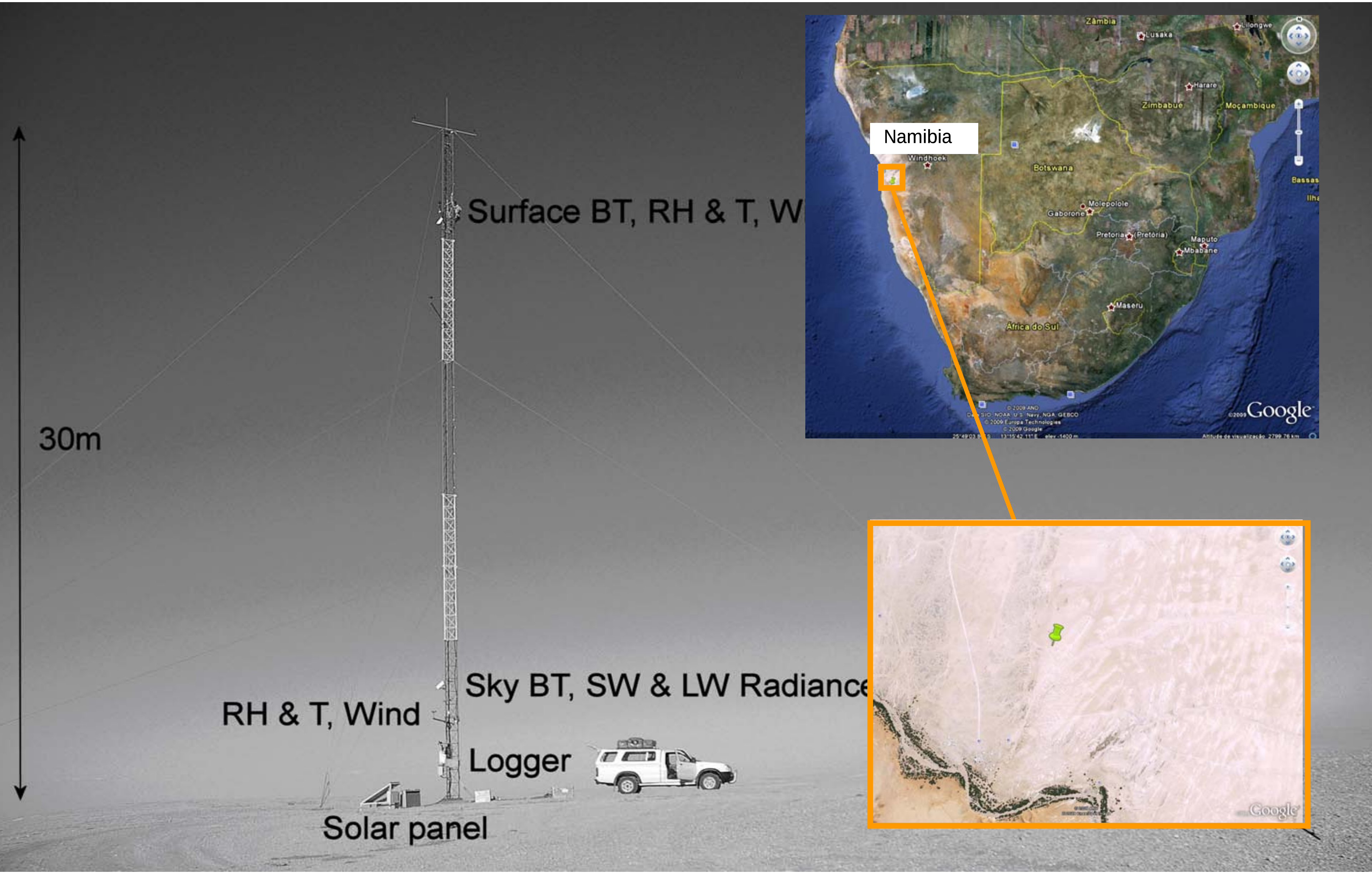




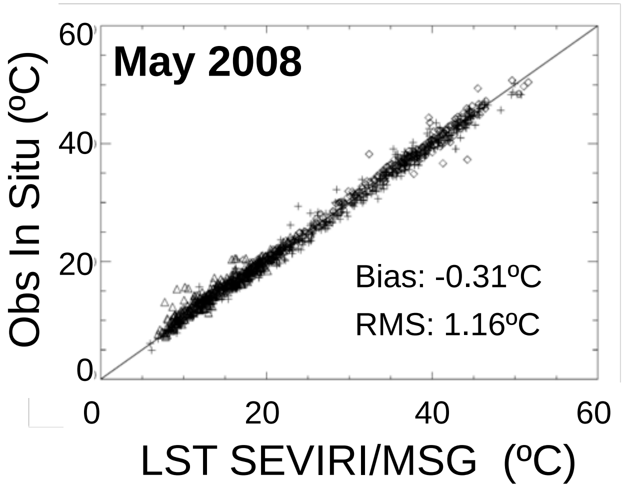
Land Surface Temperature

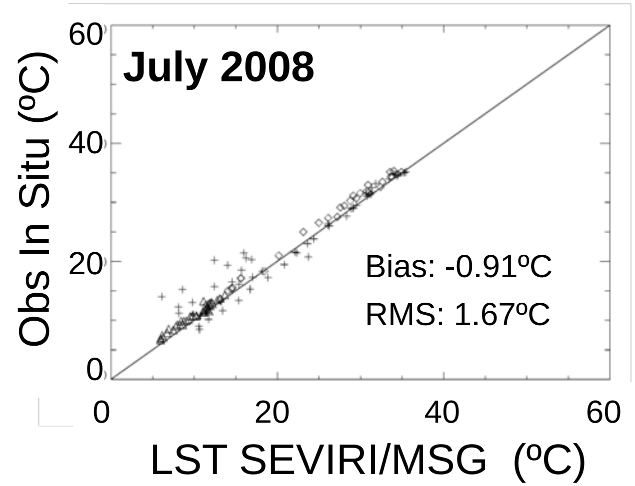
- **Estimates of LST are regularly validated by comparison with**
  - **In-situ radiometer observations**
  - **Comparison with LST from other sources (e.g., polar orbiters)**
- **In-situ observations**
  - **Africa**
    - **Gobabeb, Namibia**
    - **AMMA area**
  - **Europe**
    - **Évora, Portugal**
    - **BSRN**

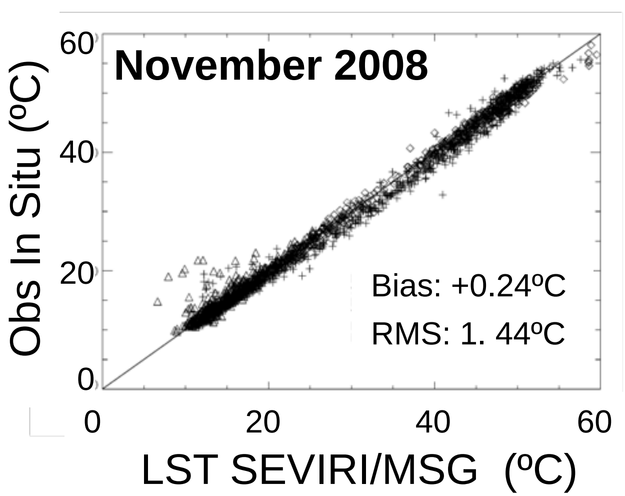
LST: In situ obs

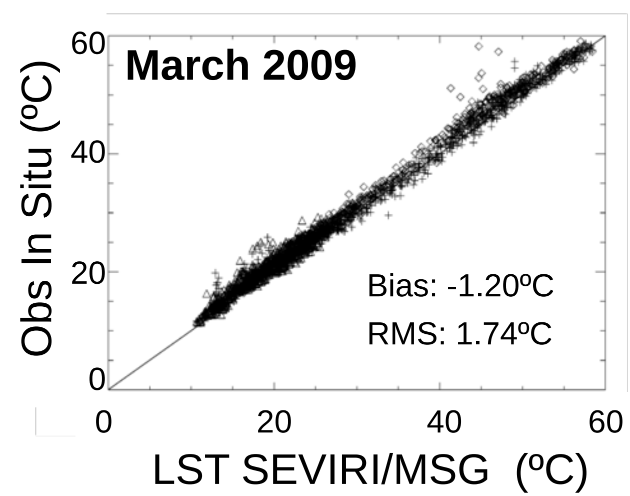


LST validation: LSA SAF vs. in situ



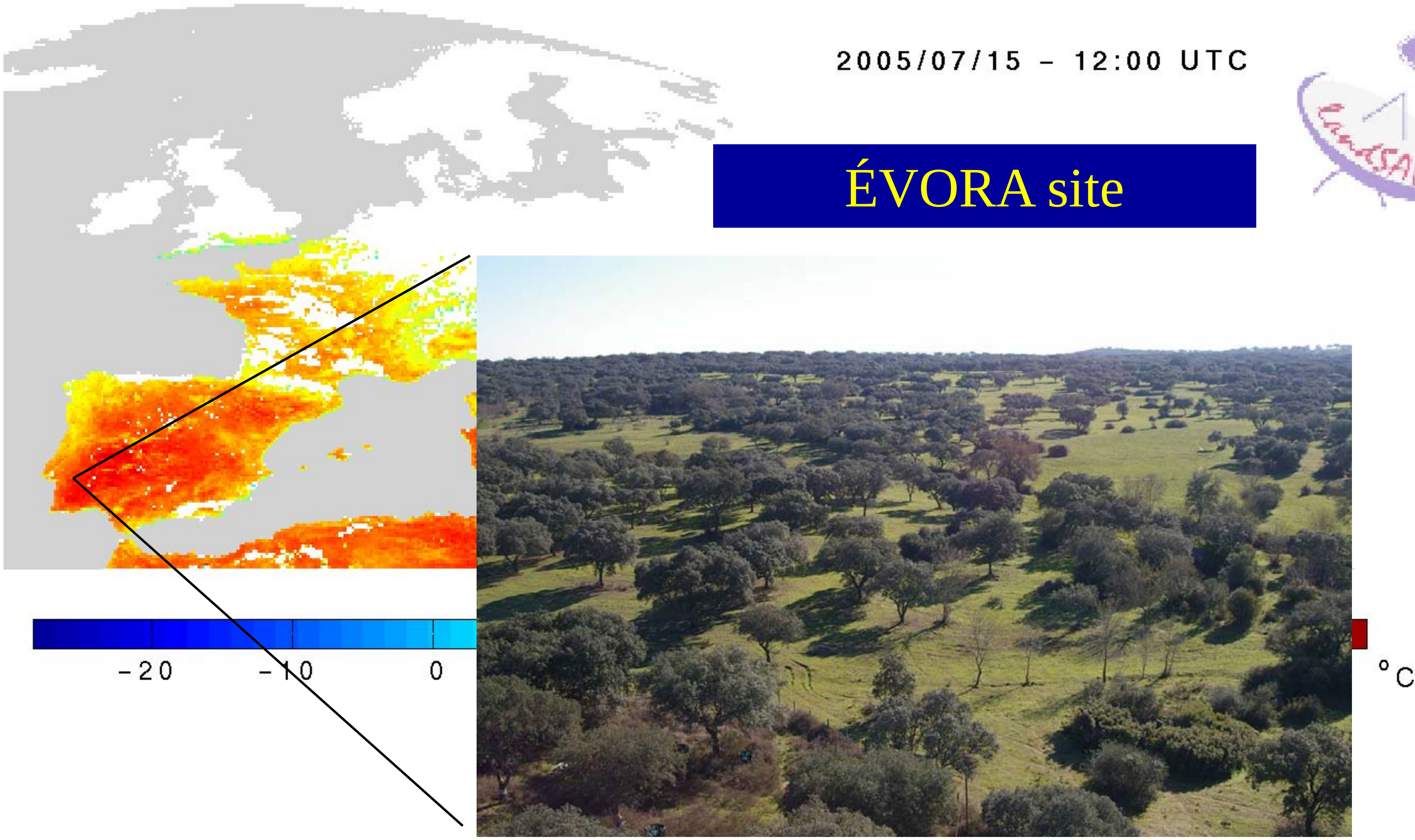






In-situ observations

LST - no permanent site with ground measurements within MSG disk before ....



LSA SAF
Land Surface Analysis

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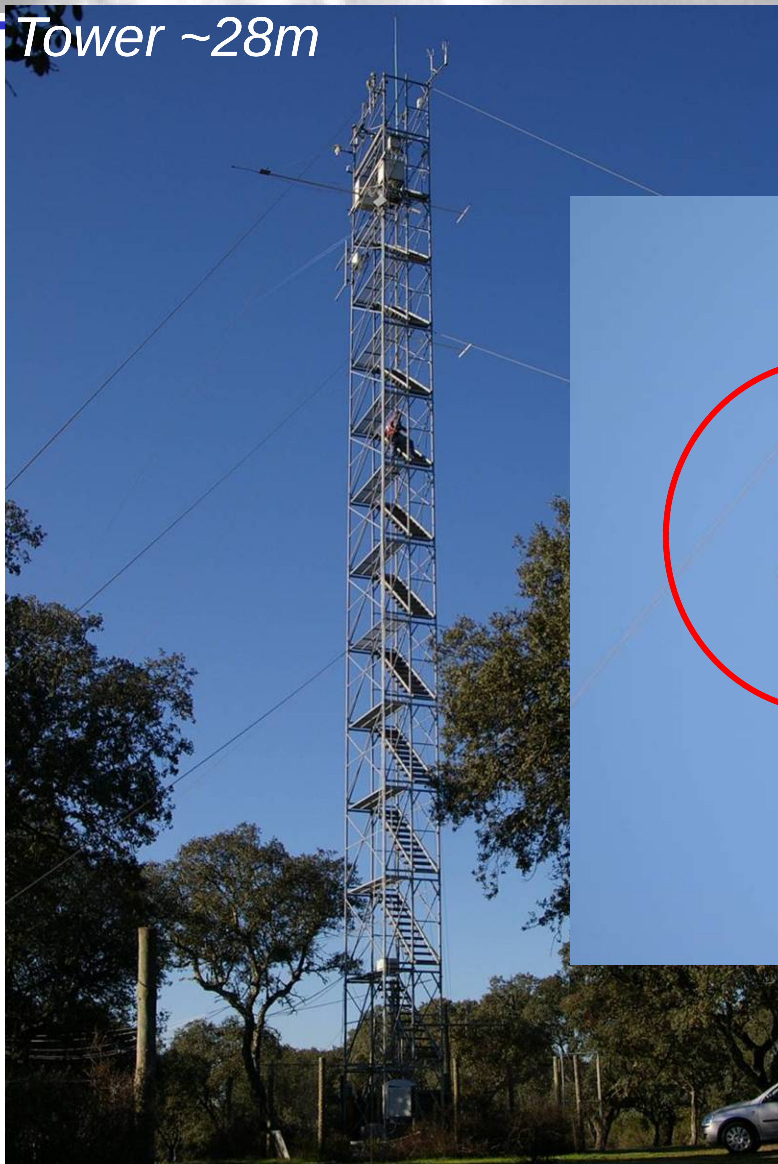
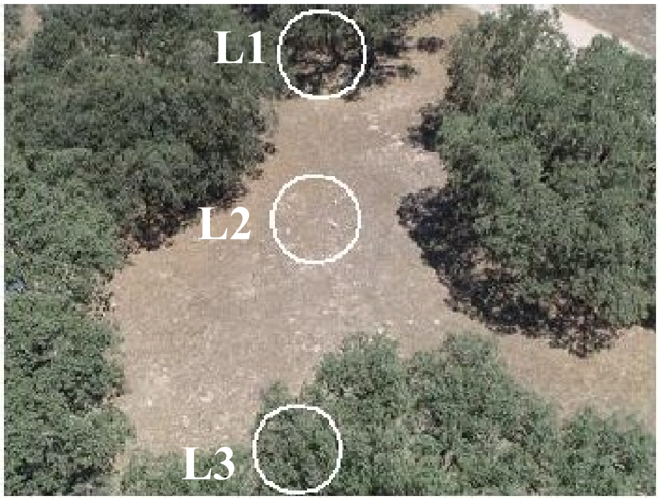
Évora



KT15 (1 FOV at ground Ø 14m

Rotating Radiometer
(3 FOV at ground Ø 3m)

LST: Weighted averaged of 3 radiometers



(L1, L2, L3) average

$$L_{RR} = \varepsilon_{RR\_sfc} L_{RR}(T_{sfc}) + (1 - \varepsilon_{RR\_sfc}) L^{\downarrow}_{RR\_atm}$$

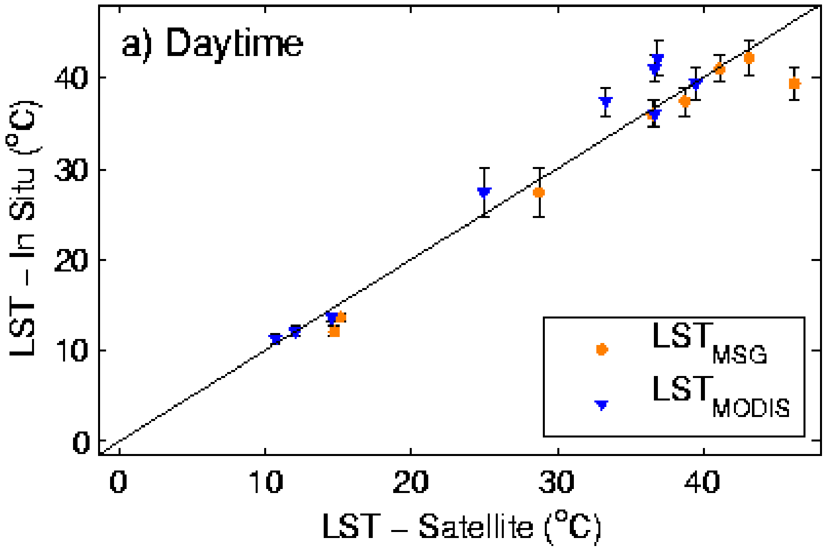
scene emissivity

LST_InSitu

downward radiation

$$\delta(LST_{InSitu}) = \left[(\delta LST_{\varepsilon})^2 + (\delta LST_{InSituVarT})^2 + (\delta LST_{InSituVarSp})^2 + (\delta RotRad)^2 \right]^{1/2}$$

Évora: SEVIRI & MODIS vs. OBS

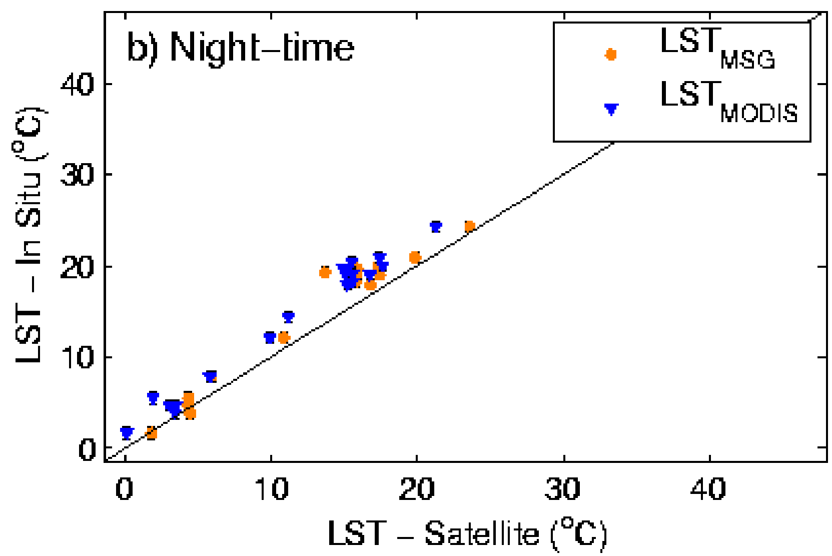


Daytime

(ºC)	BIAS	RMSE
SEVIRI	+1.9	2.2
MODIS	-1.8	2.6

Night-time

(ºC)	BIAS	RMSE
SEVIRI	-1.7	2.1
MODIS	-2.6	2.7



Estimating LST uncertainty on an operational basis

LSA SAF Land Surface Analysis

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LST Errors

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

Input errors

↓

Sensor noise; emissivity

Algorithm uncertainty

↓

Retrieval conditions

Model parameters/ Implicit input variables

↓

TCWV (ECMWF); view angle

LSA SAF
Land Surface Analysis

LST: Value & uncertainty estimate

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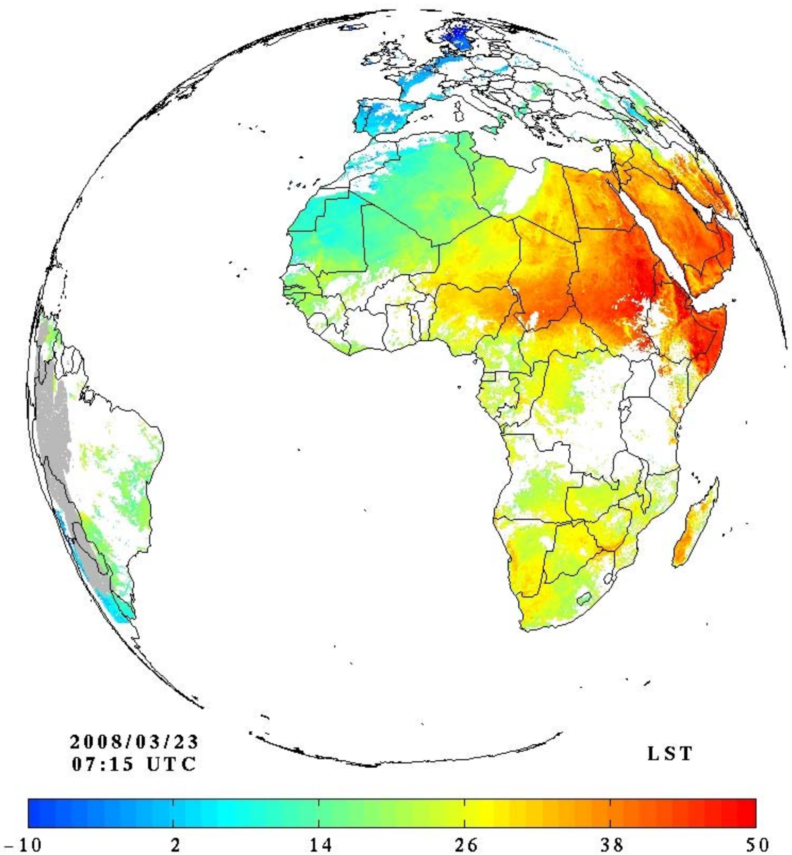
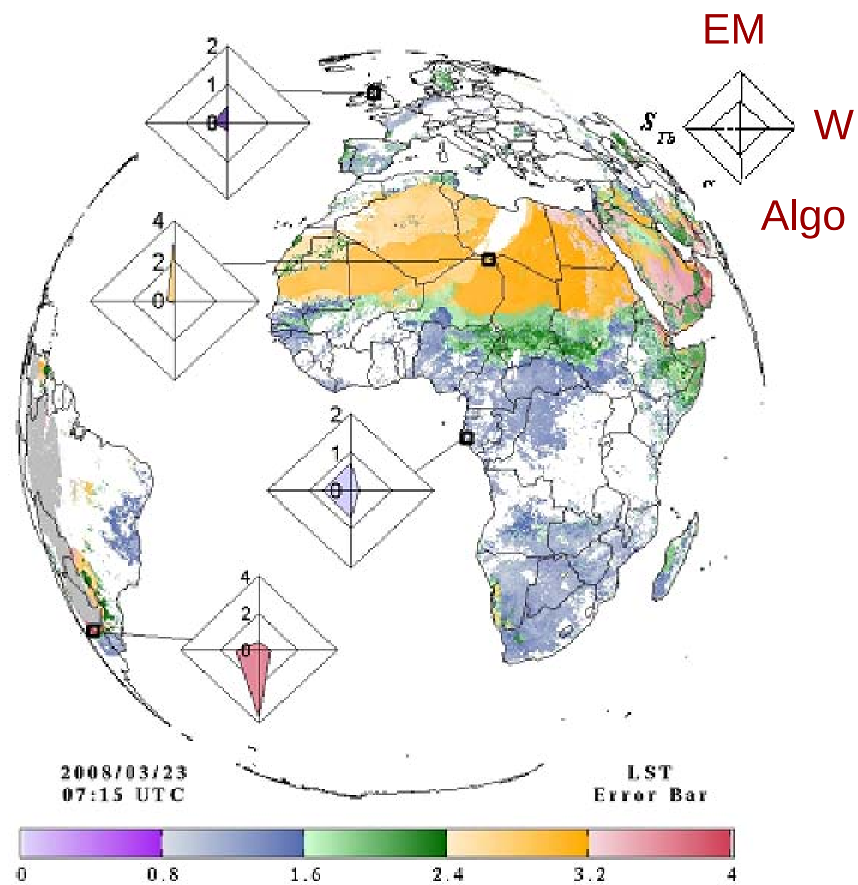
LST



LST Error Bars



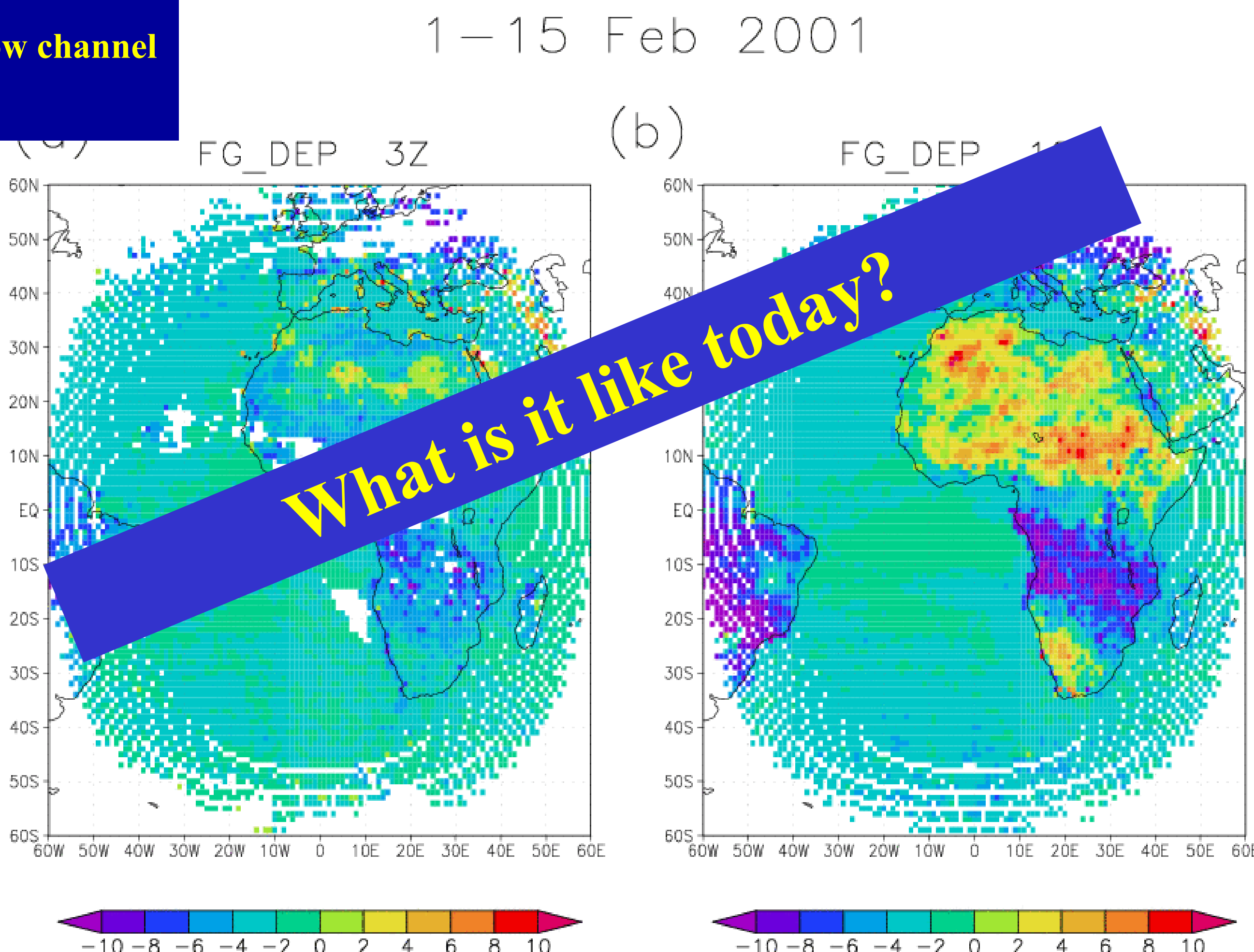
7 years ago ...

- **Model skin temperatures have large errors over land, underestimating the diurnal cycle, in arid/semi-arid areas**

METEOSAT

Clear sky Tb window channel

OBS - model



What is it like today?

Trigo and Viterbo, 2002

LST: Conclusions

- **Uncertainty estimate is essential for many applications**
- **LSA SAF comes with an associated δLST**
- **The error is larger in areas**
  - **Dry areas, with large uncertainty on surface emissivity**
  - **Moist atmospheres and high viewing angles (mask out of values where δLST > 4 K**
- **This is complemented by validation from independent sources and in-situ validation**
- **We came a long way since first evaluation 7 years ago, at least on the remote sensing side**
  - **But we do not know where we are on the model side**
- **LST from the LSA SAF can be used for**
  - **Model verification & monitoring**
  - **Data assimilation**

Validation of DSLF (Downward Surface Longwave Flux) against in-situ data

Different LSA SAF algorithms & ECMWF

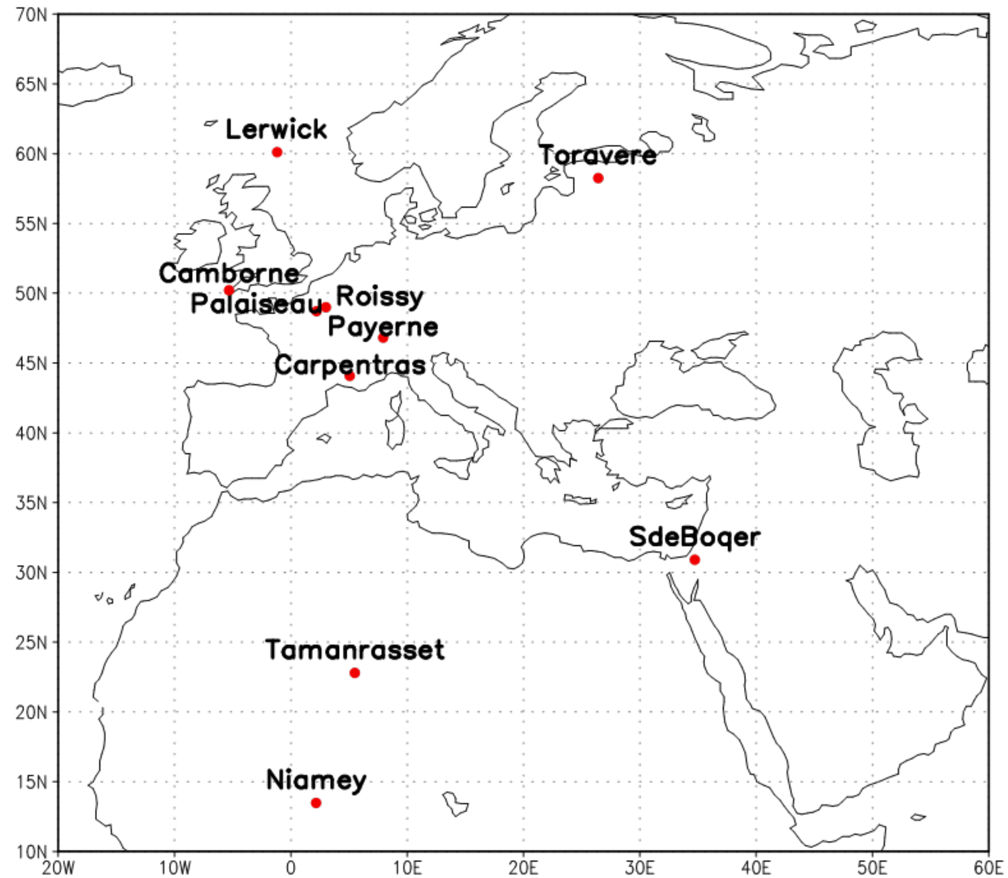
versus

In Situ Observations
(BSRN)

3-hourly averages

Data collected between

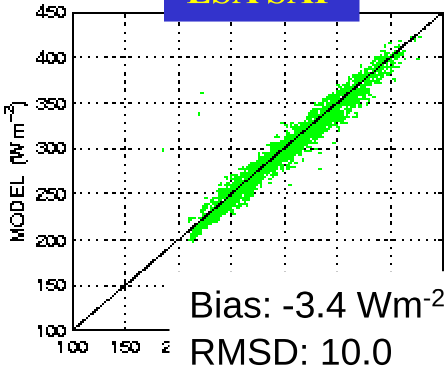
2005 and 2007



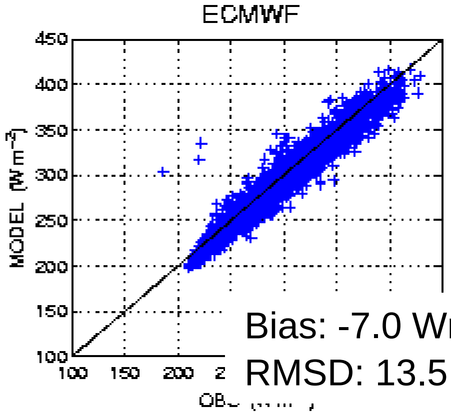
DSLF: Carpentras (France), mid-latitudes

Clear Sky

LSA SAF



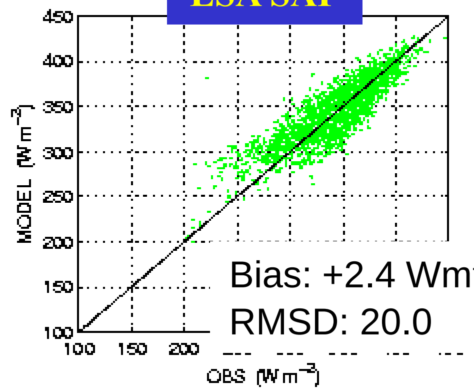
Bias: -3.4 Wm^{-2}
RMSD: 10.0



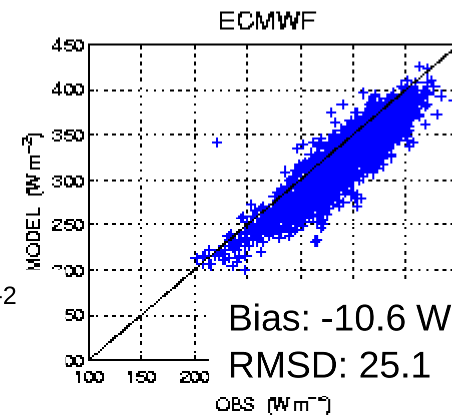
Bias: -7.0 Wm^{-2}
RMSD: 13.5

Cloudy Sky

LSA SAF



Bias: +2.4 Wm^{-2}
RMSD: 20.0



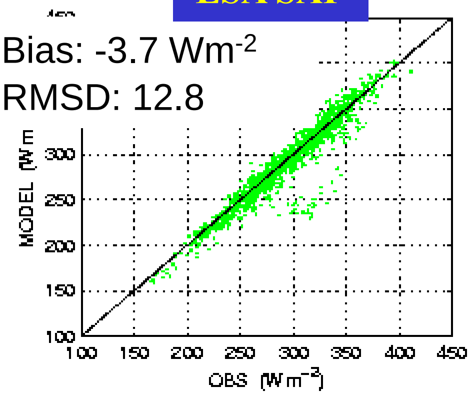
Bias: -10.6 Wm^{-2}
RMSD: 25.1

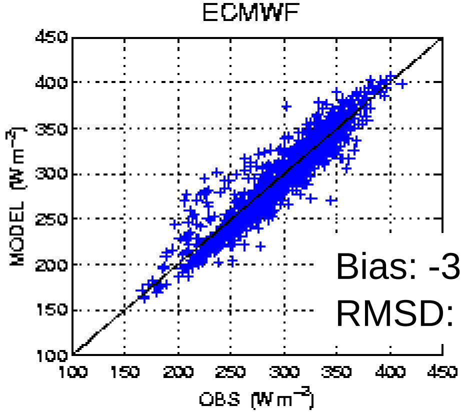
DSLF: Toravere (Estonia), high latitudes

Clear Sky

LSA SAF

Bias: -3.7 Wm^{-2}
RMSD: 12.8



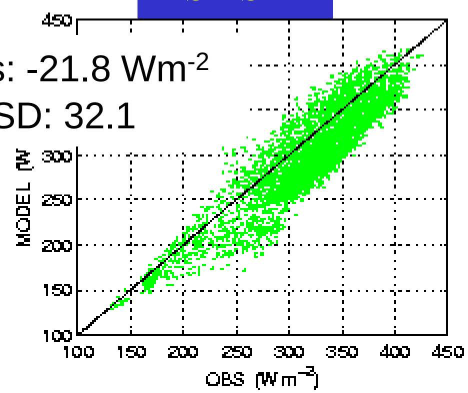


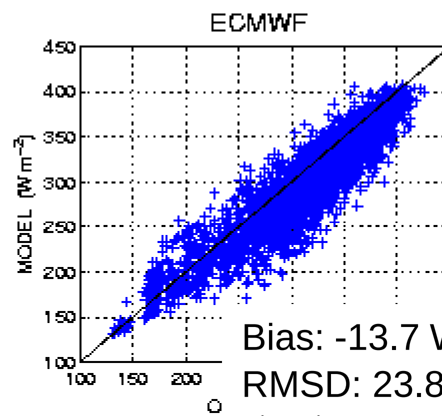
Bias: -3.7 Wm^{-2}
RMSD: 14.5

Cloudy Sky

LSA SAF

Bias: -21.8 Wm^{-2}
RMSD: 32.1





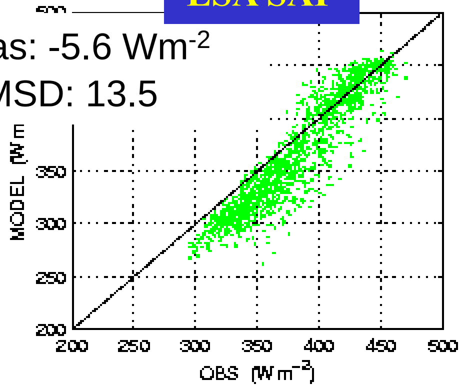
Bias: -13.7 Wm^{-2}
RMSD: 23.8

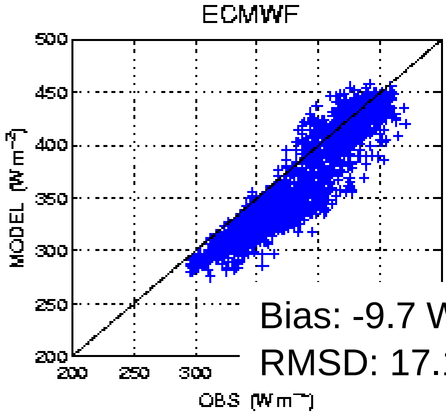
DSLF: Tamanrasset (Algeria), Sahara

Clear Sky

LSA SAF

Bias: -5.6 Wm^{-2}
RMSD: 13.5



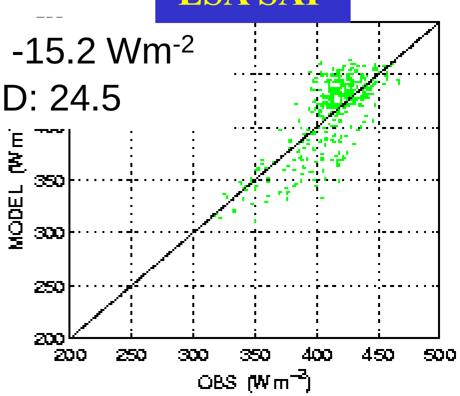


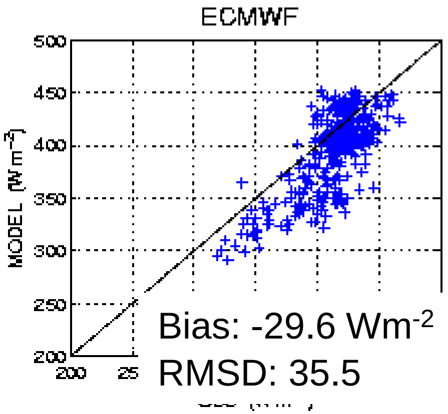
Bias: -9.7 Wm^{-2}
RMSD: 17.1

Cloudy Sky

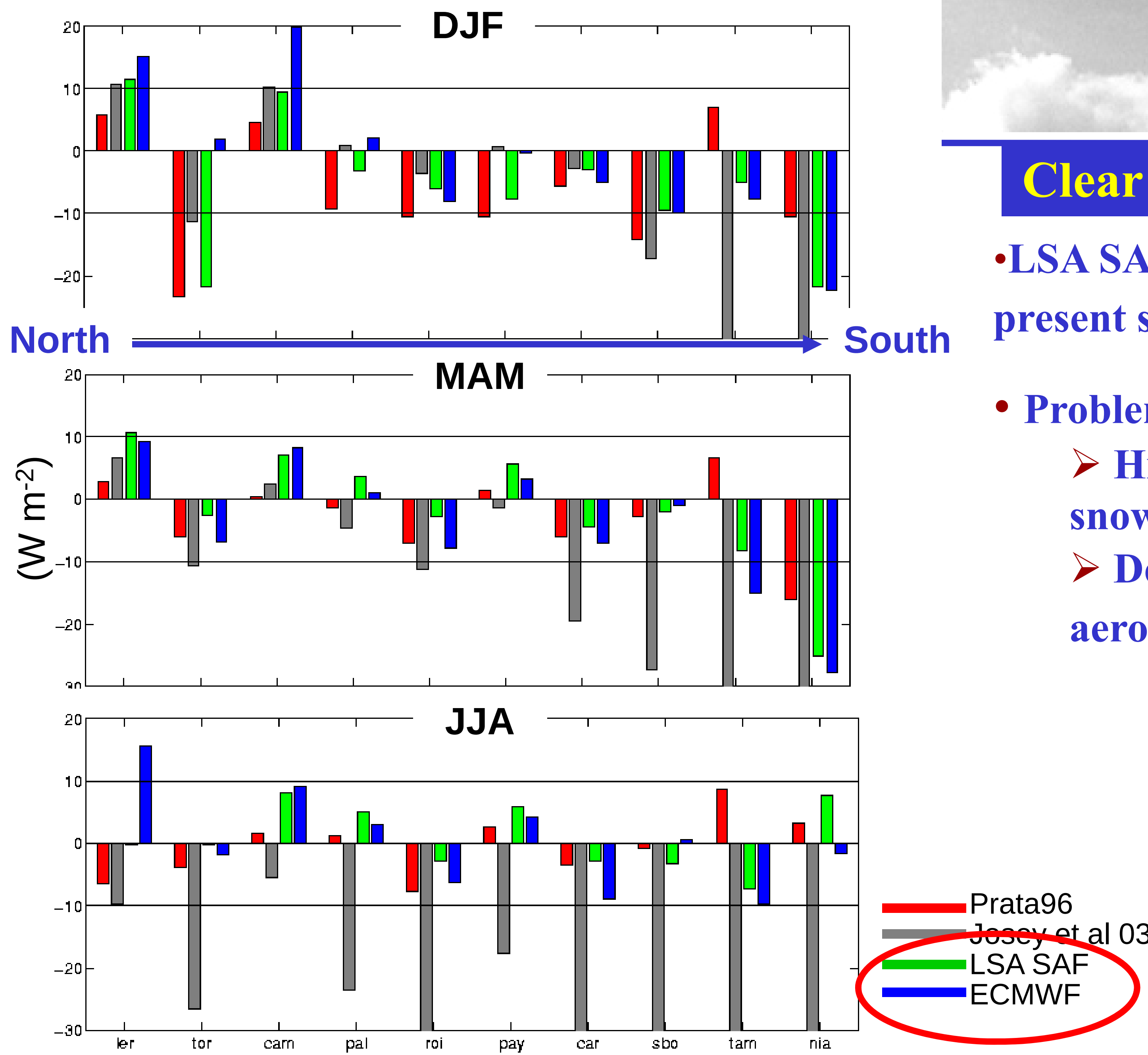
LSA SAF

Bias: -15.2 Wm^{-2}
RMSD: 24.5





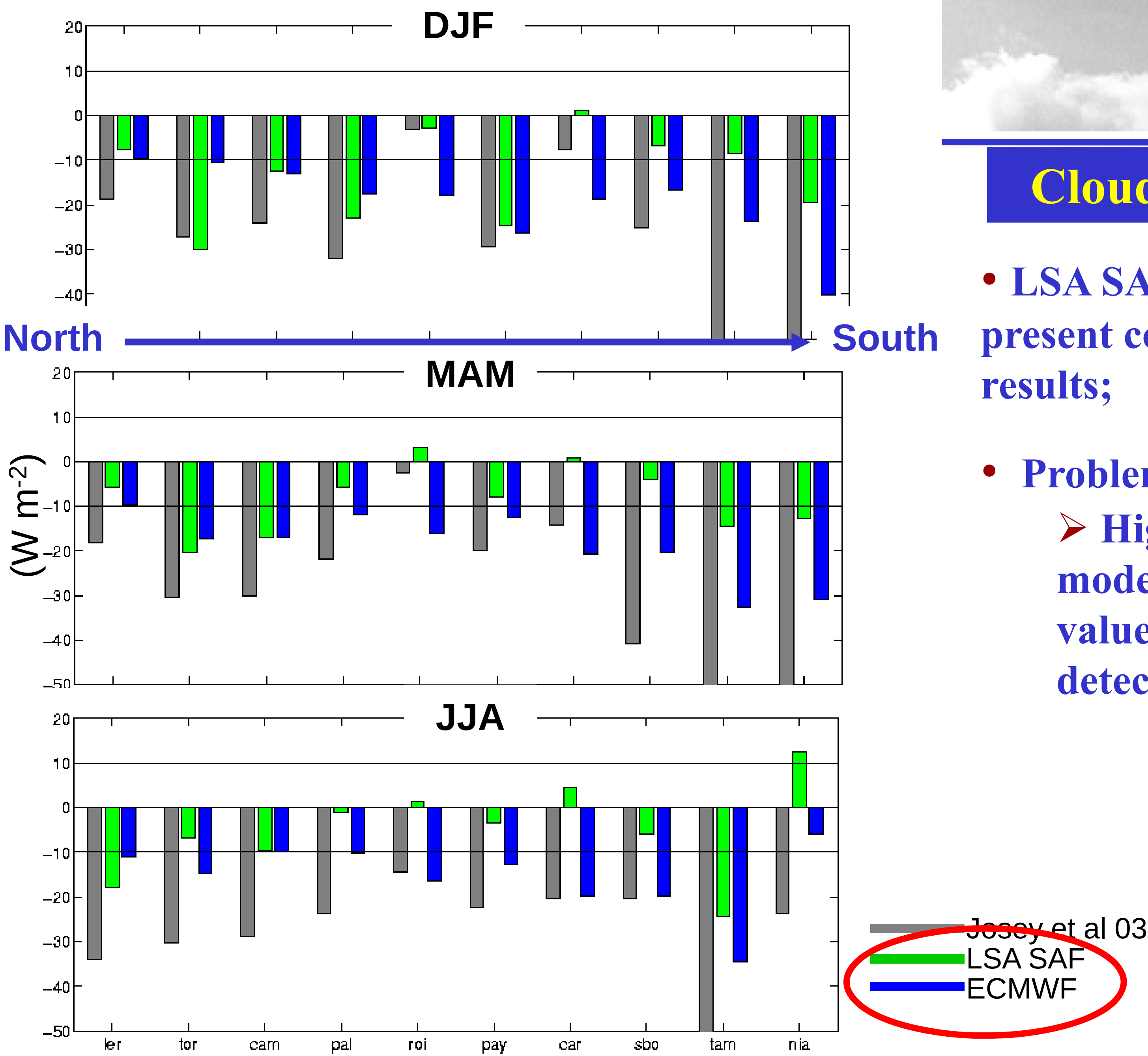
Bias: -29.6 Wm^{-2}
RMSD: 35.5



Clear Sky Bias

- LSA SAF and ECMWF present similar results;
- Problem areas:
  - ➢ High latitudes: snow and clouds
  - ➢ Deserts: Very high aerosol loads.

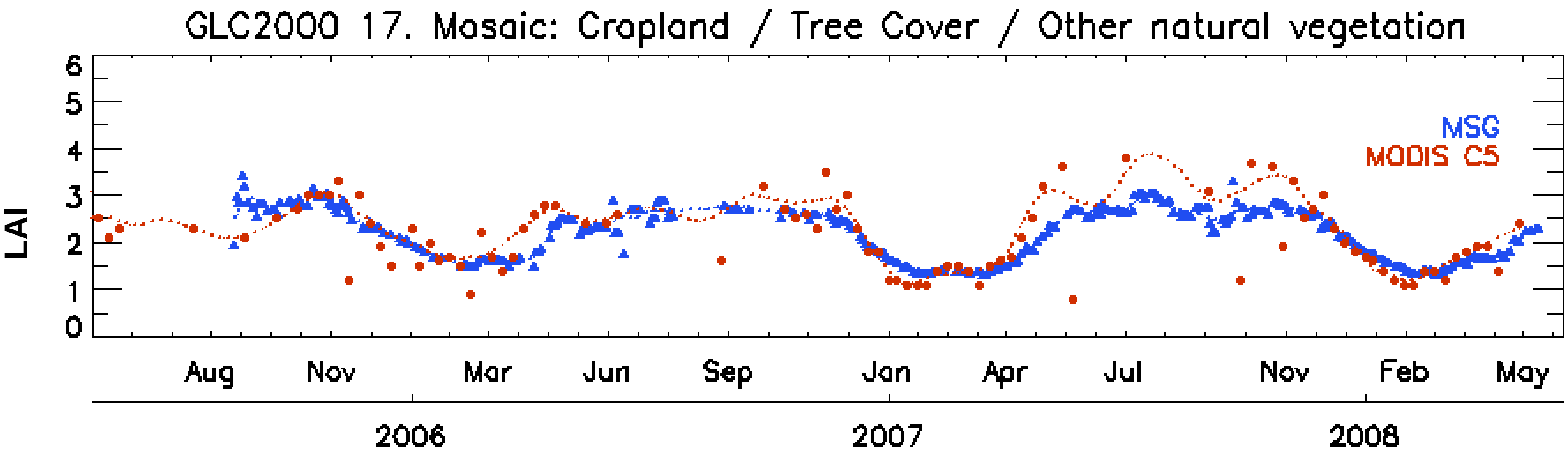
Cloudy Sky Bias



- LSA SAF and ECMWF present comparable results;
- Problem areas:
  - ➢ High latitudes – modelling low DSLF values & cloud detection.

Less is more: MSG vs. MODIS vegetation parameters

Leaf Area Index: Central Africa



- MSG product is more robust against double-season false alarms
- The temporal continuity benefits the accuracy of retrieved seasonal parameters
  - MODIS (1 km) has better resolution than MSG (3 km)
  - Both products are based on cloud-free images only, and MSG samples 50 times/day, while MODIS samples 2 times/day
  - Improved time sampling of MSG compensates lower resolution

Thanks to J. Garcia-Haro, U. Valencia

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Conclusions

- **Conventional observations for data assimilation: A few datasets might become available in the near future, but no real revolution**
  - **Important shortcoming: SYNOP snow depth information is ambiguous**
- **Remote sensing observation:**
  - **L-band & C-band Tb for soil moisture**
  - **C-band Tb for SWE**
  - **LST from IR for soil moisture**
  - **Vegetation (LAI/fAPAR) to initialize soil moisture and/or biomass**
  - **Radiative surface forcing (LSA SAF)**
- **Observations for validation:**
  - **LSA SAF LST, radiative fluxes, vegetation parameters, …**
  - **FLUXNET**
  - **Main gap: Precipitation over land**