Albedo and Incoming solar radiation flux from LSA-SAF : Algorithms, validation and applications

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Meteo-France

Salgee 2017

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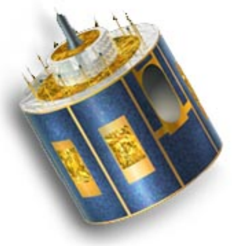
Albedo and Incoming solar radiation flux from LSA - SAF : Algorithms, validation and applications

- Introduction
- Albedo Product
  - Theory and definition
  - Bidirectional reflectance function
  - Albedo product
- Incoming solar radiation flux Product : DSSF
  - Theory and definition
  - Downwell Shortwave Solar Flux
- Applications
  - Fapar, Lai, fcover, NDVI
  - Use of albedo for Land-surface model
  - Use of albedo for Numerical Weather Prediction
  - Vegetation and soil albedo
  - Use of Downwell flux for Land-surface model
  - Use of Downwell flux for climate
  - Aerosol Icare

LSA-SAF : Land Surface Analysis Satellite Applications Facility

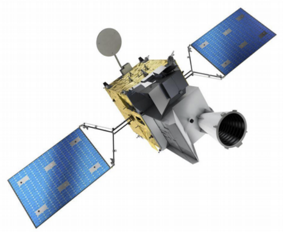


- **MSG (SEVIRI)** (Meteosat Second Generation) geostationary

  (high altitude : 36000 km)
  - High temporal resolution (15 min)
  - Spatial resolution (3km /$_{\text{cos(lat)/cos(long)}}$)

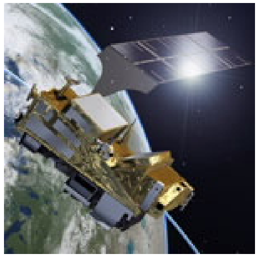
- **EPS (AVHRR)** (Metop) (Eumetsat Polar System) polar

  (Low altitude : 817 km)
  - Spatial resolution (3 à 6 km)
  - Temporal resolution (10 jours)



- **MTG** (Meteosat Third Generation) geostationary
  - High temporal resolution (10 min)
  - Higher spatial resolution

Will be lauched in 2018



- **EPS-SG** (Eumetsat Polar System second generation) polar

  (low altitude : TBD)
  - Résolution spatiale (TBD)
  - Résolution temporelle (TBD)

Will be lauched in 2020

THE PRODUCTS

MSG/SEVIRI

Wild Fires
- Fire Radiative Power - PIXEL
- Fire Radiative Power - GRID
- Fire Detection and Monitoring
- Fire Risk Map

Vegetation Stress
- Evapotranspiration
- Reference Evapotranspiration

Surface Radiation Budget
- Land Surface Temperature
- Downward Surface Shortwave Flux
- Downward Surface Longwave Flux
- Surface Albedo
- Bi-Directional Reflectance Factor
- Land Surface Emissivity

Vegetation State
- Fraction of Vegetation Cover
- Leaf Area Index
- Fraction of Absorbed Photosynthetic Active Radiation

Snow Cover
- Snow Cover

MetOp/AVHRR

Surface Radiation Budget
- EPS Daily Land Surface Temperature
- EPS Ten Day Surface Albedo

Snow Cover
- EPS Daily Snow Cover

Vegetation State
- Normalized Difference Vegetation Index

Caption

Internal	Develop.	Demo.	Pre-Operat.	Operat.

Acronym	Institution
AL	MF
BRDF	MF
LST	IM
TSP	IMK
EM	ICAT
DSSF	MF
DSLF	IM
SC	SMHI
ET	RMI
FVC	UV
LAI	UV
RFM	IDL
FRP&FRE	
fAPAR	UV

THE PRODUCTS

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ET	RMI
FVC	UV
LAI	UV
RFM	IDL
FRP&FRE	
fAPAR	UV

Land-SAF Consortium

IPMA (Portugal) ***– Leading Institut***

MF (France)

RMI (Belgium)

NIMH (Bulgaria)

ARSO (Slovenia)

KCL (King's College London)

IDL (Univ Lisbon)

KIT (Karlsruhe Inst Technology)

UV (Univ Valencia)

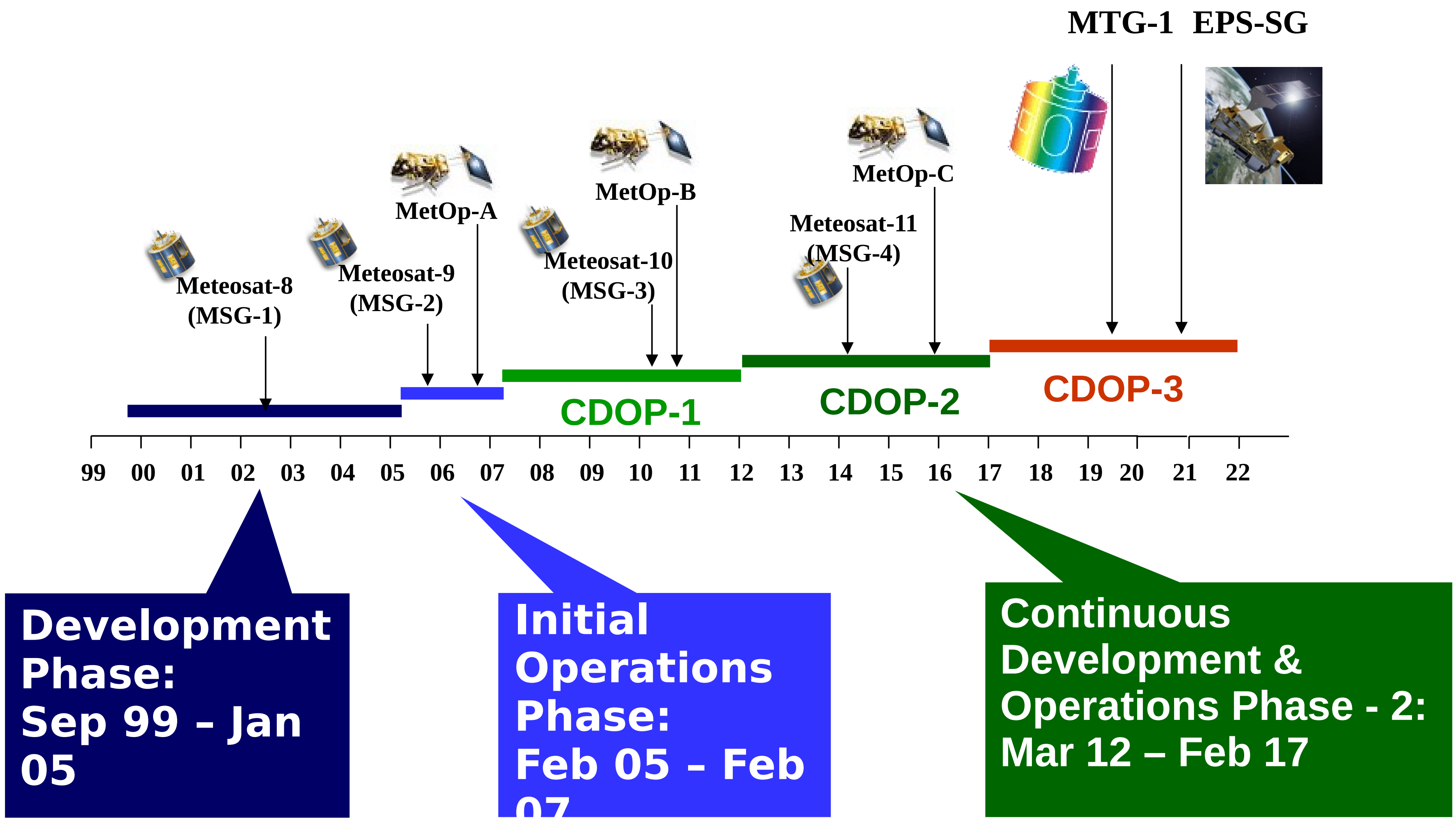
VITO (Flemish Inst Technological)

10 Institutes / 8 Countries

Total Funding: > 10 M€

(EUMETSAT Contribution : ~ 67%)

Land-SAF Chronogram



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LSA-SAF users and applications

Users/applications:

Land Surface Modelling – Energy and Carbon fluxes; Hydrology

- Radiation: LST (Land Surface Temperature), Albedos, Down-welling Radiation Fluxes
- Vegetation Parameters and Indices
- ET (Evapo-Transpiration) and Turbulent Heat Fluxes
- Fire: Fire Radiative Power

Agriculture and Forestry applications

- Vegetation Parameters and Indices
- ET, Reference ET and Turbulent Heat Fluxes
- Fire Products: identification, FRP, risk and burnt areas
- Radiation: LST, Albedos, Down-welling Radiation Fluxes

Air Quality Monitoring and Forecasting

- Fire: FRP

Environmental monitoring

- LST
- ET and Reference ET
- Vegetation Parameters and Indices
- Fire Products

Food Security

- ET and Reference ET
- Vegetation Parameters and Indices
- Fire Products

Energy sector

- Radiation: Short-wave Down-welling Radiat Fluxes

Climate applications

Numerical Weather Prediction

- LST (and Emissivity), Albedos
- Vegetation Parameters and Indices

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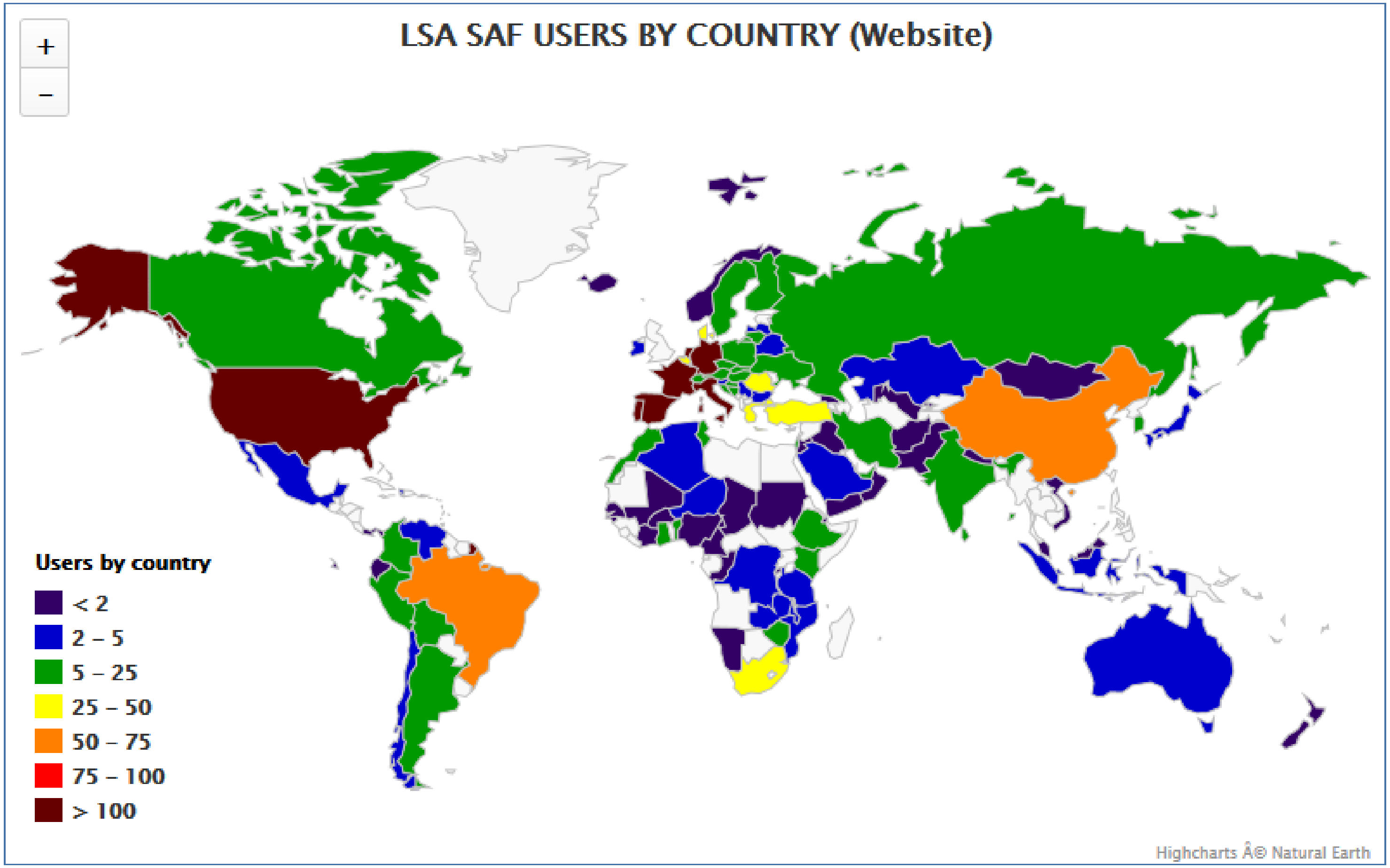
EUMETSAT LSA SAF LAND SURFACE ANALYSIS

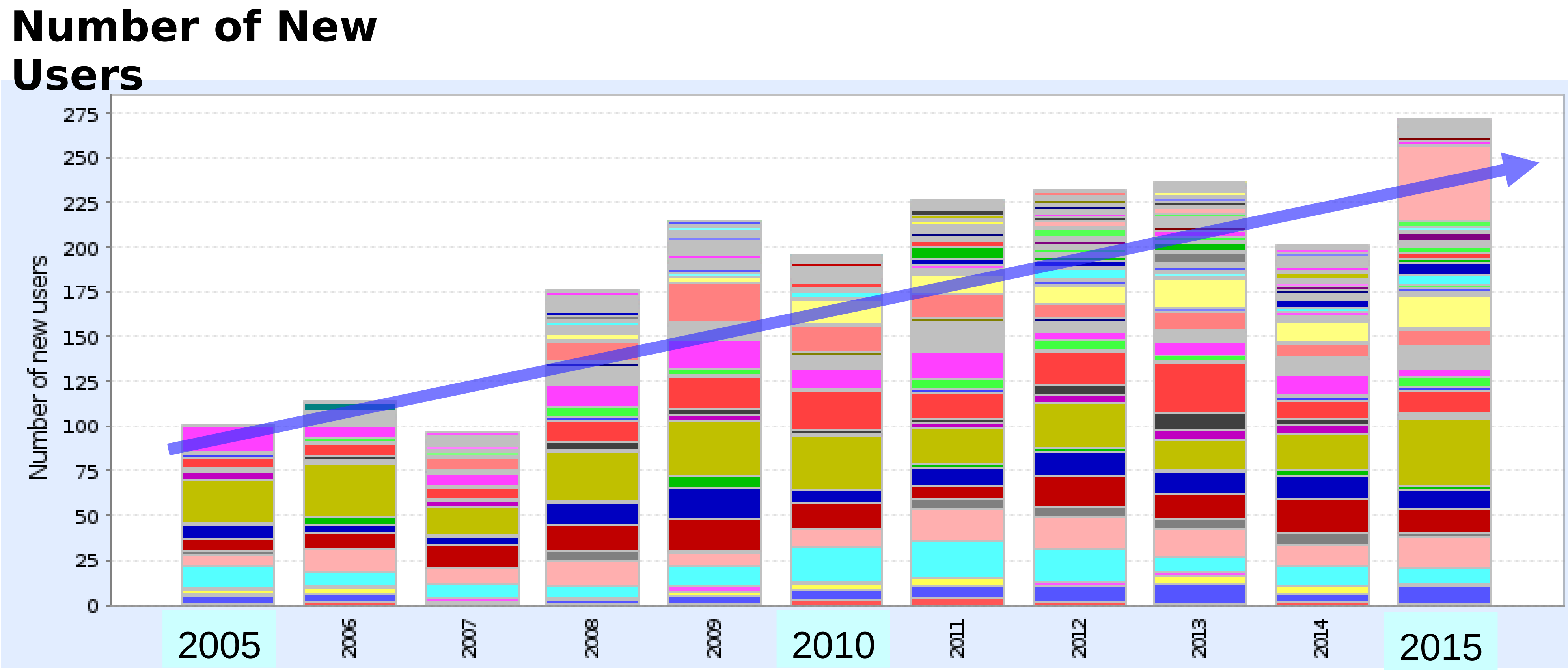
Users

Registered for regular/offline acquisition of LandSAF Products

- EUMETCast: > 1000 in Jul 2014
- LandSAF website: > 1500
- ftp NRT dissemination 20-30



New Users


Number of New Users
Number of new users
0
25
50
75
100
125
150
175
200
225
250
275
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015

LSA-SAF Set of Albedo Products

Instrument	Product	Status
SEVIRI/**MSG** (2005 until now) (MSG disk - 3km sub-satellite)	Total surface albedo (LSA108/daily & LSA109/10-day & LSA150/Reprocessing daily) Vegetation albedo, bare soil albedo, and snow albedos (LSA104/daily)	Operational In Development
AVHRR/**Metop** (2016 until now) (Global - 1km)	Total surface albedo (LSA103/10-day)	Pre-Operational
FCI/MTG (launch in 2020) *(MTG disk - 1km sub-satellite)*	*Total surface albedo* *(LSA107-108/daily)*	-
VII/EPS-SG (launch in 2022) *(Global – 0,75km)*	*Total surface albedo (LSA110/10-day)*	-
3MI/EPS-SG (launch in 2022) *(Global - 4km)*	*Total surface albedo (LSA111/10-day)*	-

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Albedo Algorithm

Observations : TOA Top-of atmosphere
- 3 wavelenghts
  (0,6 µm 0,8 µm et 1,6 µm)
- Multiple solar angles on 1 day (MSG)
- **or**
- Multiple view angles on 10 days (EPS)

800k simulations of atmosphere interaction using (6S)
Modeling gaz (Ozone, H2O, CH4, …) and aerosols
Statistics → Approximation parameters. OFF-LINE.

TOA

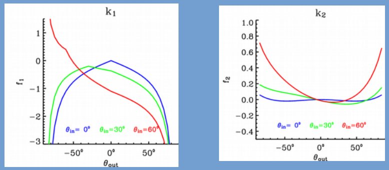
Step 1 : Atmospheric Correction

Coefficients (Smac)

Top-of-Canopy (TOC)

Step 2 : Surface Interaction

Step 2 : Surface interaction
Semi-empiracal model based-on kernels
brdf(lambda, thetaS, thetaV) = k0 + k1 f1( ) + k2 f2( )



Bidirectional Reflectance :
BRDF(lambda, thetaS, thetaV)
- Depends on the wavelenght
- Depends on the solar angles
- Depends on the view angles

Reflectance (BRDF)

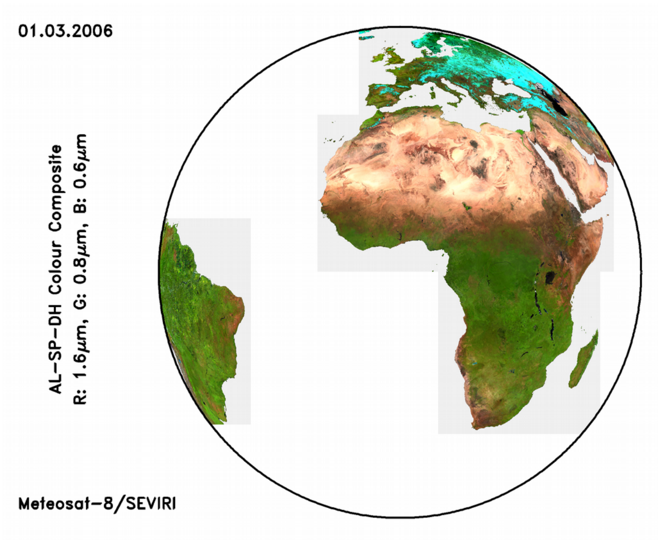
Step 3 : Integration

Step 3 : Integration
Angular integration (on thetaS et thetaV)
Spectral integration

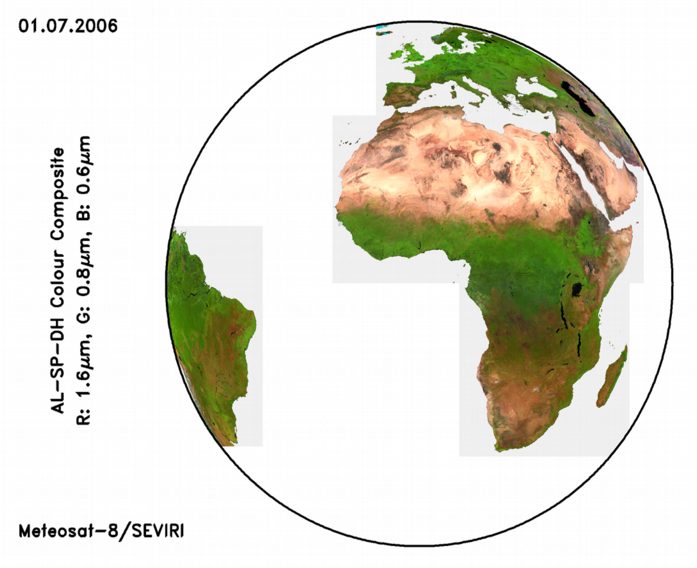
- Visible Albedos
- NIR Albedos
- Broad band albedo
- Narrow band albedo

Albedos

PRODUCT CHARACTERISTICS (MDAL - LSA108)



Color Composite Of Spectral Albedo



Spatial Resolution: 3km at Sub-Satellite Point
Projection: native MSG/SEVIRI Projection
Production Frequency: Daily (also 10 days)
Effective Temporal Resolution: 5 Days (also monthly)
Format: HDF5
Timeliness: 3 hours
Dissemination:
- EUMETSAT broadcast system (EUMETCast)
- project website (http://landsaf.meteo.pt)

Spectral Albedos (6):
- 0.6µm (DH&BH)
- 0.8µm (DH&BH)
- 1.6µm (DH&BH)

BroadBand Albedos (4):
- VIS-DH [0.4µm, 0.7µm]
- NIR-DH [0.7µm, 4.0µm]
- SW-DH [0.3µm, 4.0µm]
- SW-BH [0.3µm, 4.0µm]

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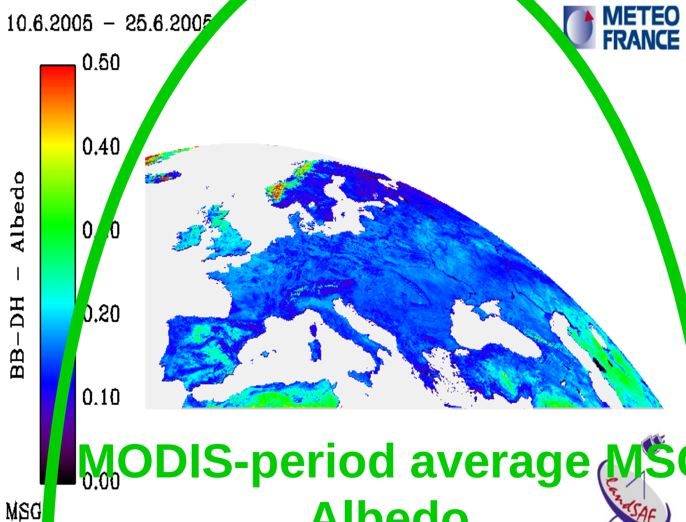
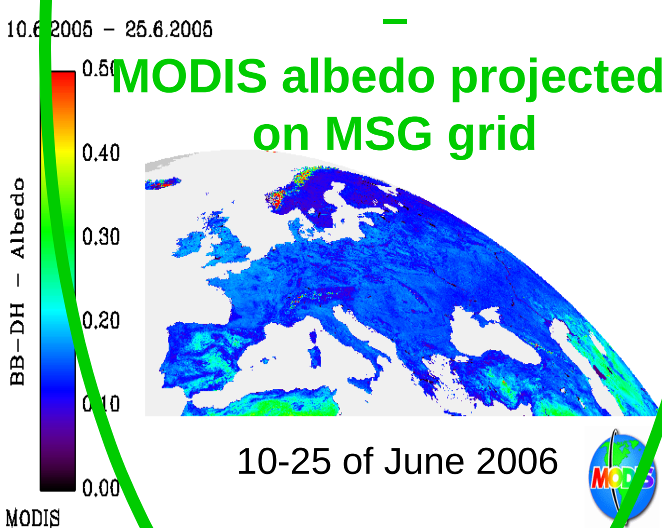
COMPARISON WITH MODIS ALBEDO (1/2)



MODIS-period average MSG Albedo

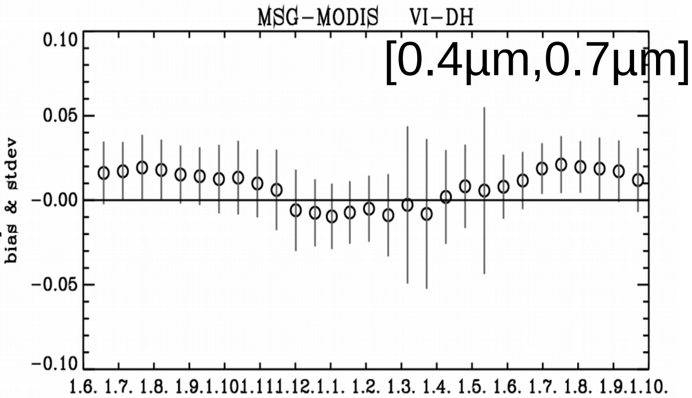
–

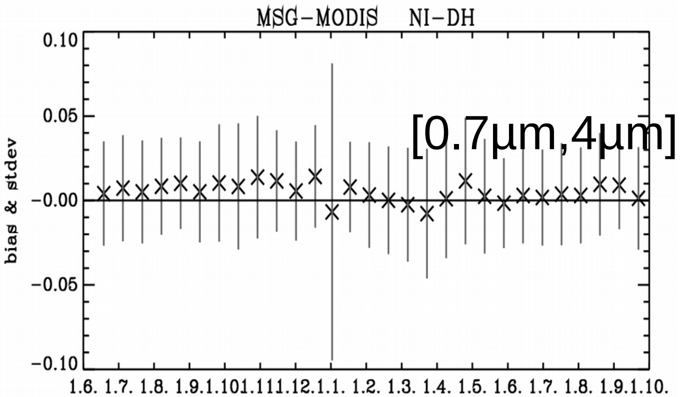
MODIS albedo projected on MSG grid

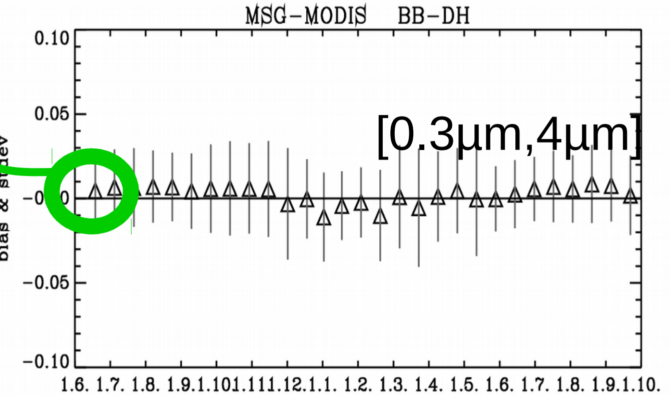


10-25 of June 2006

over Europe (from 2005-06-01 to 2006-10-01)







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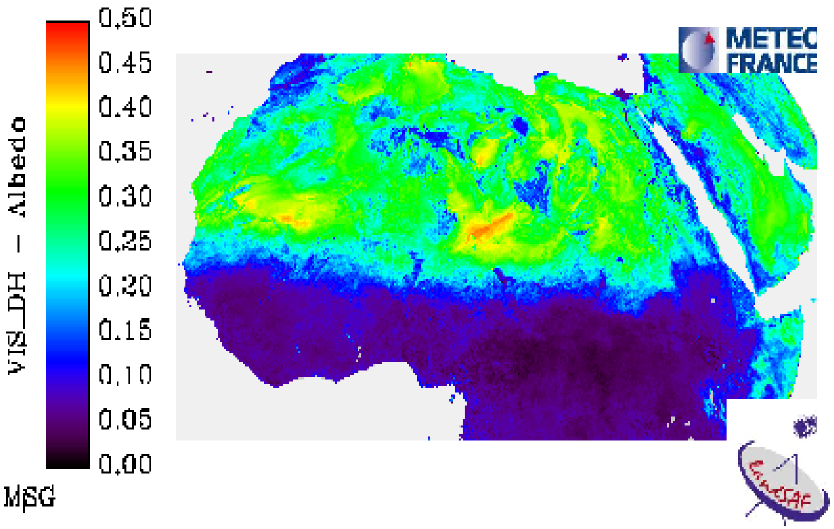
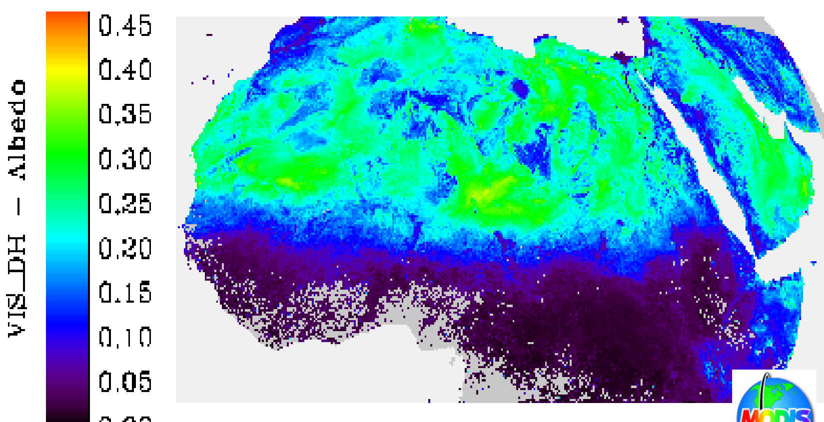
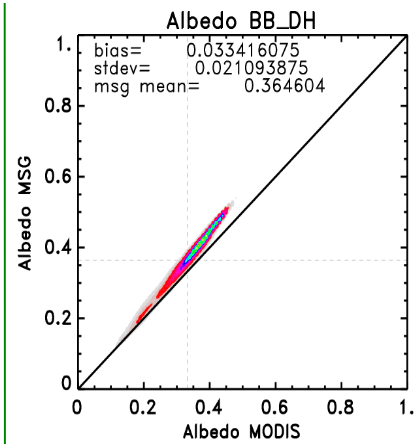
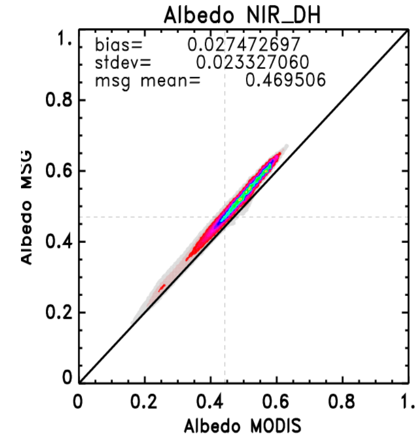
COMPARISON WITH MODIS ALBEDO (2/2)

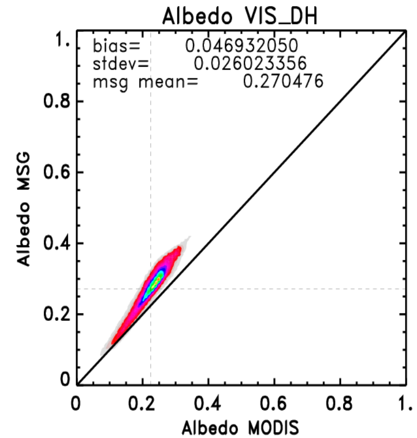




12-27 of July 2006







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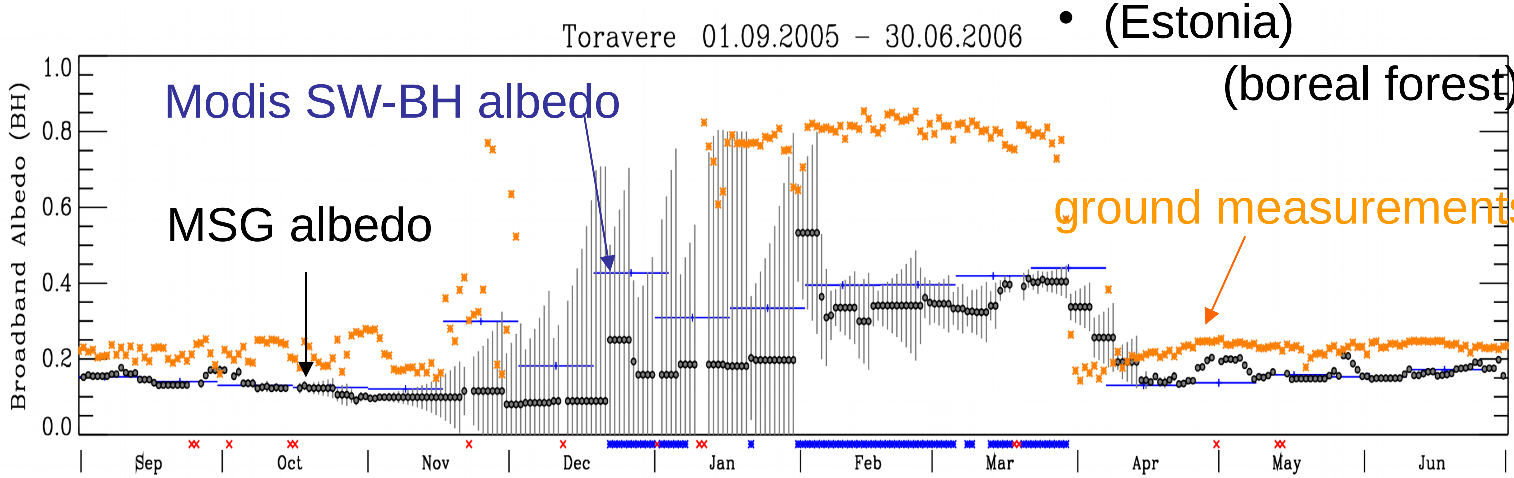
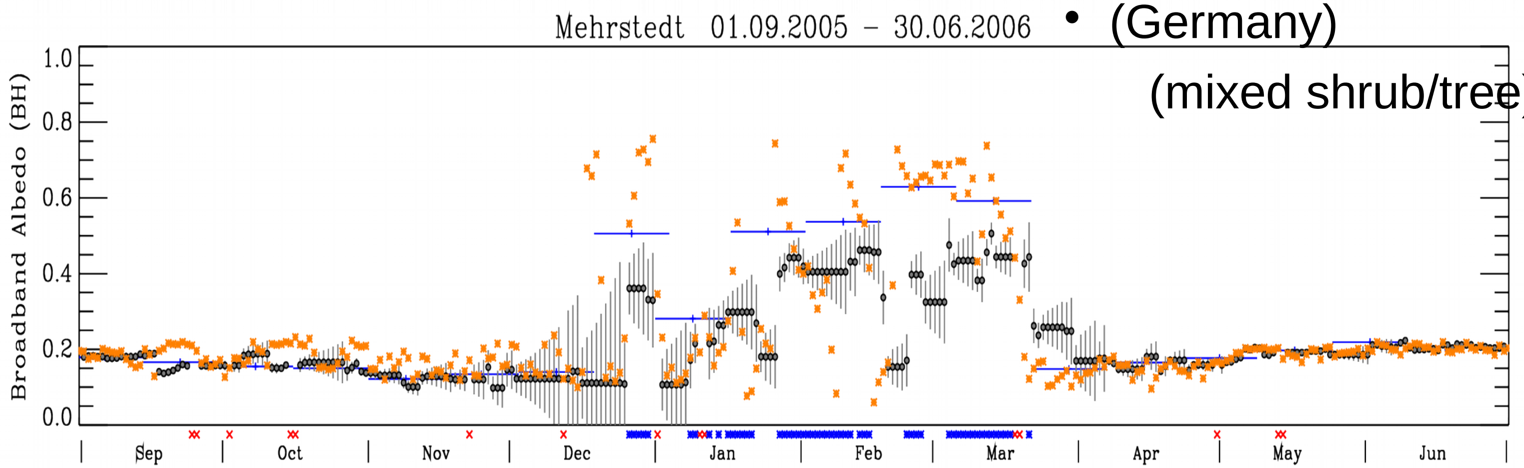
ALBEDO TIME SERIES (snowfall episodes)



- (Estonia)

(boreal forest)



- (Germany)

(mixed shrub/tree)

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SUMMARY OF PERFORMANCES (ALBEDO MSG)

Accuracy

Over mid-latitude region:

bias: 5% in relative units for SW and NIR broadband albedo (except for snow/ice pixels) – below 0.01 in absolute unit

20% for VIS broadband albedo (potentially due to the use of different BRDF models and aerosol products)

stdev: 0.015 for VIS and 0.030 for NIR and SW (or BB)

Over brightening surfaces (North Africa): no degradation in relative units

Documentation :

(Product User Manual + Validation Report + ATBD + internal documents)

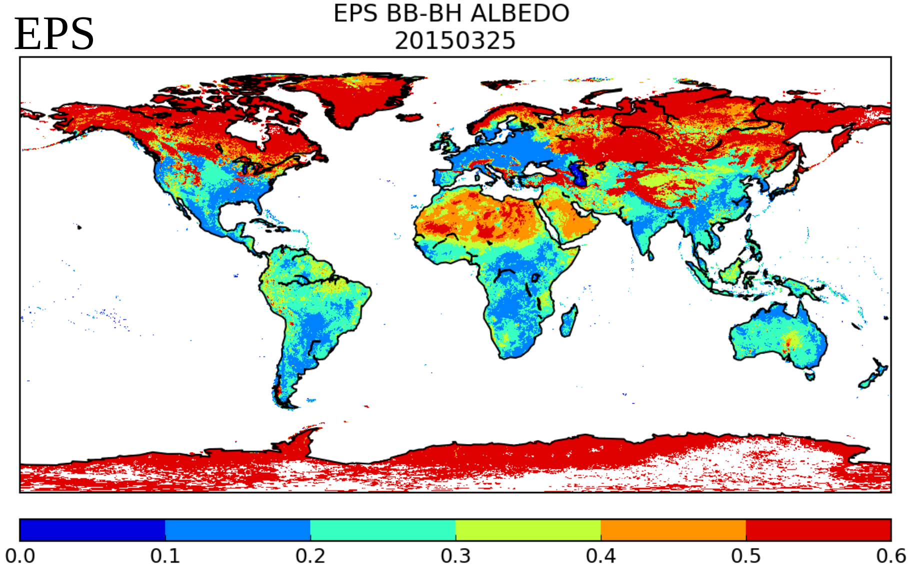
Available here : http://lsa-saf.eumetsat.int/

Publications:

Carrer, D., Roujean J.-L., Meurey C., “Evaluating operational MSG/SEVIRI land surface albedo products from LSA-SAF with ground measurements and MODIS”, IEEE Transactions on Geoscience and Remote Sensing, doi:10.1109/TGRS.2009.2034530.

Geiger, B., Carrer D., Franchistéguy L., Roujean J.-L., Meurey C., 2008, “*Land Surface Albedo derived on a daily basis from Meteosat Second Generation Observations*”, IEEE Transactions on Geoscience and Remote Sensing, 46, 3841–3856, doi:10.1109/TGRS.2008.2001798.

PRODUCT CHARACTERISTICS (ETAL - LSA103)



Spatial Resolution: 0.01°x0,01°
Projection: Global - native EPS
Production Frequency: 10-Day
Format: HDF5
Timeliness: 3 hours
Status: pre-operational

Spectral Albedo (6):
0.6µm, 0.8µm, and 1.6µm (DH&BH)

Broad band Albedo (4):
VIS-DH ([0.4µm, 0.7µm])
NIR-DH ([0.7µm, 4.0µm])
SW-DH ([0.3µm, 4.0µm])
SW-BH ([0.3µm, 4.0µm])

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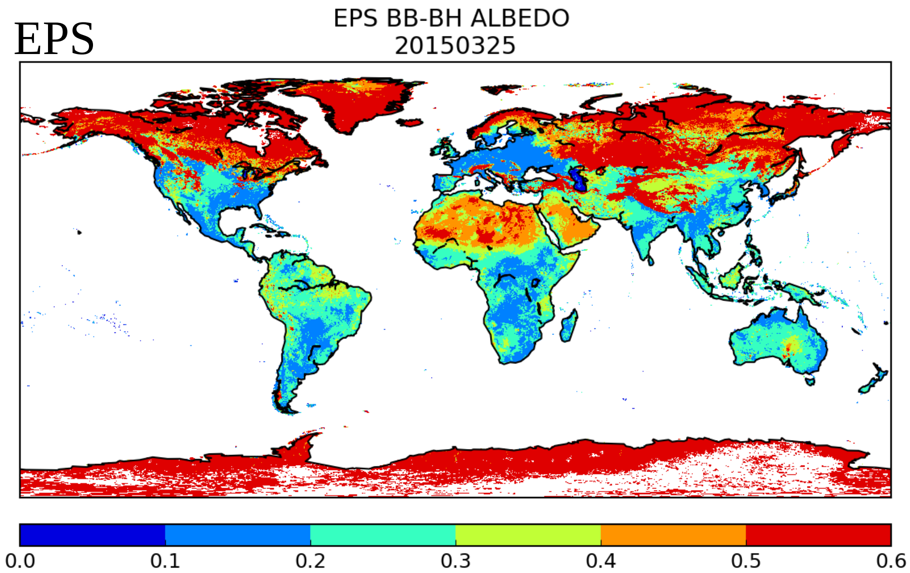
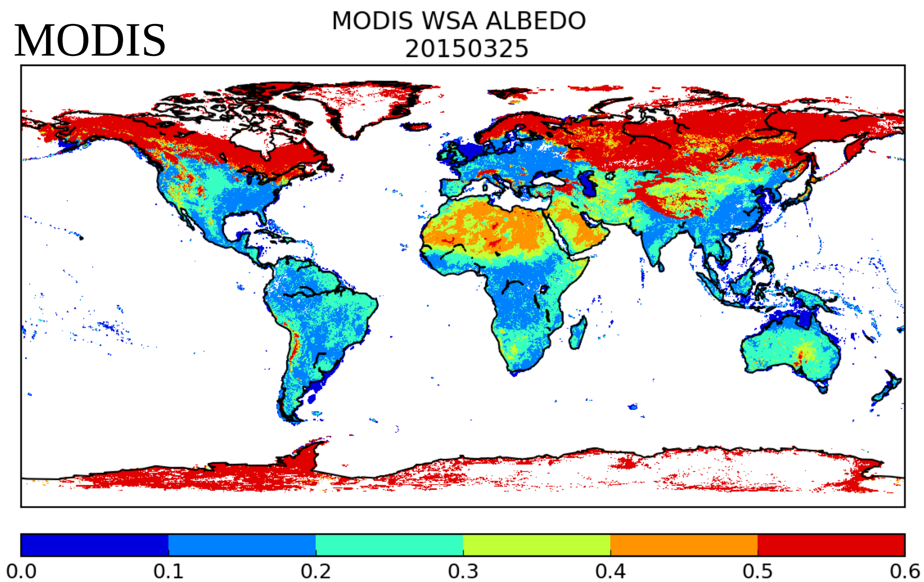
PRODUCT CHARACTERISTICS (ETAL - LSA103)

EPS



MODIS



Spatial Resolution: 0.01°x0,01°
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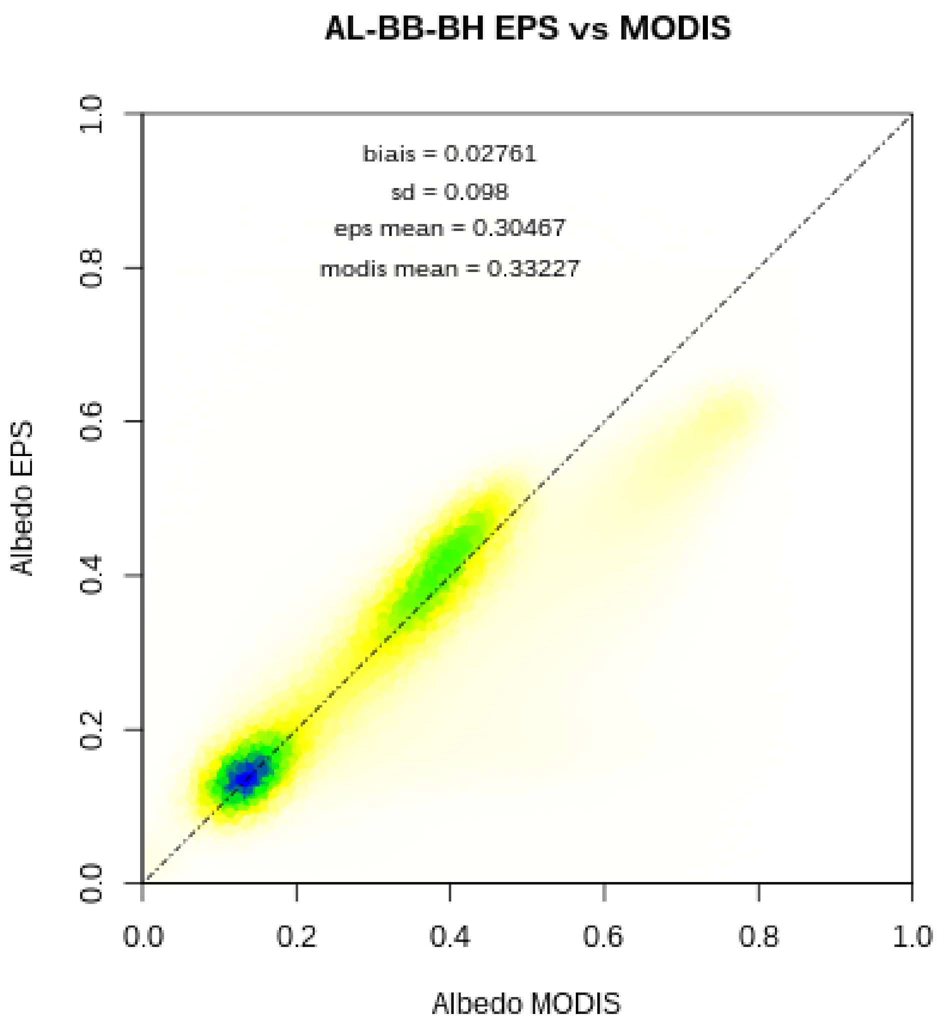
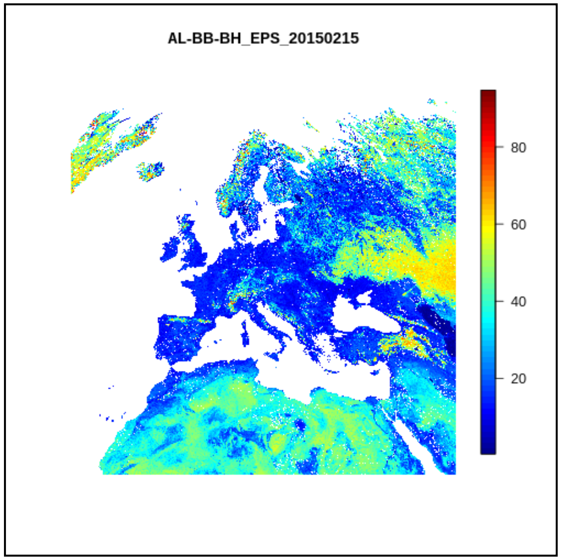
EUMETSAT LSA SAF LAND SURFACE ANALYSIS

RESULTS (ETAL - LSA103)





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LSA-SAF Set of DSSF Products

Instrument	Product	Status
SEVIRI/MSG (2005 until now) (MSG disk - 3km sub-satellite)	MDSSF (LSA-201) instantaneous values DIDSSF (LSA-203) daily accumulated values MDSSFDD (LSA-207) instantaneous estimates of direct and diffuse incoming solar radiation at the surface level.	Operational Operational In Development
FCI/MTG (launch in 2020) *(MTG disk - 1km sub-satellite)*	*MDSSF (LSA-209)* *instantaneous values* *DIDSSF (LSA-211)* *daily accumulated values*	-

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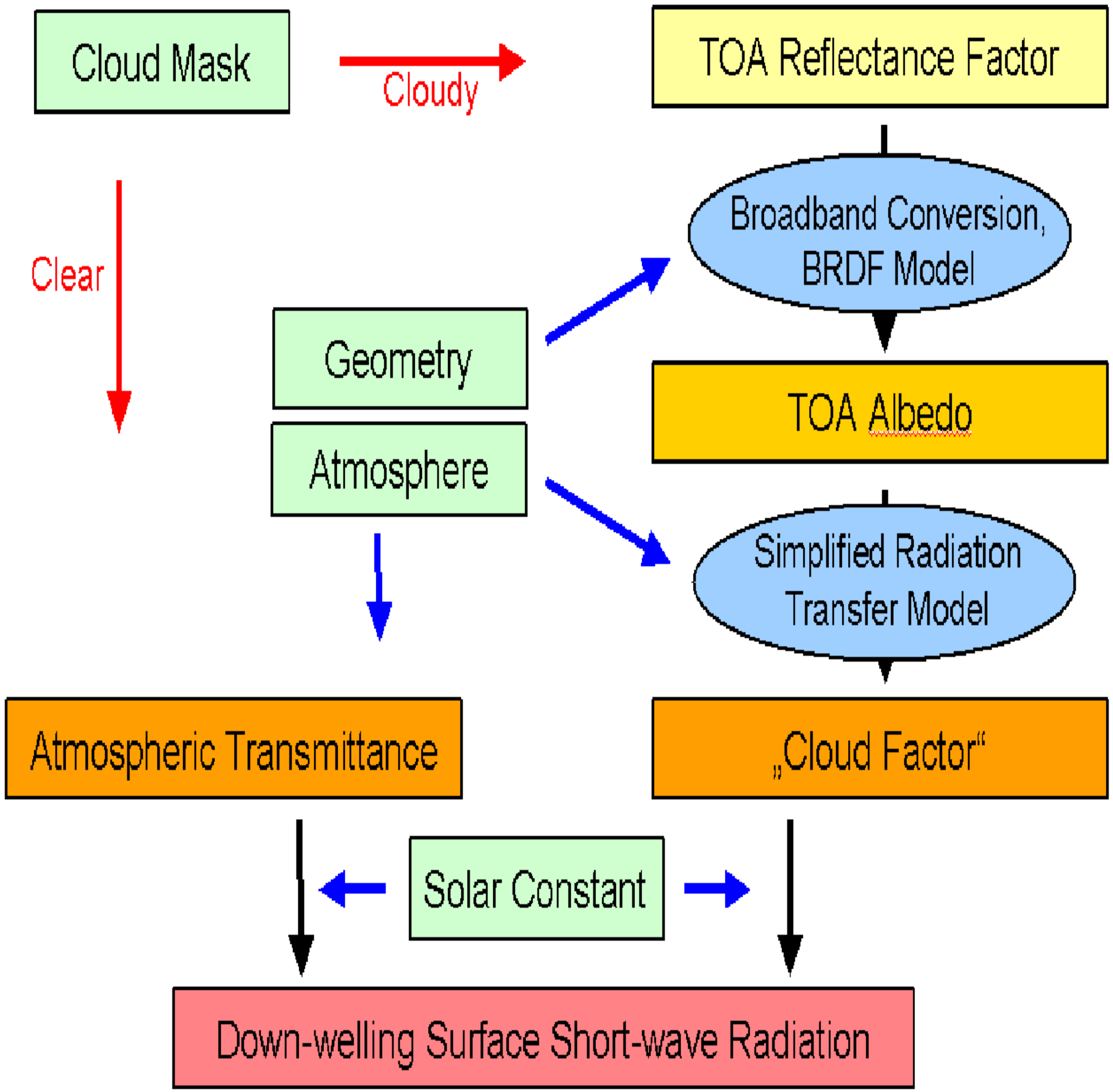
LSA SAF
LAND SURFACE ANALYSIS

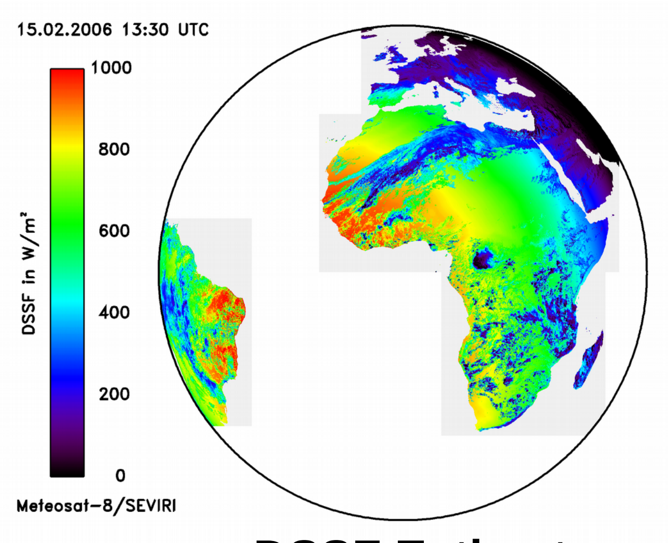
METHOD FOR RETRIEVAL DSSF – LSA-201/203



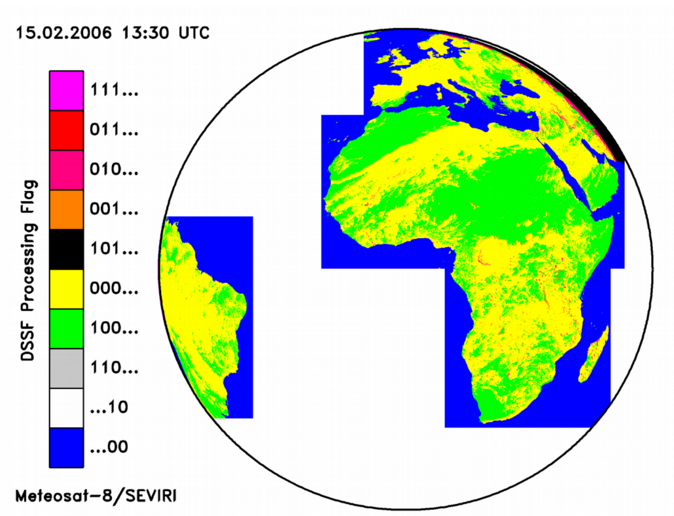
DSSF INPUT DATA

- Satellite Data (TOA-radiances)
- Solar and View Angles
- Land/Sea Mask
- Cloud Mask (SAF-NWC software)
- Total Column Water Vapour (ECMWF)
- Ozone Content (Climatology)
- Land Surface Albedo (Land-SAF AL product)

PRODUCT CHARACTERISTICS (DSSF – LSA-201/203)



DSSF Estimate



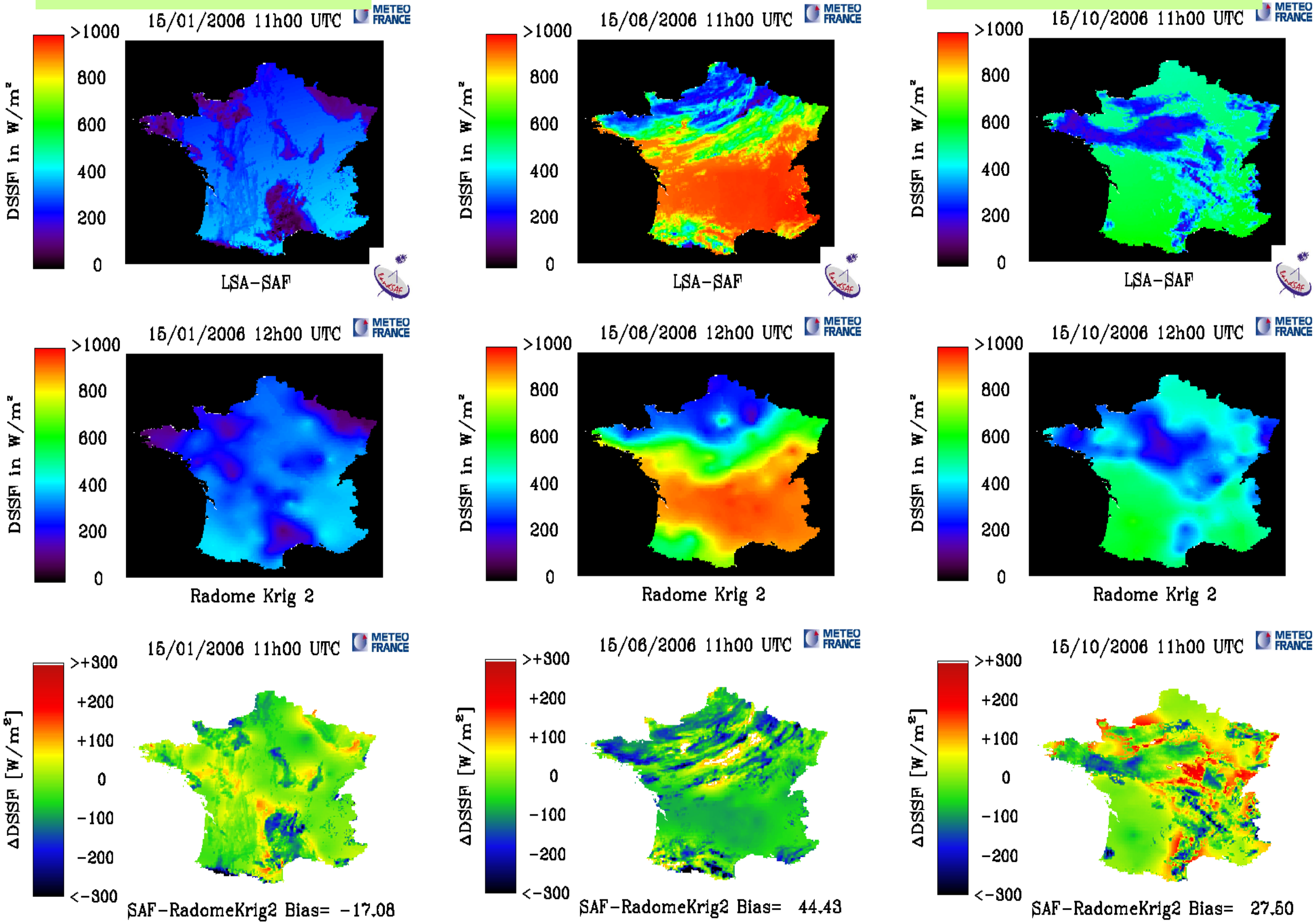
Processing Flag

Spatial Resolution: 3km at Sub-Satellite Point
Projection: native MSG/SEVIRI Projection
Production Frequency: 30 Minutes
Instantaneous Flux Estimate
Format: HDF5
Timeliness: 3 hours
Dissemination:
- EUMETSAT broadcast system (EUMETCast)
- project website (http://landsaf.meteo.pt)

Wavelength interval: [0.3µm, 4.0µm]

Validation of DSSF over France with RADOME network (LSA-201)

15/01/2006 12 h	15/06/2006 12 h	15/10/2006 12 h



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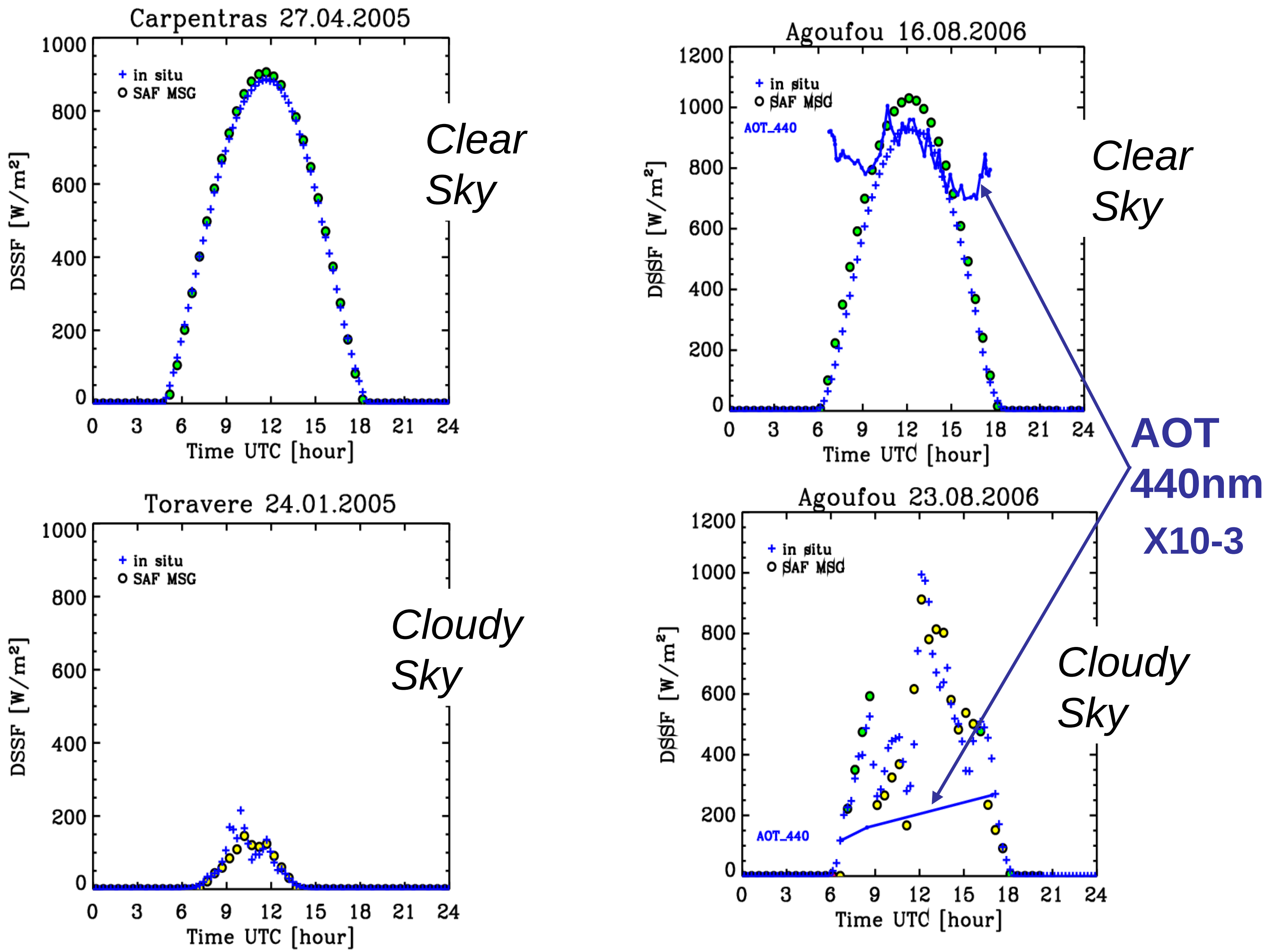
Time series example (LSA-201)



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SUMMARY OF PERFORMANCES (DSSF)

Accuracy

Biais :
Between the satellite product and the ground data is small : **< 10 W.m−2** (absolute value)

Stdev :
Between instantaneous satellite estimates and ground measurements :

~ 40 W m−2 for clear sky data
~ 110 W m−2 for cloudy sky data.

Related publications:
- Geiger, B., Meurey, C., Lajas, D., Franchistéguy, L., Carrer, D. and Roujean, J.-L. (2008), Near real-time provision of downwelling shortwave radiation estimates derived from satellite observations. Met. Apps, 15: 411–420. doi:10.1002/met.84
- See also : Product User Manual, and Validation Report, internal documents

Applications

Use of BRDF for Fapar, Lai, fcover, NDVI

Use of albedo for Land-surface model

Use of albedo for Numerical Weather Prediction

Use of Albedo for Vegetation and soil albedo

Use of Downwell flux for Land-surface model

Use of Albedo for climate

Aerosol product from MSG (Icare)

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Use of Albedo for climate

Aerosol product from MSG (Icare)

Application of Albedo Algorithm

Observations : TOA Top-of atmosphere
- 3 wavelenghts
  (0,6 µm 0,8 µm et 1,6 µm)

TOA

Step 1 : Atmospheric Correction

Top-of-Canopy (TOC)

Step 2 : Surface Interaction

Reflectance (BRDF)

Step 3 : Integration

Albedos

The BRDF function has a lot more information to give about the surface (than Albedo).

BRDF is (currently) an internal product.

Collaborations welcome !

NDVI

FAPAR

fCover

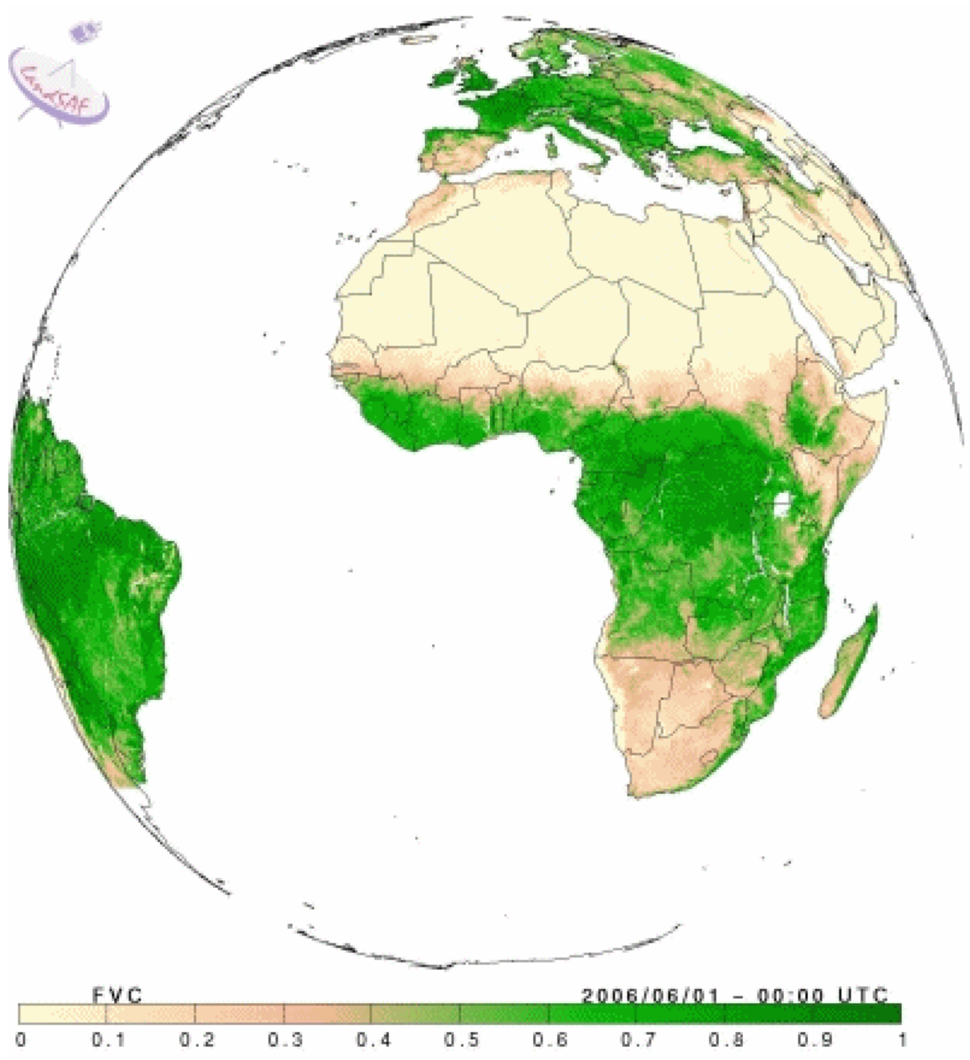
LAI

Custom parameter ?

Bidirectional Reflectance :
BRDF(lambda, thetaS, thetaV)
- Depends on the wavelenght
- Depends on the solar angles
- Depends on the view angles

- Visible Albedos
- NIR Albedos
- Broad band albedo
- Narrow band albedo

FRACTIONAL VEGETATION COVER



Geostationary

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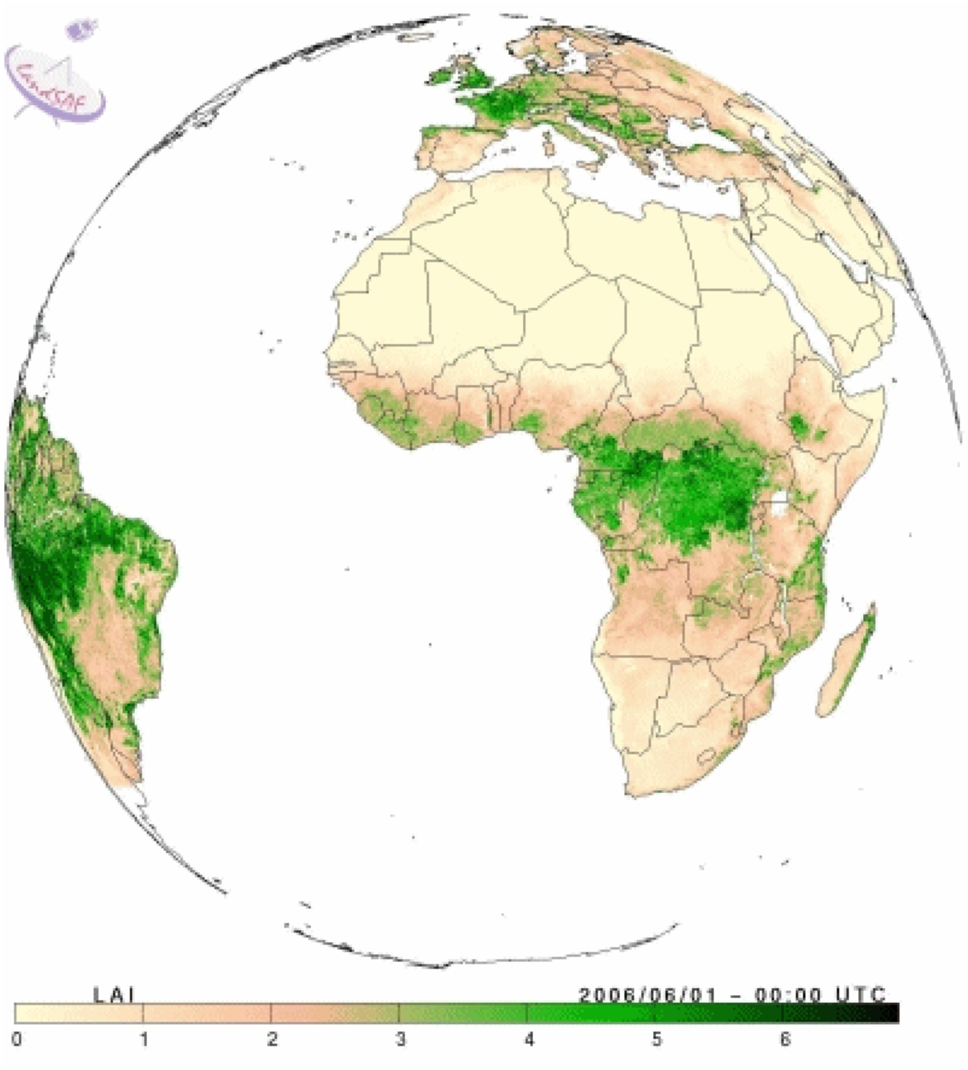
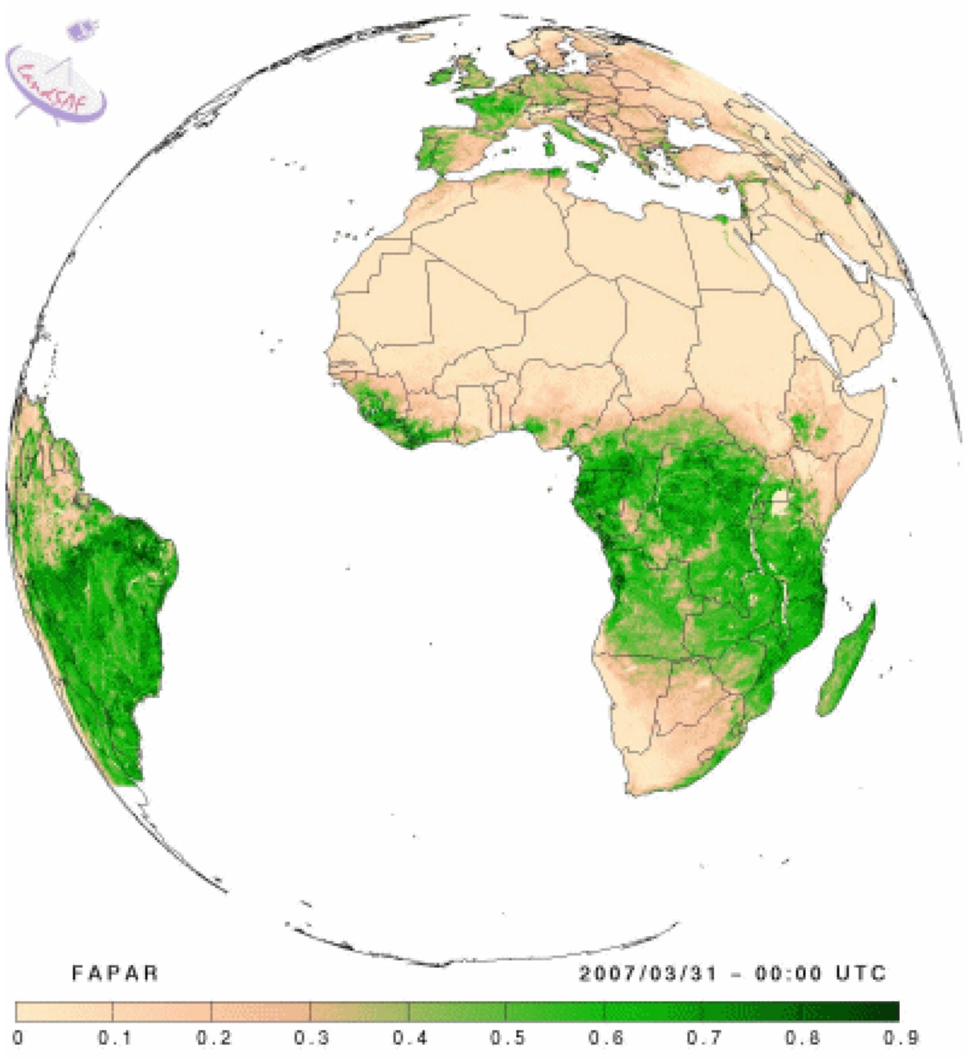
LEAF AREA INDEX



Geostationar
y

UMR3589
CNRM

fAPAR



Geostationary

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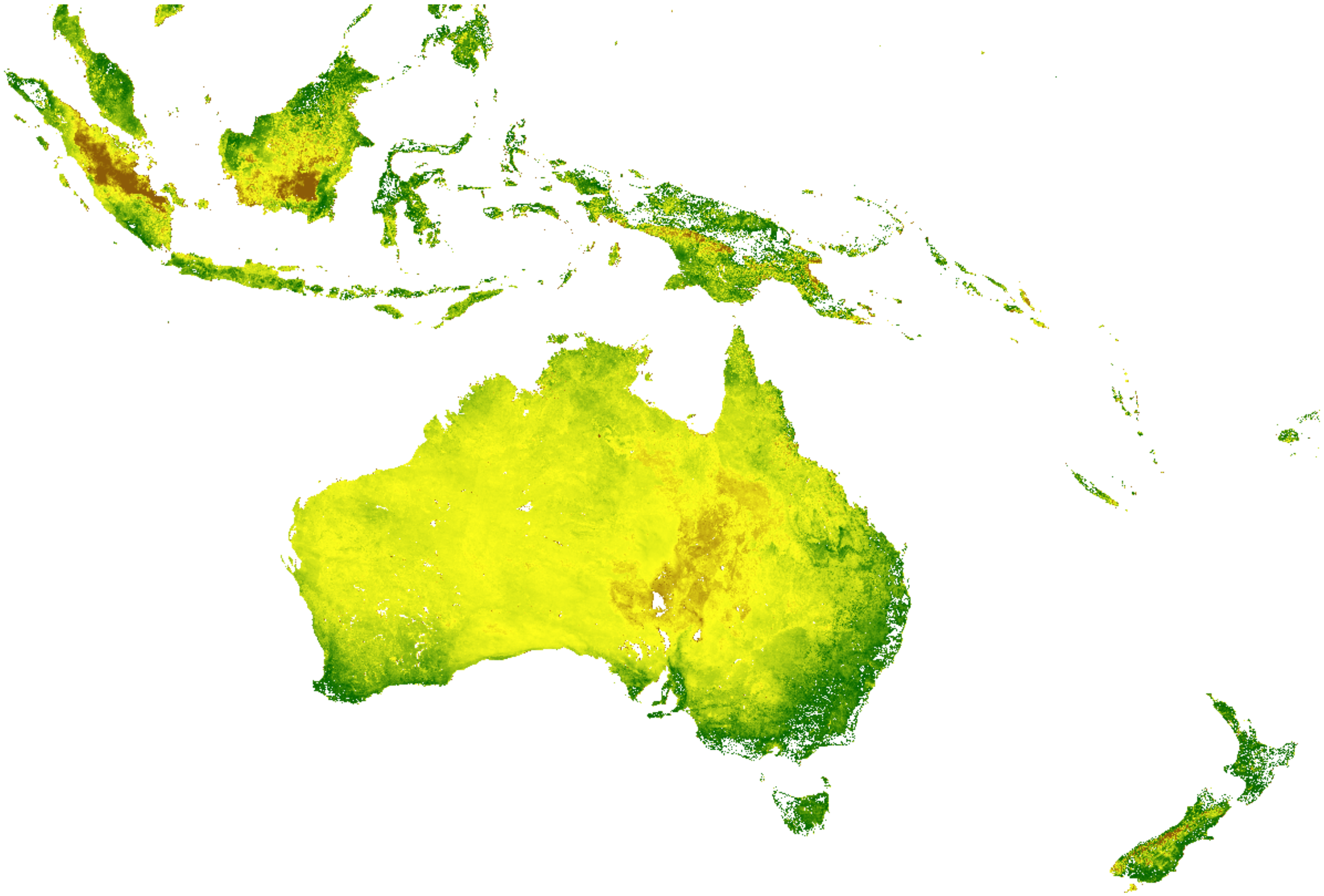
CNRM

NDVI (METOP-AVHRR)

Polar



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Applications

Use of BRDF for Fapar, Lai, fcover, NDVI

Use of albedo for Land-surface model

Use of albedo for Numerical Weather Prediction

Use of Albedo for Vegetation and soil albedo

Use of Downwell flux for Land-surface model

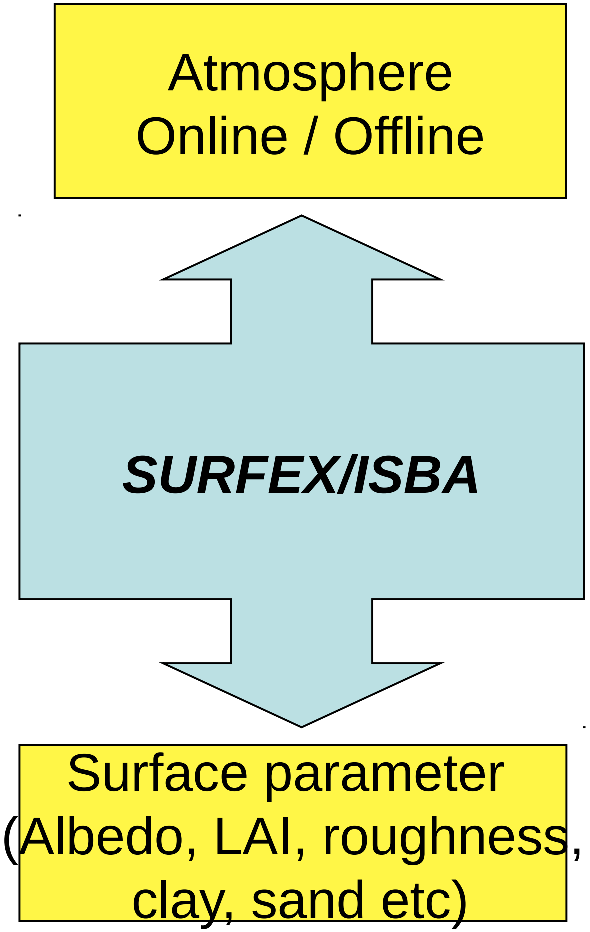
Use of Albedo for climate

Aerosol product from MSG (Icare)

Use of albedo product

- Use of albedo product for Land Surface model (LSM) : OFFLINE
  - Injecting the albedo in the ISBA model improve its performances

ISBA Land Surface Model



Atmosphere:

- Online: NWP/climate atmospheric model
- Offline: Temperature, water vapor, rainfall, incoming solar radiation, longwave flux, wind, etc. from reanalysis (SAFRAN, ERA-Interim) or observations.

Surface:

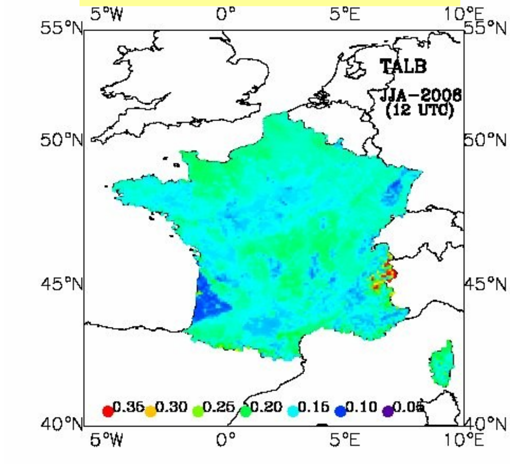
- Isba model: energy, water and carbon fluxes.

Physiography:

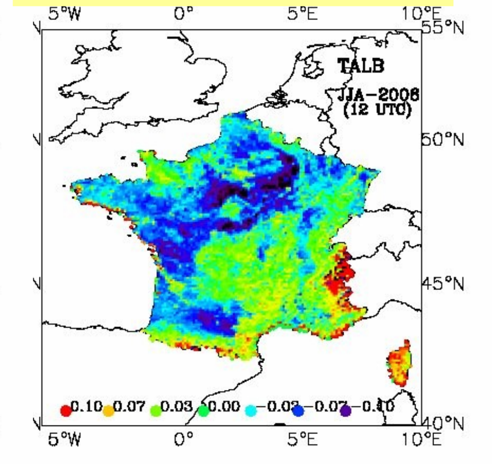
- Two experiments :
  - Eco : Albedo from database (ECOCLIMAP)
  - Saf : Albedo from SAF MSG observations.

Use of albedo product for LSM (OFFLINE)

Mean Eco. JJA



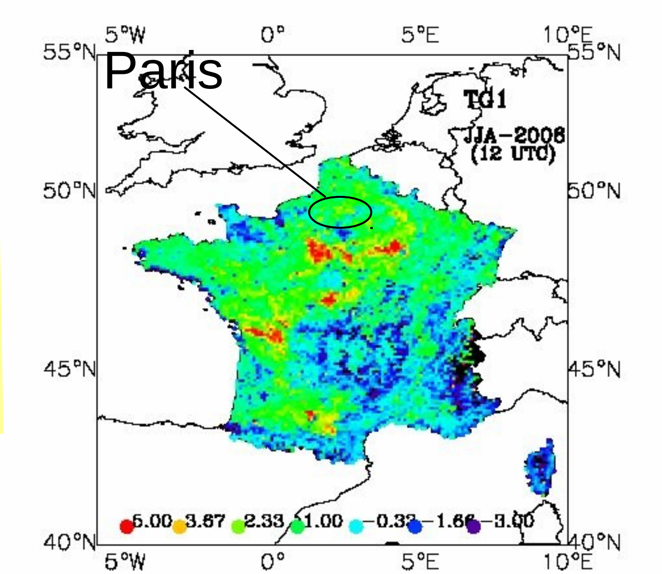
Max Alb(SAF-Eco)



Land surface model: ISBA (~9.5km) forced by SAFRAN atmospheric analysis.
Two experiments: with Ecoclimap albedo and with LSA-SAF albedo analysis
Run every day at 00h (2006) – in offline mode

JJA: maximum difference TG1 (Eco vs SAF)

reference-LandSAF



JJA:
-ΔALB between -0.1 and 0.1

Impact on:
-ΔTG1 between -3 and +6°K
-ΔTG2 between -1 and +2°K
-ΔWG1 between –0.04 and +0.04 m3/m3
-ΔWG2 < 0.01 m3/m3

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Aerosol product from MSG (Icare)

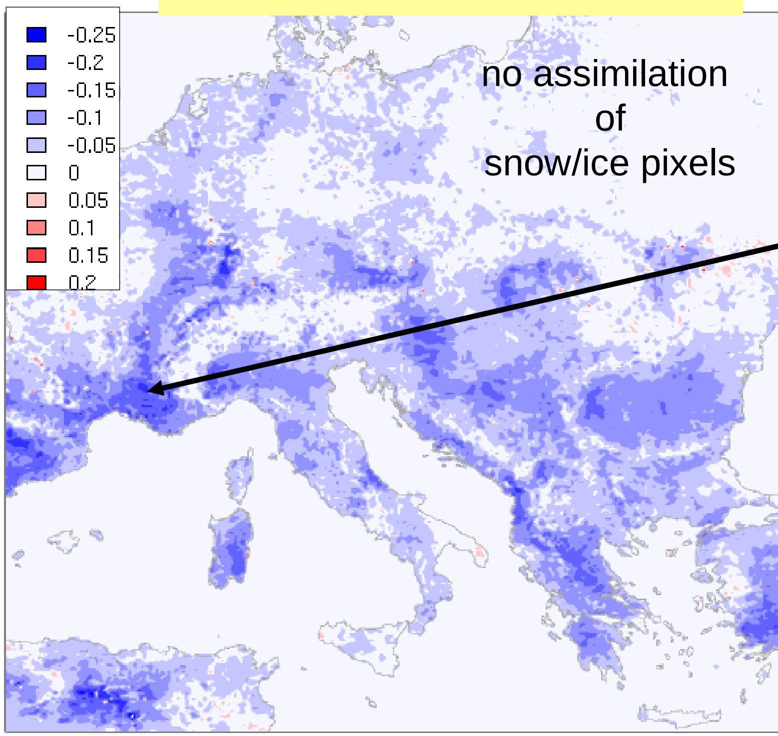
Use of albedo product

- Use of albedo product for Numerical Weather Predition (NWP) : ONLINE
  - Injecting Albedo in NWP model reduces the temperature bias in winter.

Use of albedo product for NWP (ONLINE)

Weather forecast model: ALADIN (~9.5km)
Two experiments: with ALADIN albedo and with LSA-SAF albedo analysis
Run every day at 00h (2007) - 54h forcast

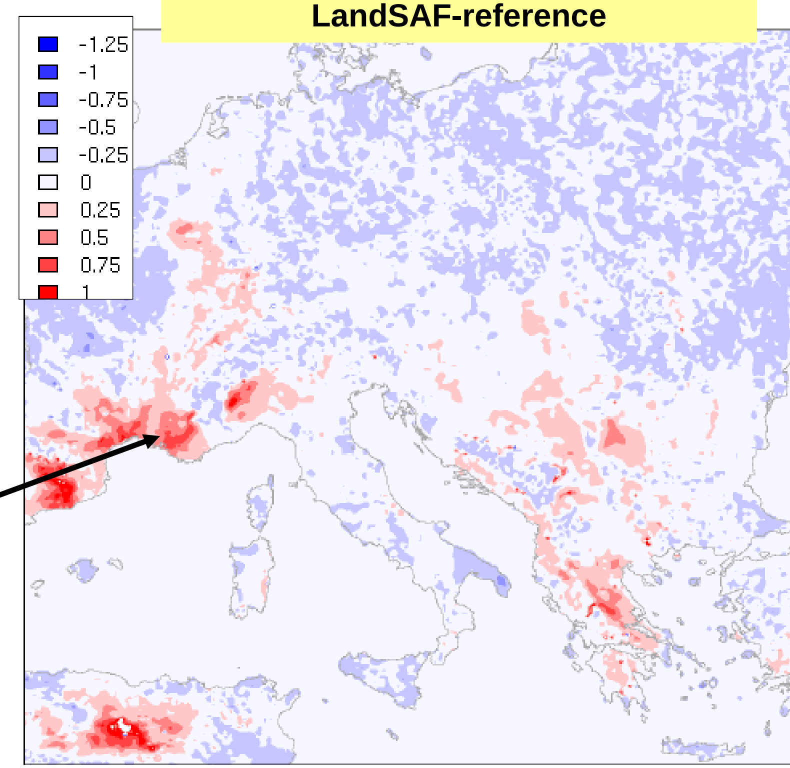
Surface albedo 15022007 00UTC+12
LandSAF-reference



LandSAF albedo is lower than Aladin albedo

a lower albedo induced warmer atmospheric T2m

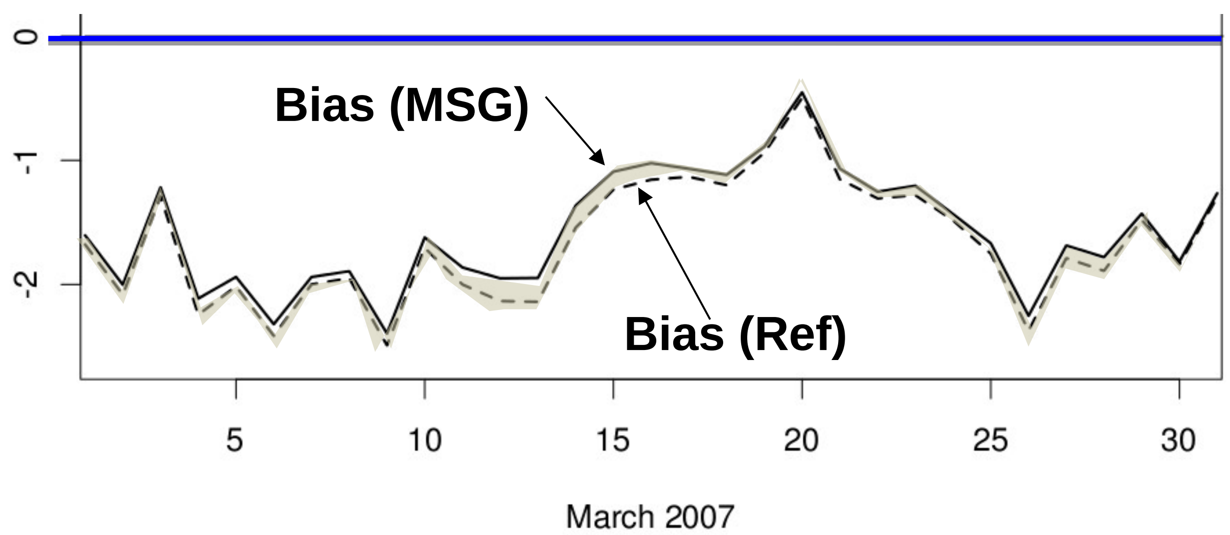
2m temperature 15022007 00UTC+12
LandSAF-reference



(J. Cedilnik, D. Carrer, J.-F. Mahfouf, and J.-L. Roujean "Impact assessment of daily satellite derived surface albedo in a limited area NWP model", **Submitted to J. of Ap. Meteorology and Climatology**)

Use of albedo product for NWP (ONLINE)

Score T2m (forecast 12h)
(mean average over East of Europe)



Conclusion of Score Study: weather model has a significant cold bias in winter. Satellite data allows to reduce the bias.

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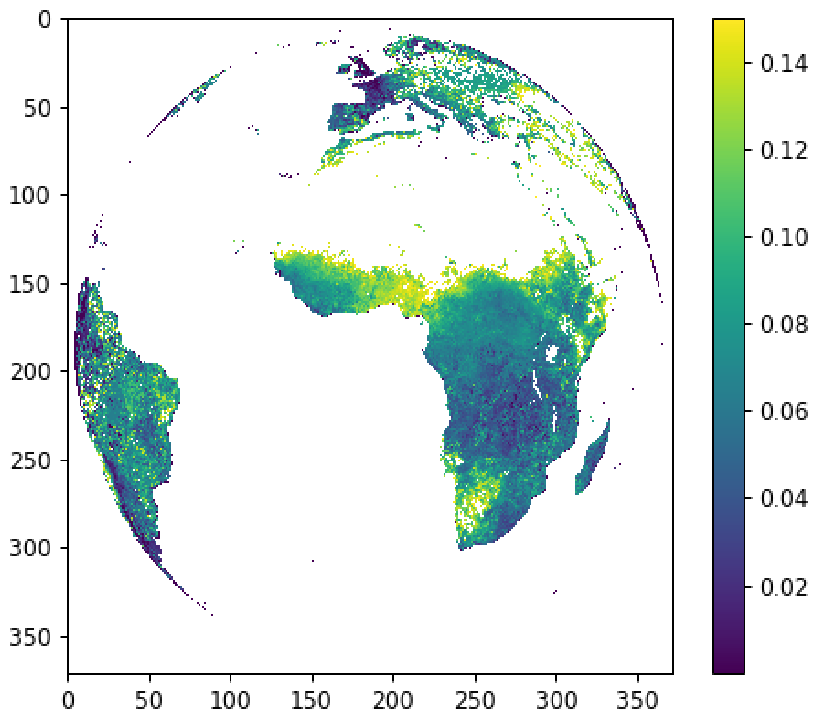
Aerosol product from MSG (Icare)

MDAL-SVS PRODUCT CHARACTERISTICS (LSA-104)

19th of February, 2017.



MSG/SEVIRI Directionnal-Hemispherical vegetation albedo in the visible domain [0,3-0,7µm]

Separated Soil Vegetation Snow Albedo (MDAL-SVS)

Spatial Resolution: 3km at Sub-Satellite Point
Projection: native MSG/SEVIRI Projection
Production Frequency: Daily
Effective Temporal Resolution: 5 Days

Format: HDF5
Timeliness: 3 hours
Status: in development

BroadBand Albedo (6):
- soil, vegetation, and snow albedos
- VIS-BH [0.4µm, 0.7µm]
- NIR-BH [0.7µm, 4.0µm]

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METHOD FOR RETRIEVAL (LSA104)

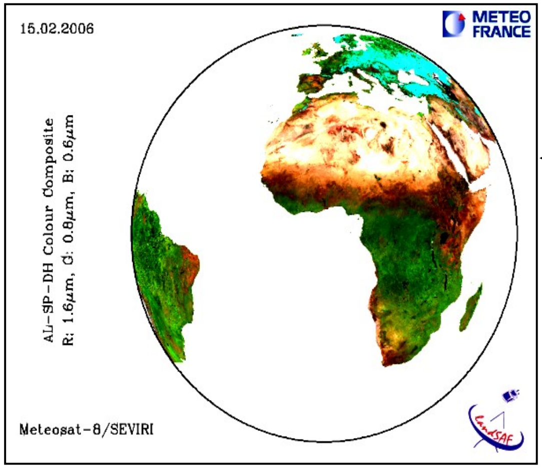
Method: Kalman Filtering to generate a daily analysis of the surface albedo components

Satellite product: total surface albedo and its uncertainty
Output fields: - bare soil albedo
- vegetation albedo

$$x_i^a = x_i^b + K_i [y_i - H x_i^b]$$

$$K_i = A_i^b H^T [H A_i^b H^T + R_i]^{-1}$$

- state vector .... $x_i^a = [a_{veg}^a , a_{sn}^a]^T$
- obs. vector .... $y_i = [a_{veg}^{clim} , a_{sn}^{clim} , a_{tot}^{saf}]^T$
- obs. operator........ $H = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ veg^{clim} & 1 - veg^{clim} \end{bmatrix}$
- obs. error .... $R_i = \begin{bmatrix} (\sigma_{veg}^{clim})^2 & 0 & 0 \\ 0 & (\sigma_{sn}^{clim})^2 & 0 \\ 0 & 0 & (\sigma_{tot}^{saf})^2 \end{bmatrix}$

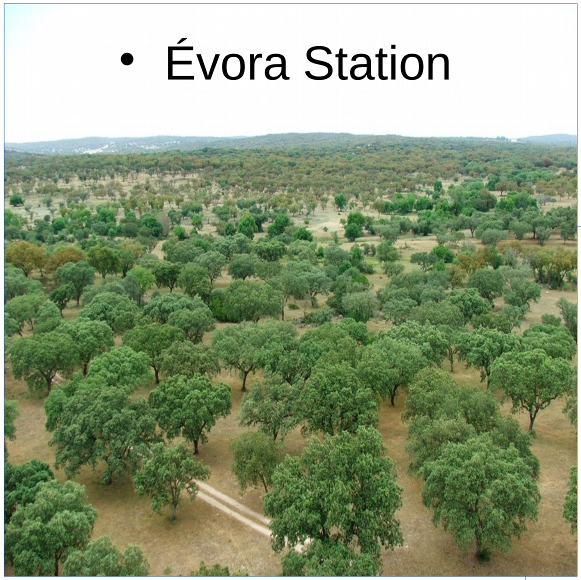


$\leftarrow a_{tot}^{saf}$

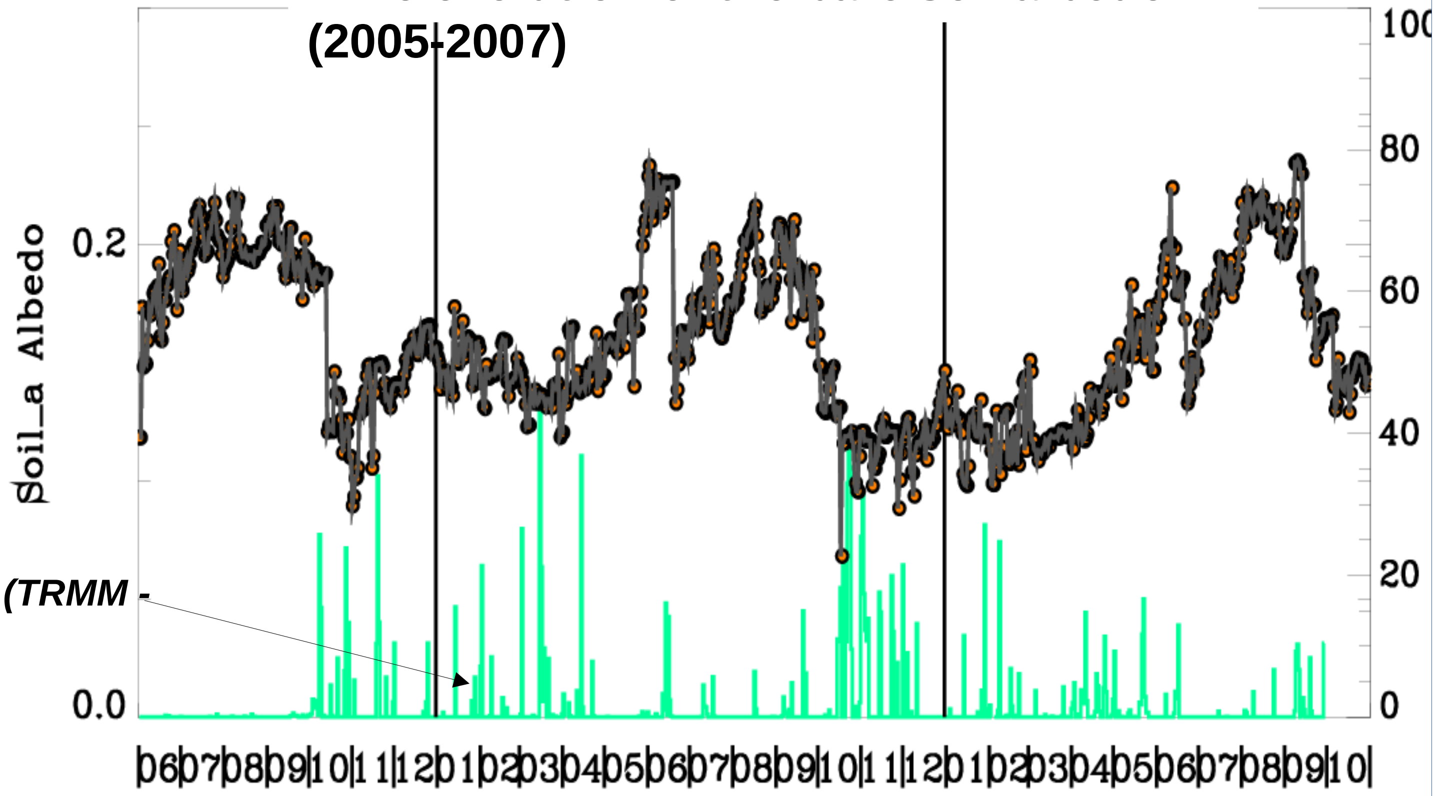
- *J. Cedilnik, D. Carrer, J.-L. Roujean and J.-F. Mahfouf, 2012, Analysis of satellite derived surface albedo for numerical weather prediction, J. Climate Appl. 2012*
- *Carrer, D., Meurey, C., Ceamanos, X., Roujean, J.-L., Calvet, J.-C., and Liu, S. (2014), Dynamic mapping of snow-free vegetation and bare soil albedos at global 1km scale from 10-year analysis of MODIS satellite products, Remote Sensing of Environment, Vol. 140, pp. 420-432.*

RESULTS

- Évora Station



Time evolution of the bare soil albedo (2005-2007)



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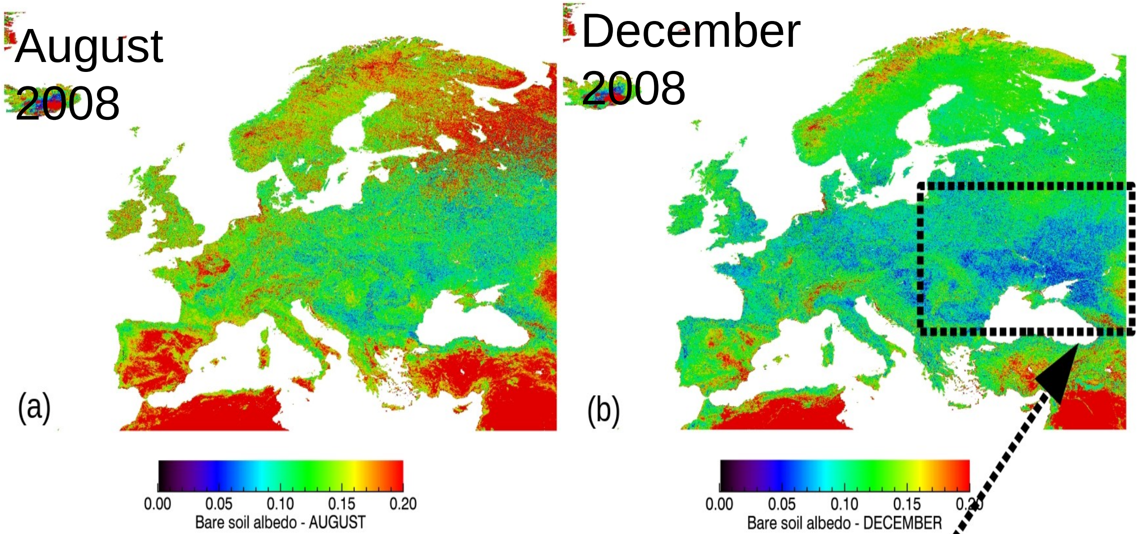
EUMETSAT
LSA SAF
LAND SURFACE ANALYSIS

RESULTS

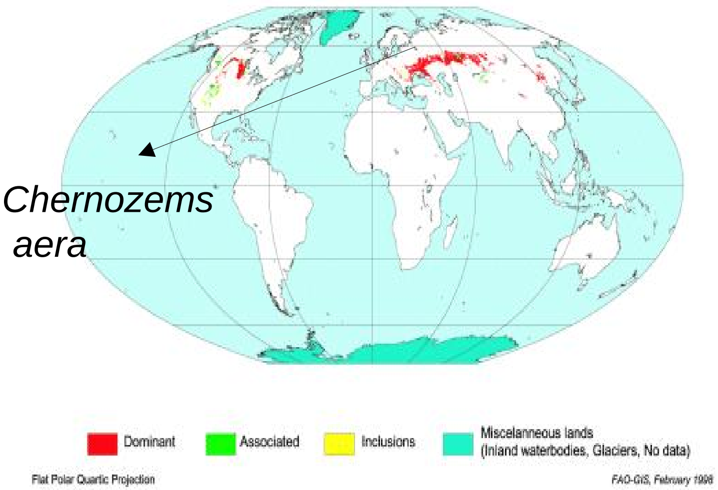
Bare soil albedo

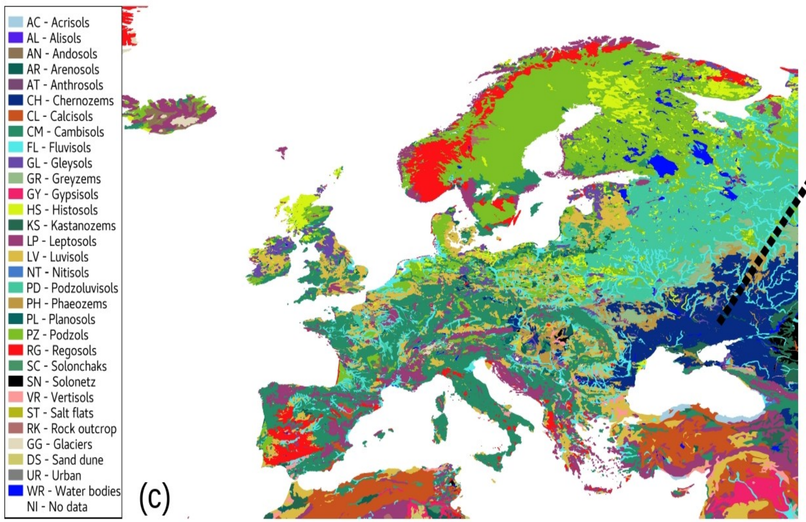
August 2008

December 2008



Global Distribution





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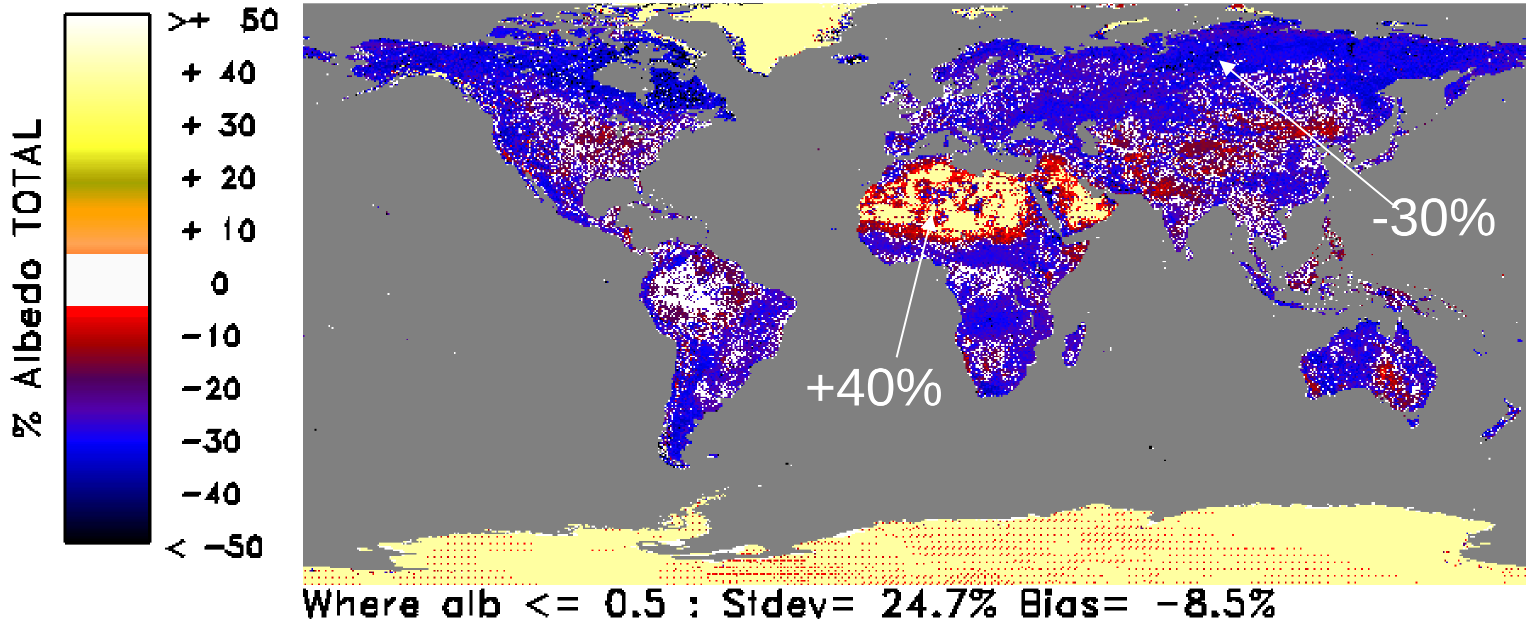
Aerosol product from MSG (Icare)

Use of albedo product for climate (ONLINE)

Model: ARPEGE-Climat
Run: 1979-2010

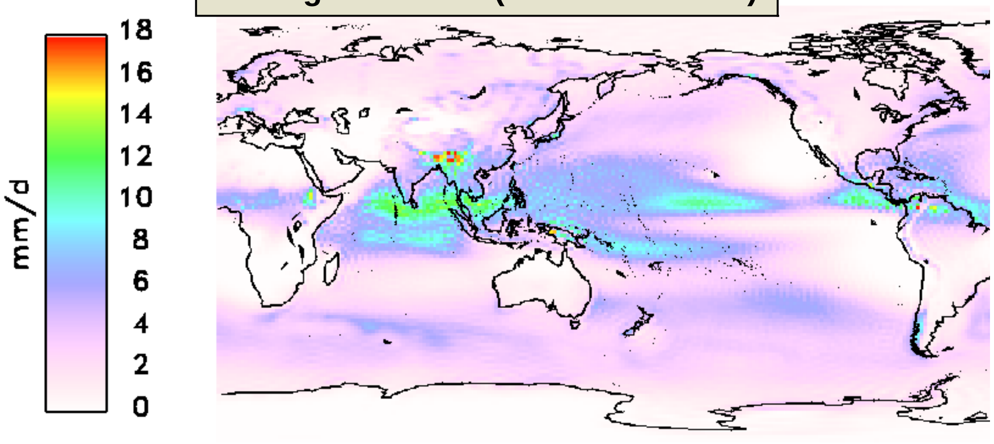
2 experiments:
-with ECOCLIMAP albedo (Ref.);
-with MODIS albedo (10ans). **(Carrer et al., RSE, 2014a)**

Relative difference betwen ECOCLIMAP and MODIS

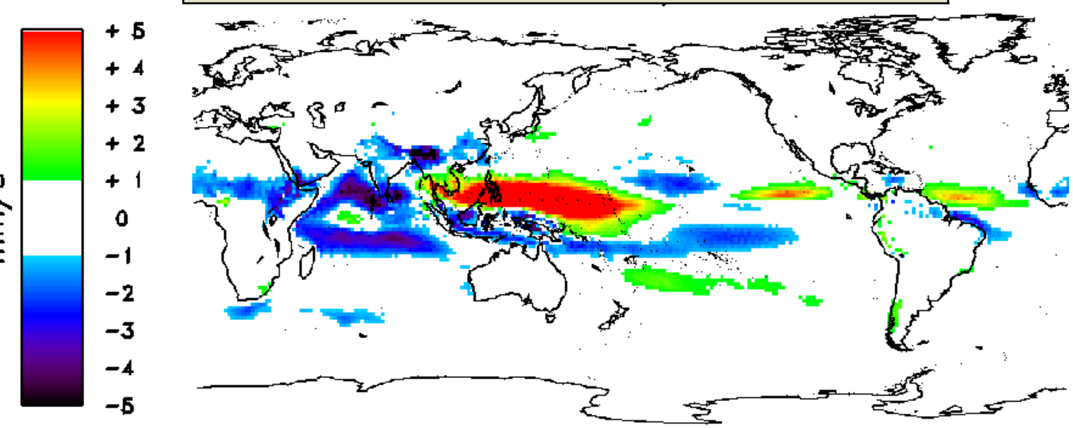


Use of albedo product for climate (ONLINE)

Average RR : CTL (JJAS 1979-2010)



Average RR : ALBEDO-CTL (JJAS 1979-2010)



Use of albedo product for climate (ONLINE)

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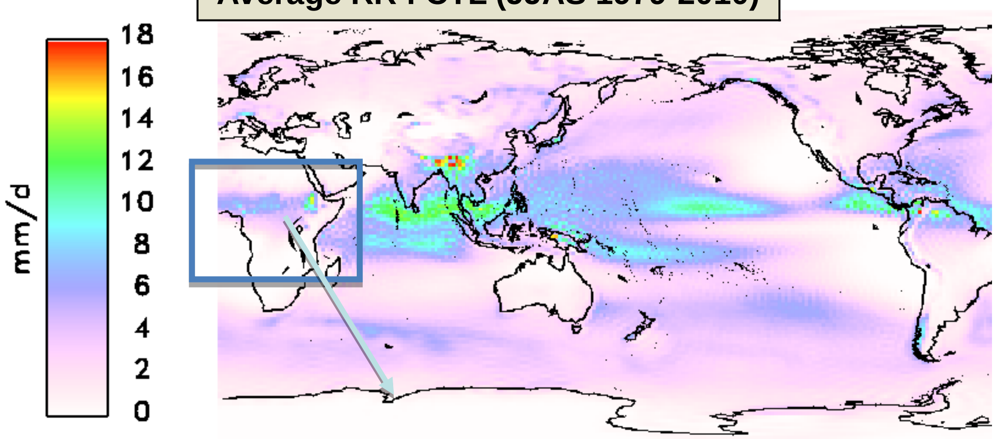
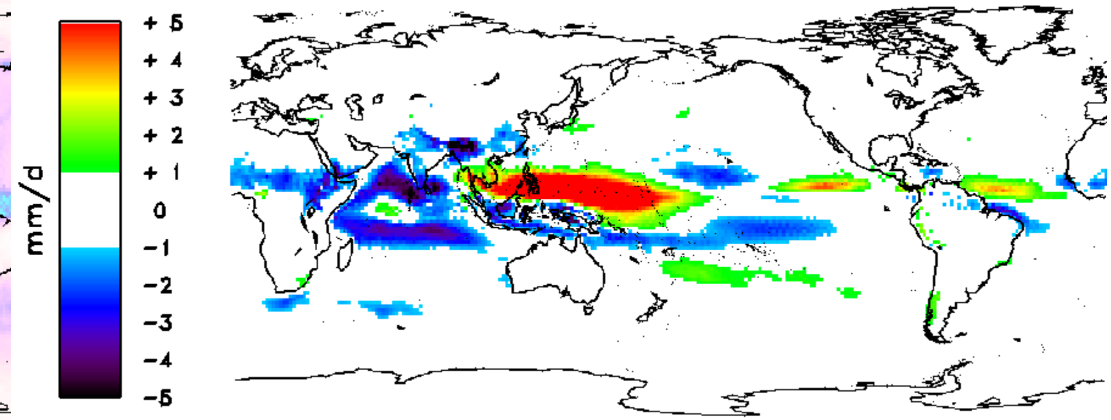
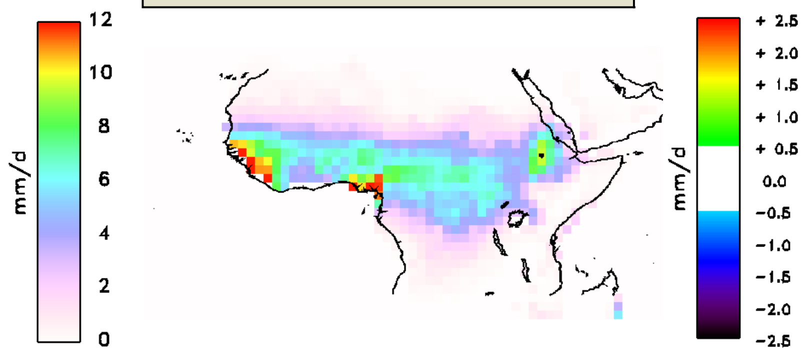


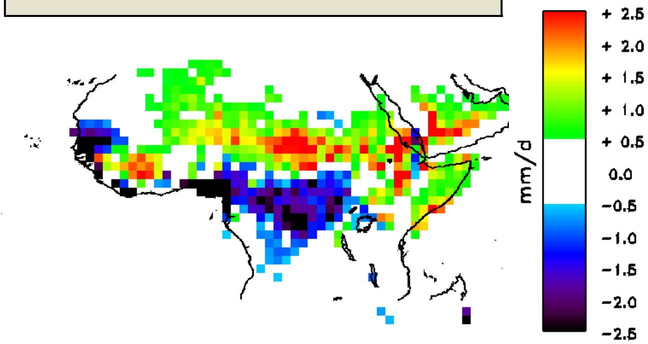
Average RR : ALBEDO-CTL (JJAS 1979-2010)



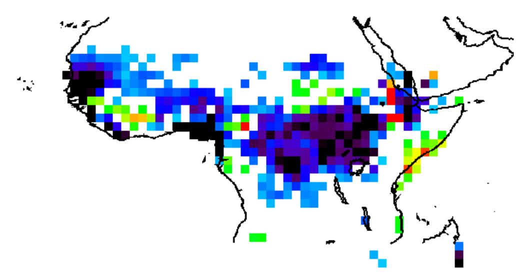
OBSERVATIONS (from GPCC)



CTL-OBS



ALB-OBS



(Carrer et al., 2014a)

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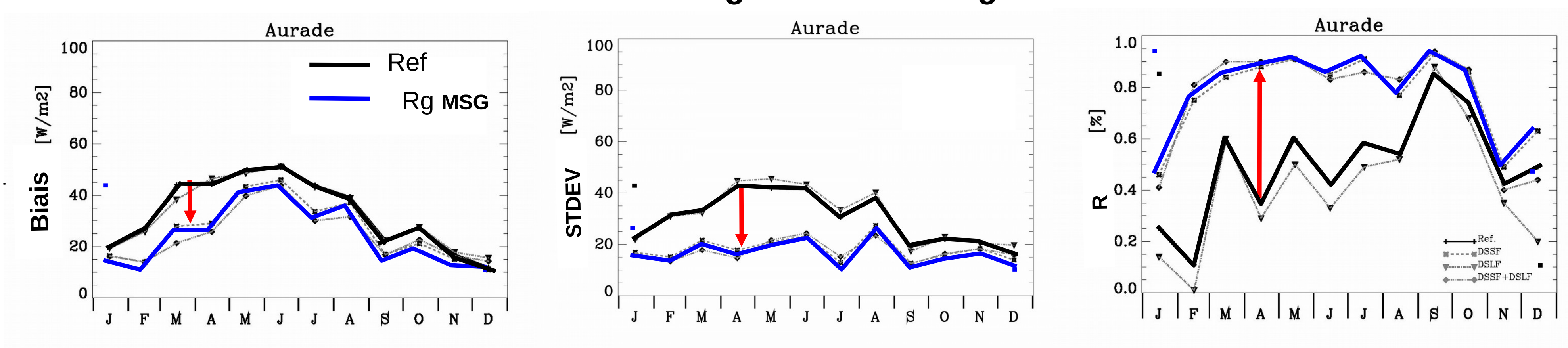
Use of DSSF product for LSM (ONLINE)

land surface model: ISBA **2 experiments:** SAFRAN atmospheric analysis (Ref)
or LSA-SAF DSSF (blue)

Difference statistics of Net Radiation (RN) over Aurade station based on ISBA simulations in using various forcing



- When satellite data are considered, the standard deviation of net radiation simulated with ISBA model can decease by 20 W.m^{-2} in comparison with ground-measurements.
- As many areas lack a high resolution meteorological forcing, the LSA-SAF radiative products provide new and valuable information.

Publication : D. Carrer, S. Lafont, J.-L. Roujean, J.-C. Calvet, C. Meurey, P. Le Moigne, and I. Trigo, 2011: *Incoming solar and infrared radiation derived from METEOSAT: impact on the modelled land water and energy budget over France*, J. Of Hydrometeorology.

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Albedo Algorithm

Observations : TOA Top-of atmosphere

- 3 wavelenghts
  (0,6 µm 0,8 µm et 1,6 µm)
- Multiple solar angles on 1 day (MSG)
- **or**
- Multiple view angles on 10 days (EPS)

TOA

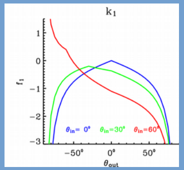
800k simulations of atmosphere interaction using (6S)
Modeling gaz (Ozone, H2O, CH4, …) and aerosols
Statistics → Approximation parameters.   OFF-LINE.

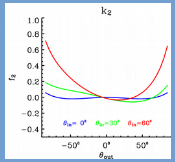
Coefficients (Smac)

Step 1 : Atmospheric Correction

Top-of-Canopy (TOC)

Step 2 : Surface interaction
Semi-empiracal model based-on kernels
brdf(lambda, thetaS, thetaV) = k0 + k1 f1( ) + k2 f2( )





Step 2 : Surface Interaction

Bidirectional Reflectance :
BRDF(lambda, thetaS, thetaV)

- Depends on the wavelenght
- Depends on the solar angles
- Depends on the view angles

Reflectance (BRDF)

Step 3 : Integration

Step 3 : Integration
Angular integration (on thetaS et thetaV)
Spectral integration

Albedos

- Visible Albedos
- NIR Albedos
- Broad band albedo
- Narrow band albedo

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Improve model parametrization

An additional kernel in the model allows direct aerosol modelling

$$\rho_{ToL}(\theta_s,\theta_v,\phi,\tau)=\sum_{i=0}^{3}k_i\, f'_i(\theta_s,\theta_v,\phi,\tau)$$

- **Surface contribution**

$$f'_{i=0,2}(\theta_s,\theta_v,\phi,\tau)=\frac{T_a(\theta_s,\tau)\,T_a(\theta_v,\tau)}{1-S_a(\tau)\langle\rho_s\rangle}\, f_i(\theta_s,\theta_v,\phi)$$

$$T_a(\theta,\tau)=e^{-\tau/\mu}+\tau e^{-u-v\tau-w\tau^2}$$

$$S_a(\tau)=\tau\left(ae^{-\tau/\alpha}+be^{-\tau/\beta}+c\right)$$

$$u,v,w \text{ depend on } \mu\wedge g$$

$$a,b,c,\alpha,\beta \text{ are constant, parameterized by } g$$

Kokhanovsky et al., 2005

- **Direct aerosols contribution**

$$f'_3(\theta_s,\theta_v,\phi,\tau)=\frac{\omega_0 P(\Theta)}{4\mu_s\mu_v}\,\frac{1-e^{-m\tau}}{m\tau}\, f_{ms}(\tau)$$

$$f_{ms}(\tau)=1+\frac{\tau(7-\tau)}{5}$$

Rozanov and Kokhanovsky, 2006

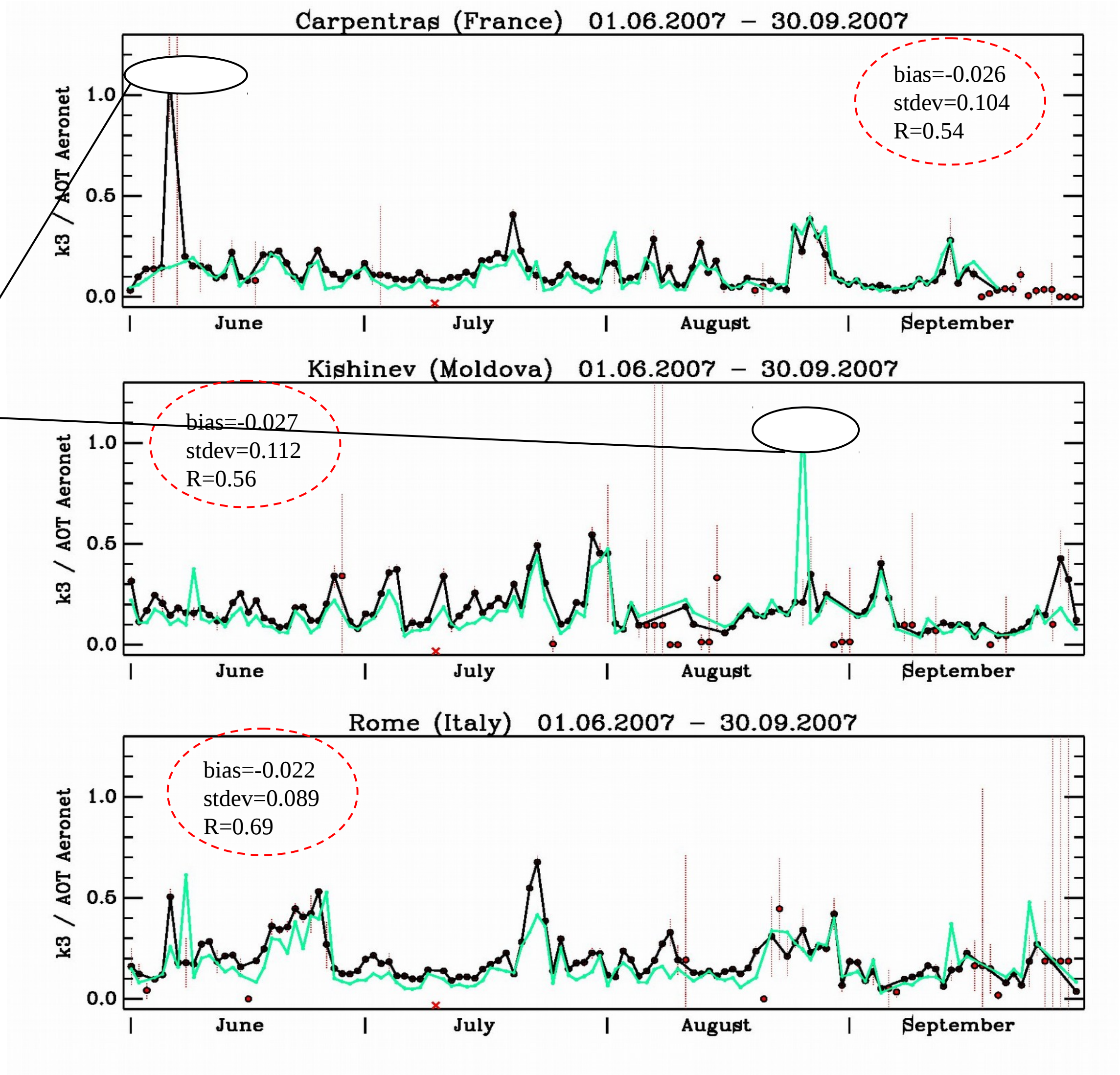
$$f_0(\theta_s,\theta_v,\phi)=1$$

$$f_1(\theta_s,\theta_v,\phi)=\frac{1}{2\pi}\left[(\pi-\phi)\cos\phi+\sin\phi\right]-\frac{1}{\pi}\left(\tan\theta_s+\tan\theta_v+\sqrt{\tan\theta_{s^2}+\tan\theta_{v^2}-2\tan\theta_s\tan\theta_v\cos\phi}\right)$$

$$f_2(\theta_s,\theta_v,\phi)=\frac{4}{3\pi}\,\frac{1}{\mu_s+\mu_v}\left[\left(\frac{\pi}{2}-\xi\right)\cos\xi+\sin\xi\right]-\frac{1}{3}$$

Roujean et al., 1992

Validation with AERONET stations in Europe



False cloud detection ?

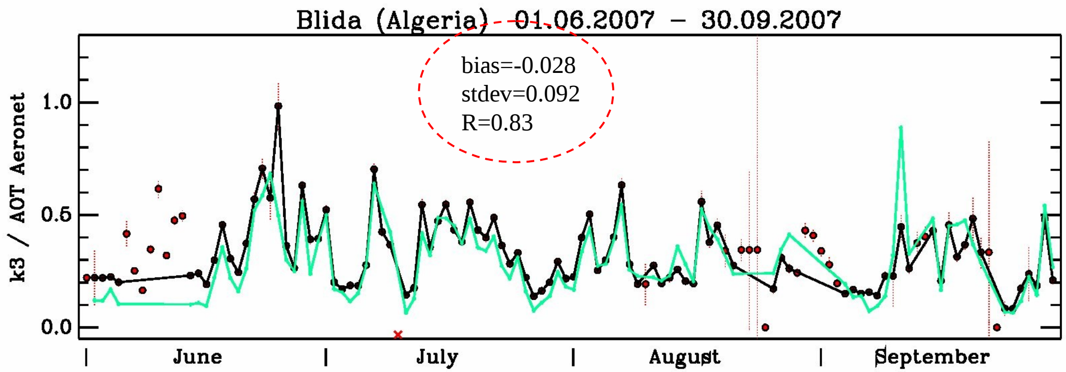
Aerosol load from AERONET (Ground measurements)

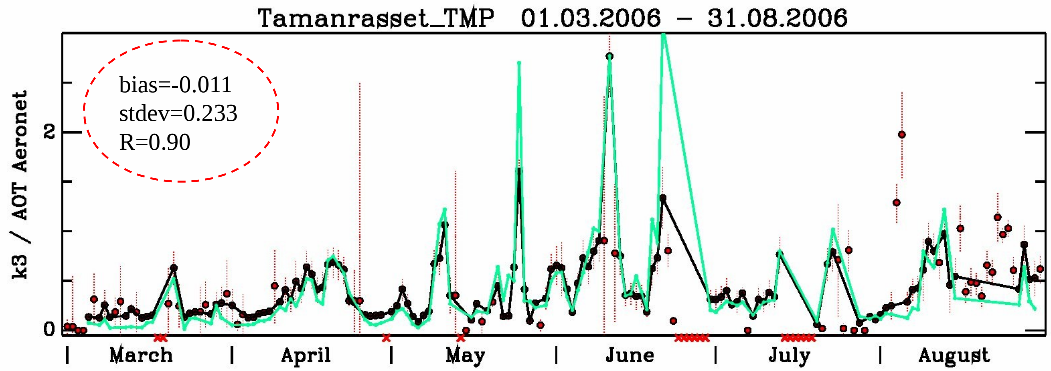
Aerosol load from MSG (SEVIRI)

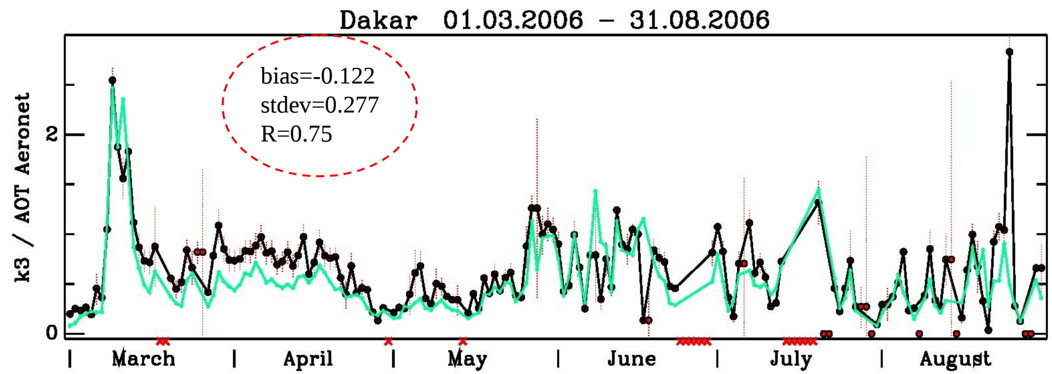
Daily AOD

Validation with AERONET stations in Africa

Daily AOD

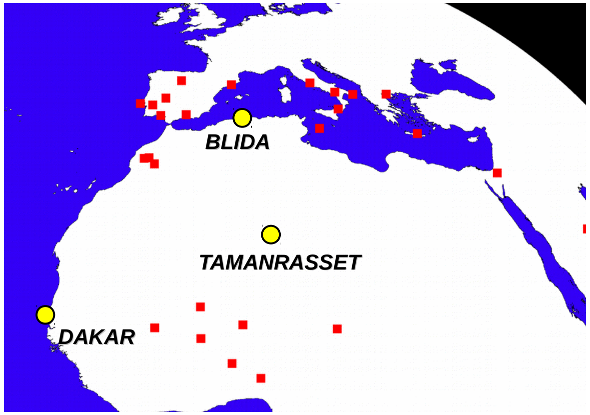




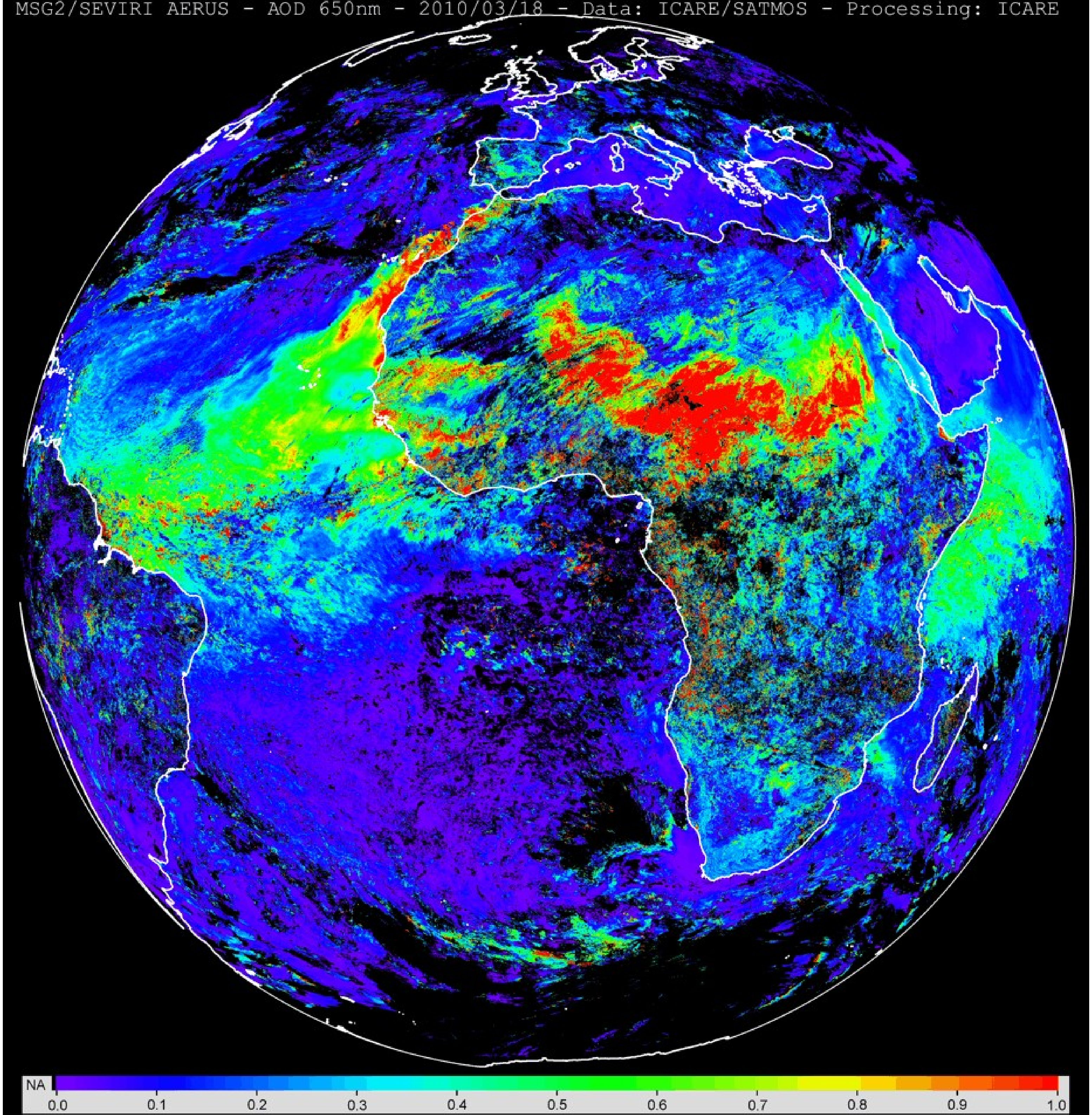


Aerosol load from AERONET (Ground measurements)

Aerosol load from MSG (SEVIRI)



UMR3589 CNRM


MSG2/SEVIRI AERUS - AOD 650nm - 2010/03/18 - Data: ICARE/SATMOS - Processing: ICARE
NA
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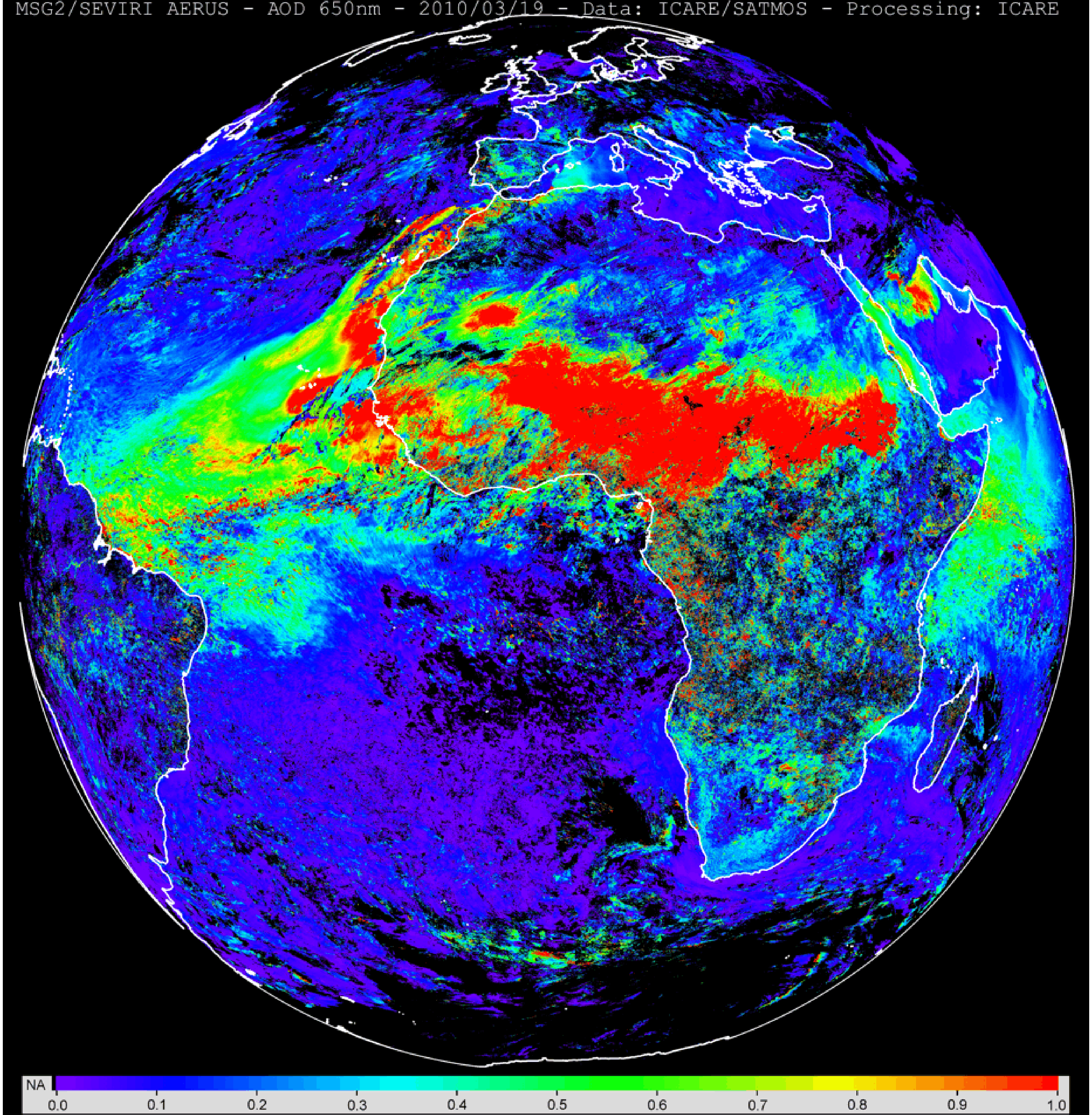
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

2010/03/18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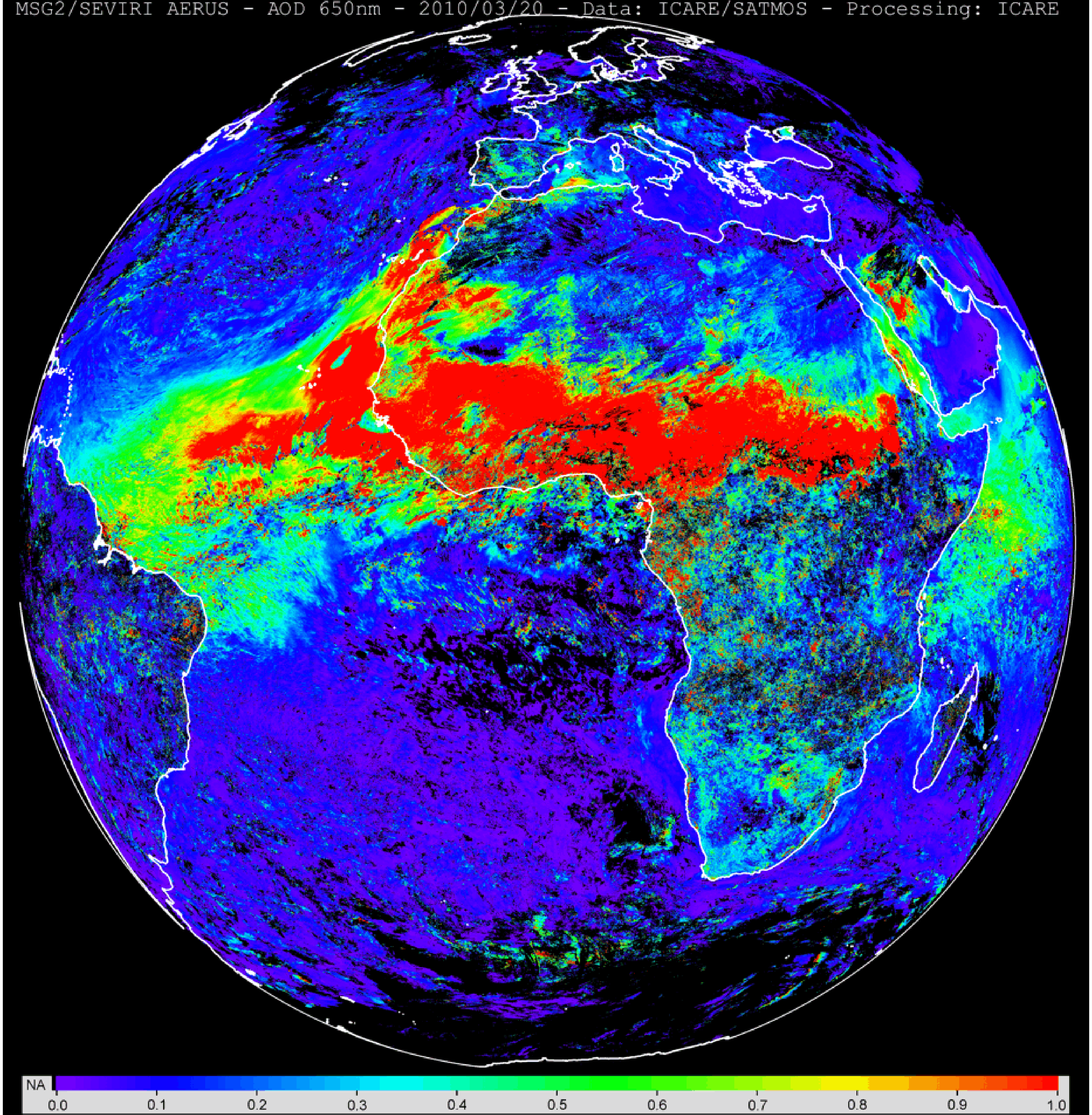
2010/03/19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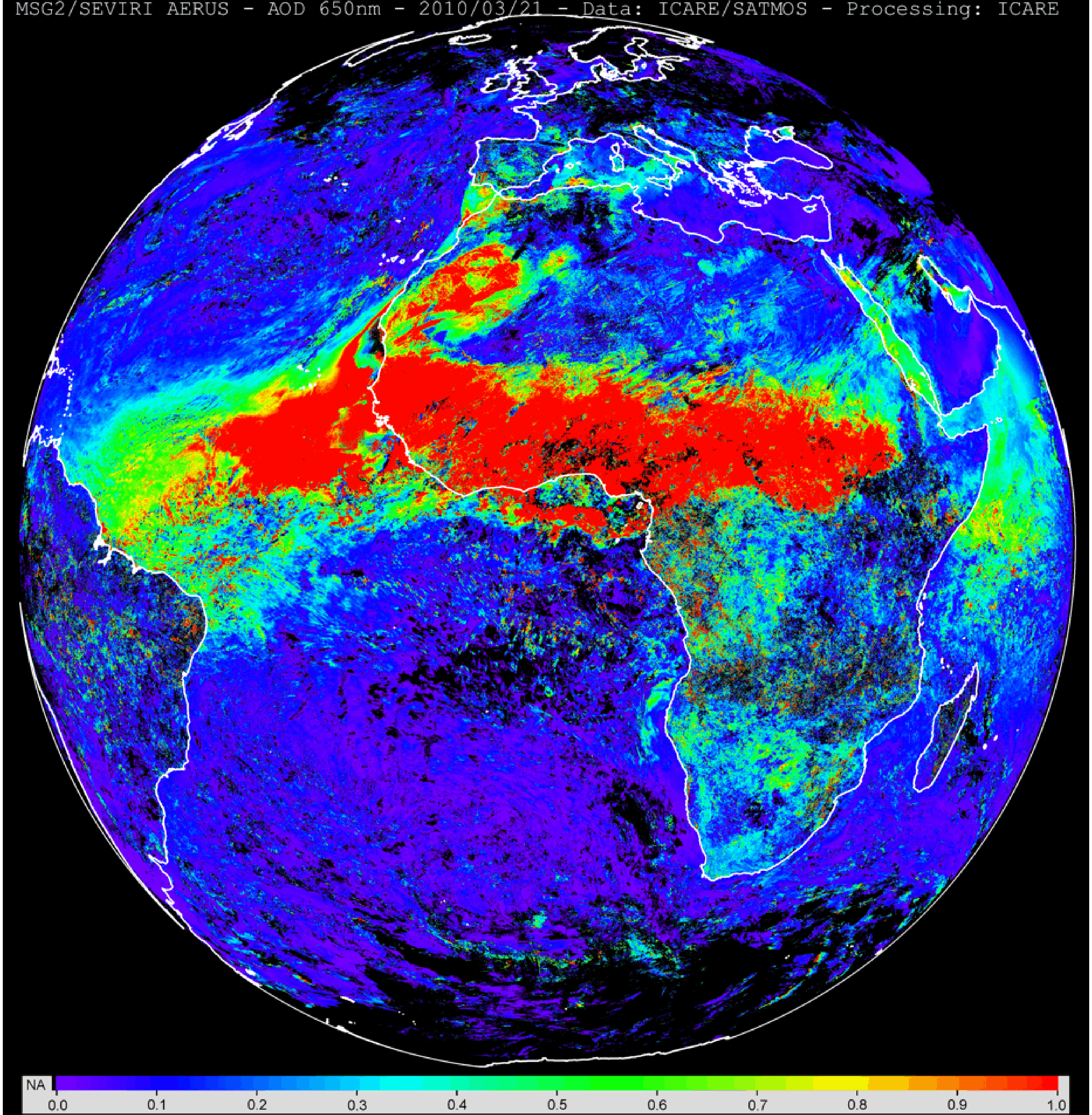
2010/03/20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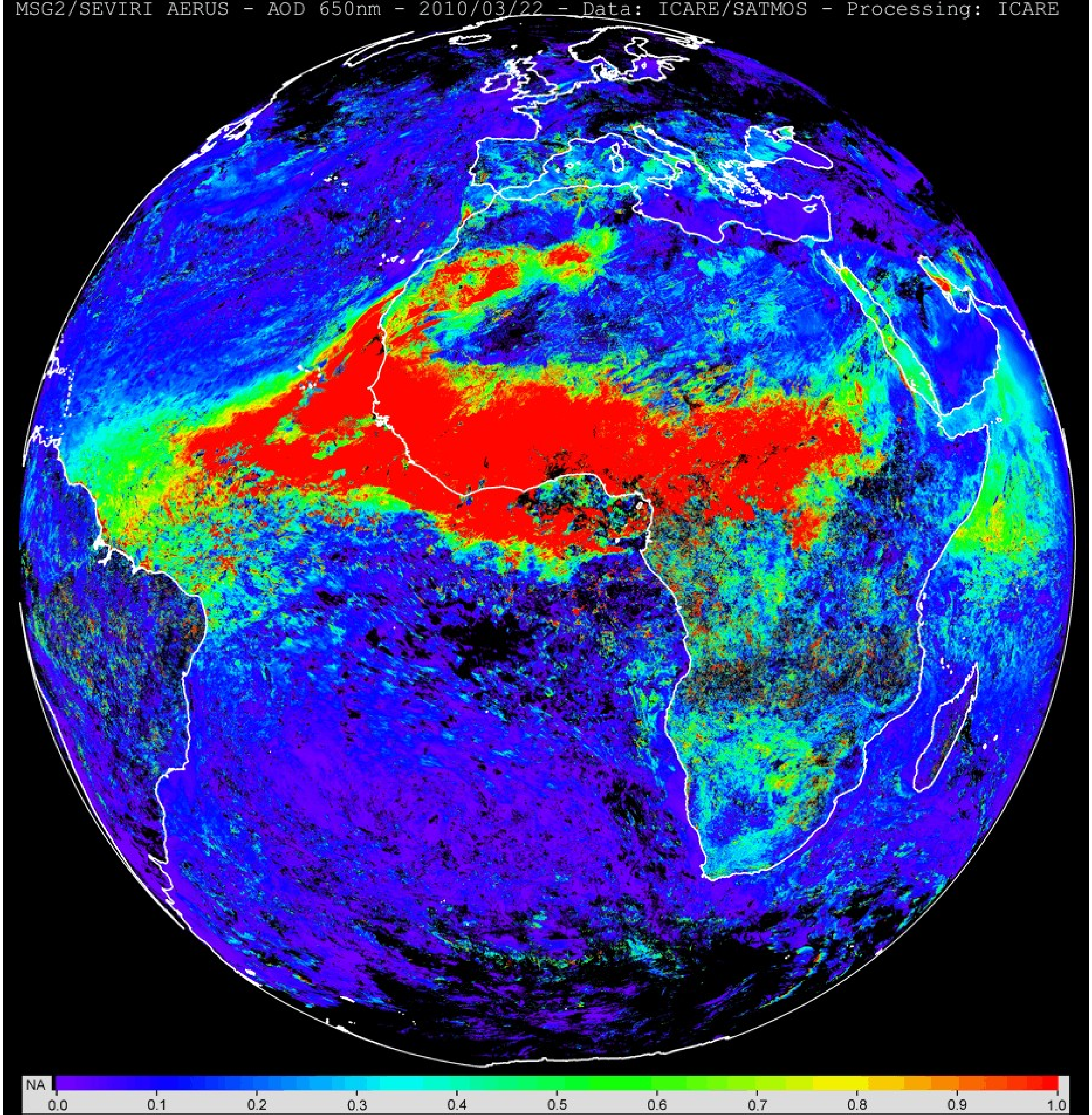
2010/03/21


MSG2/SEVIRI AERUS - AOD 650nm - 2010/03/22 - Data: ICARE/SATMOS - Processing: ICARE
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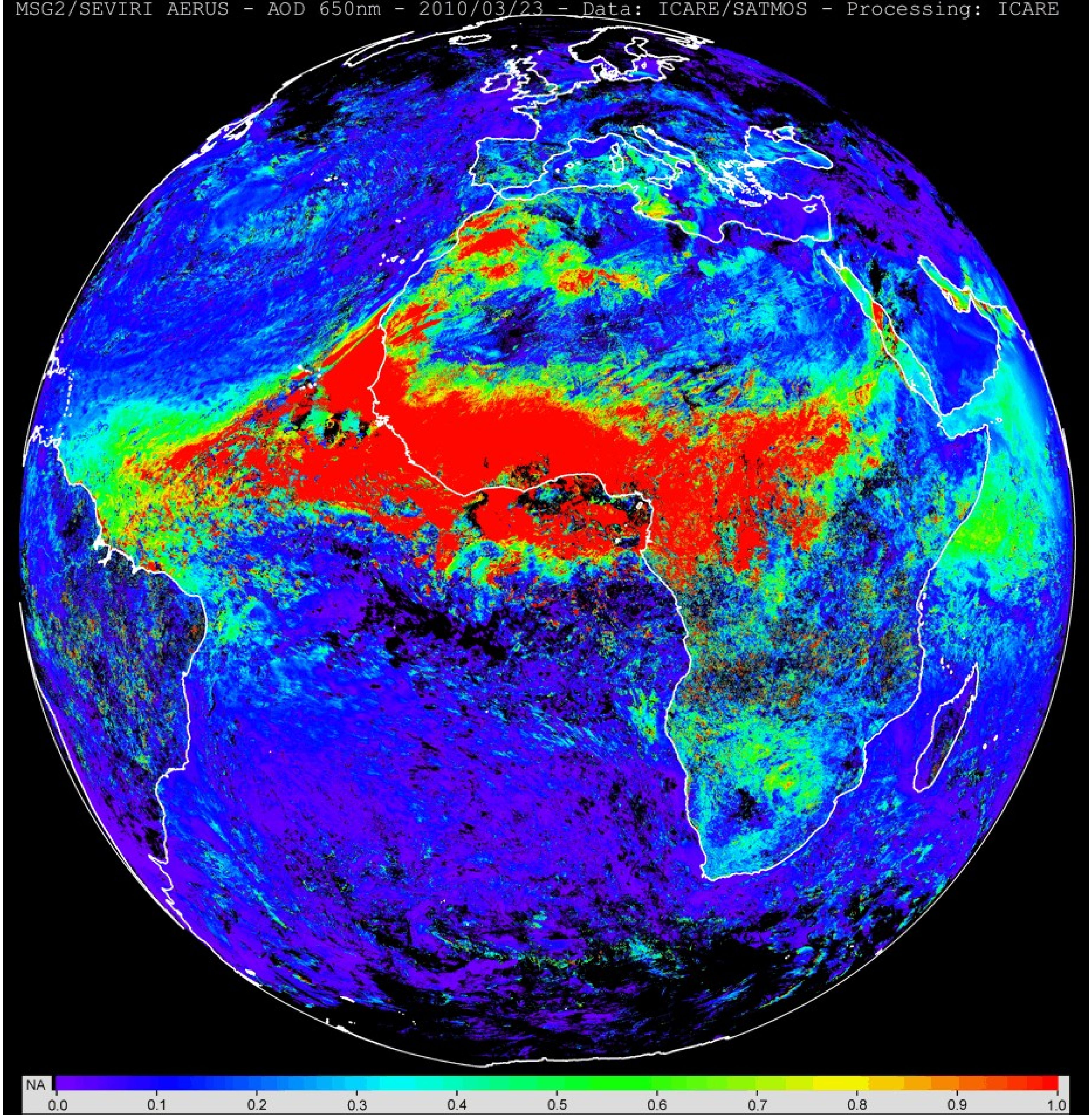
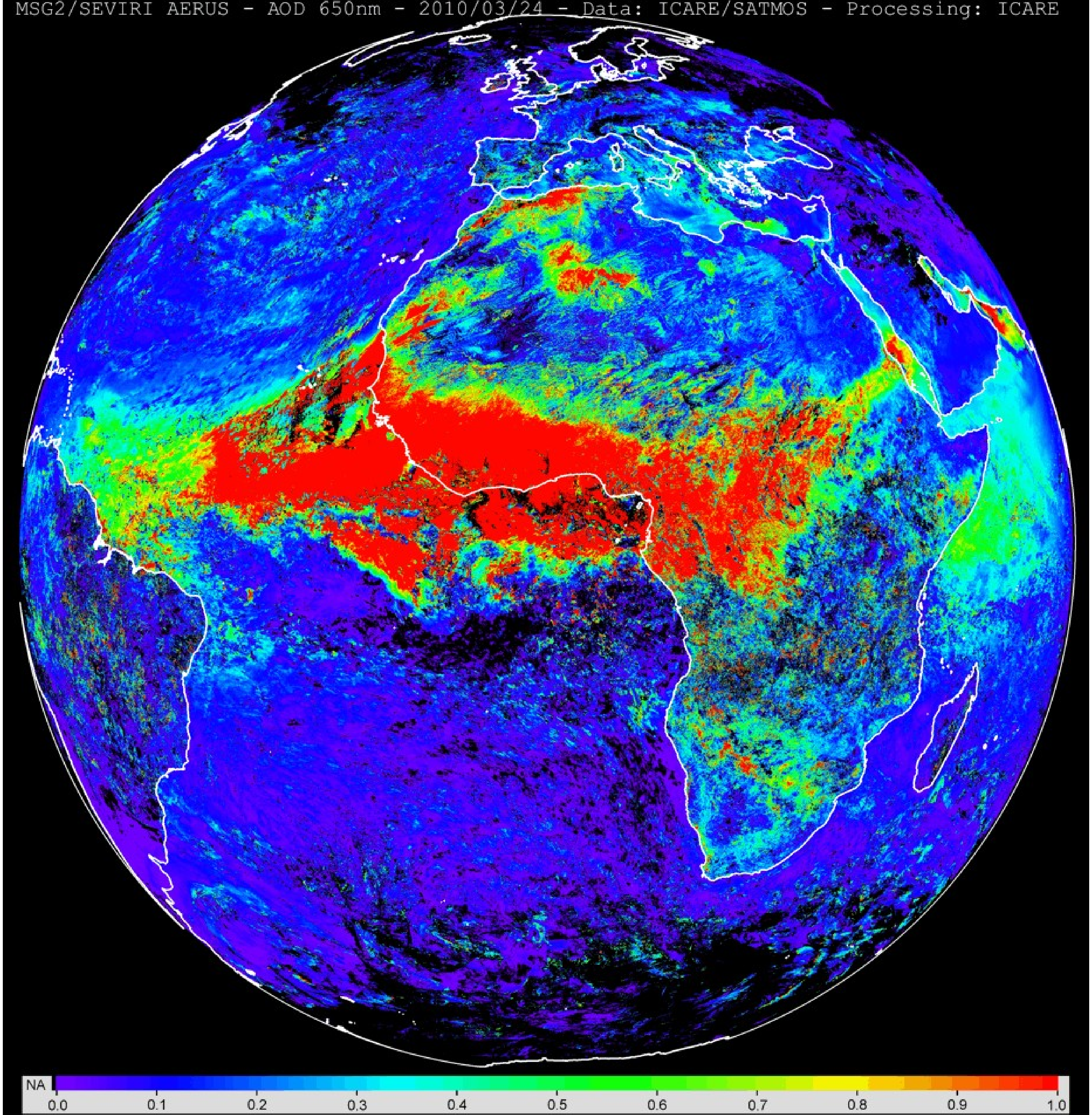
0.6
0.7
0.8
0.9
1.0

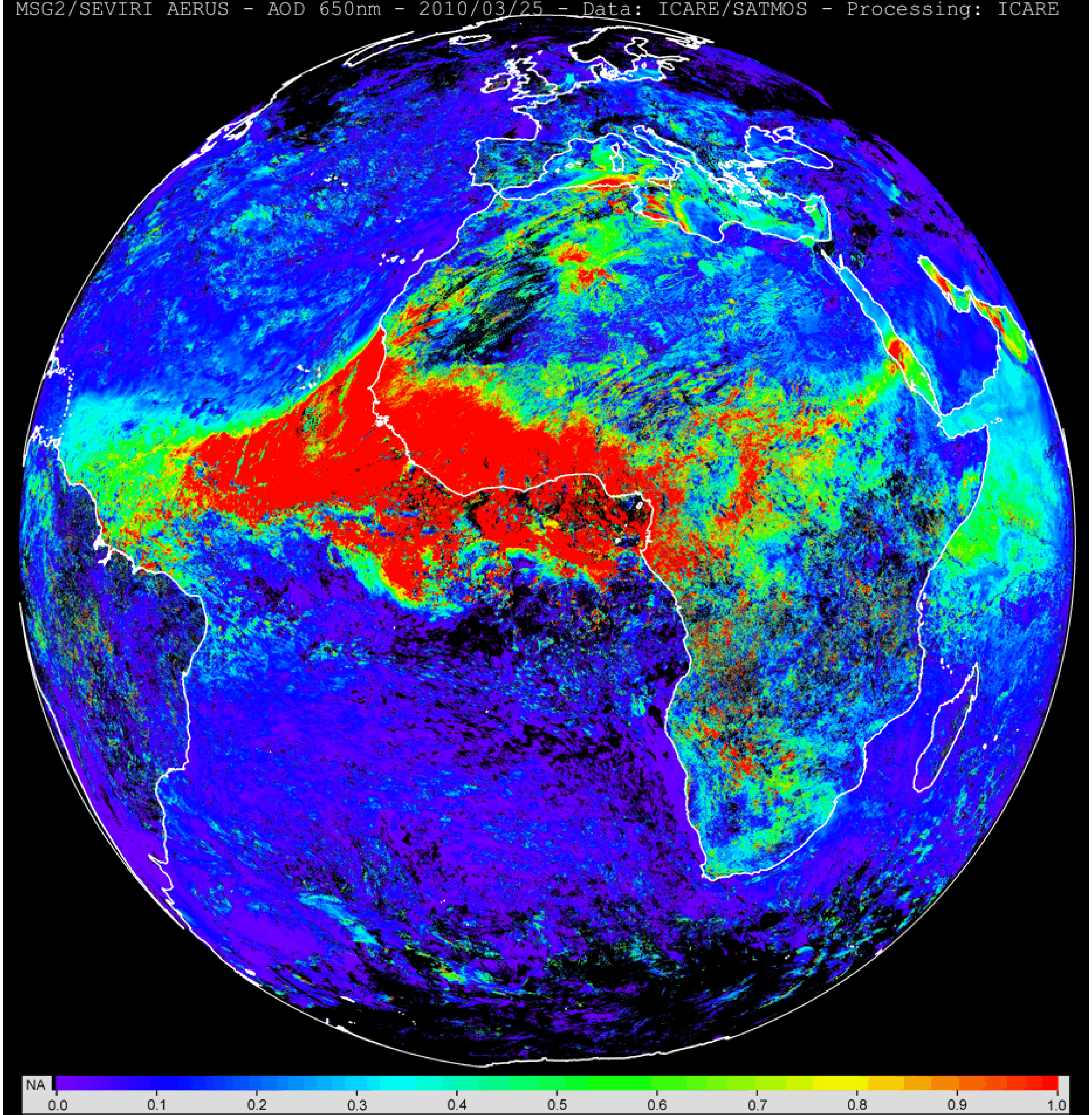
2010/03/22


MSG2/SEVIRI AERUS - AOD 650nm - 2010/03/23 - Data: ICARE/SATMOS - Processing: ICARE
NA
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

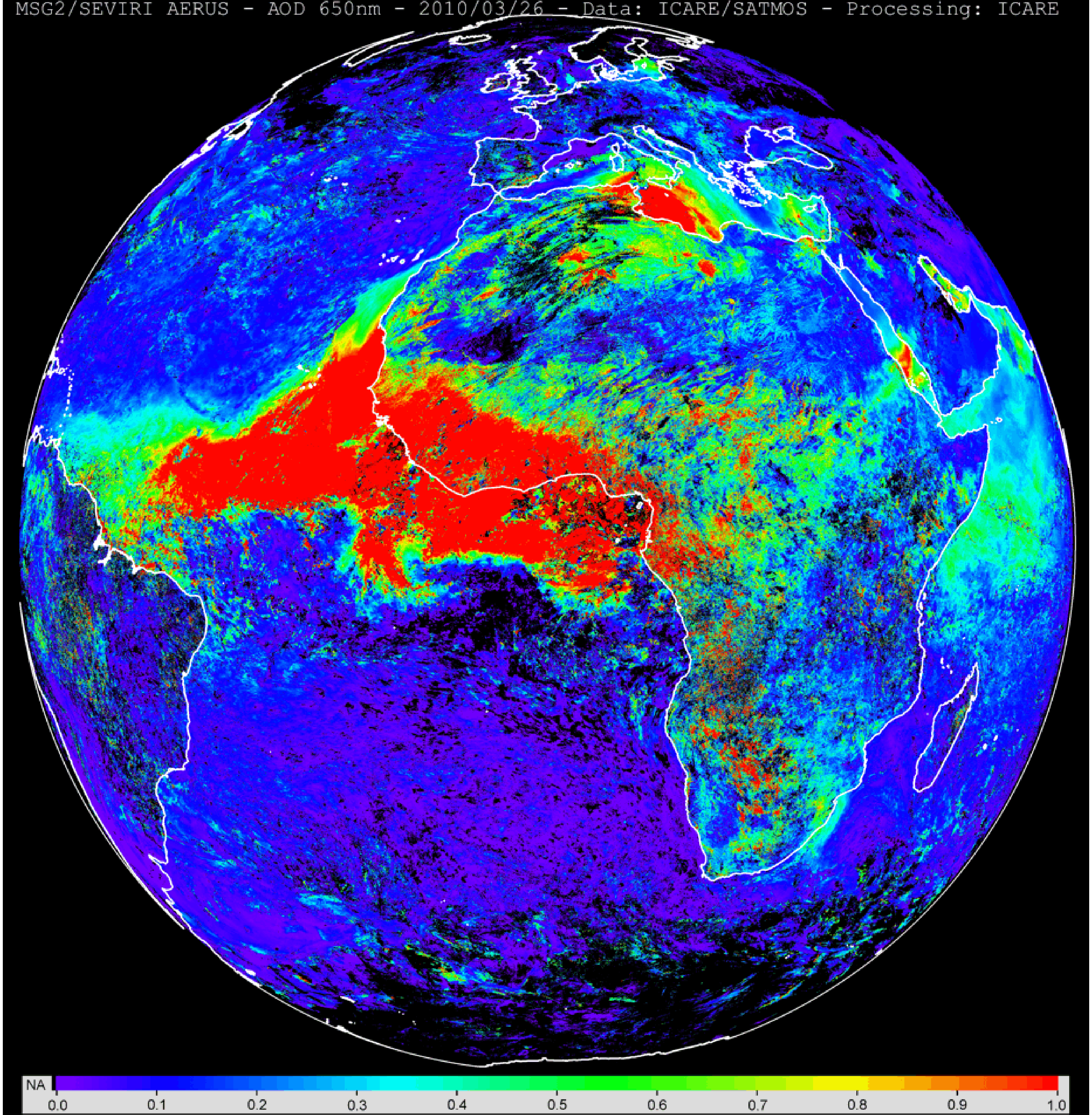
2010/03/23


MSG2/SEVIRI AERUS - AOD 650nm - 2010/03/24 - Data: ICARE/SATMOS - Processing: ICARE
NA
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

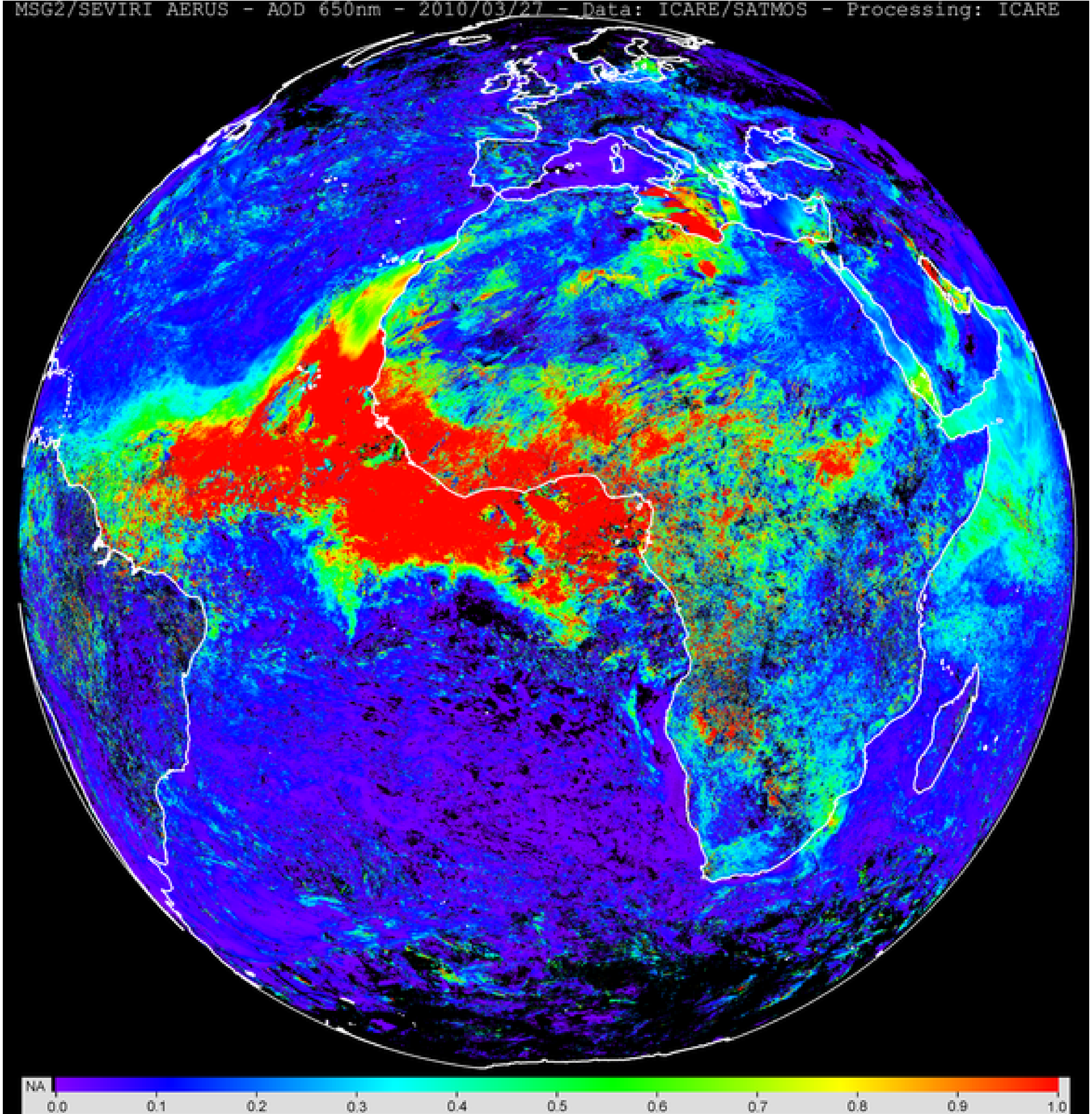
2010/03/24


MSG2/SEVIRI AERUS - AOD 650nm - 2010/03/25 - Data: ICARE/SATMOS - Processing: ICARE
NA
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

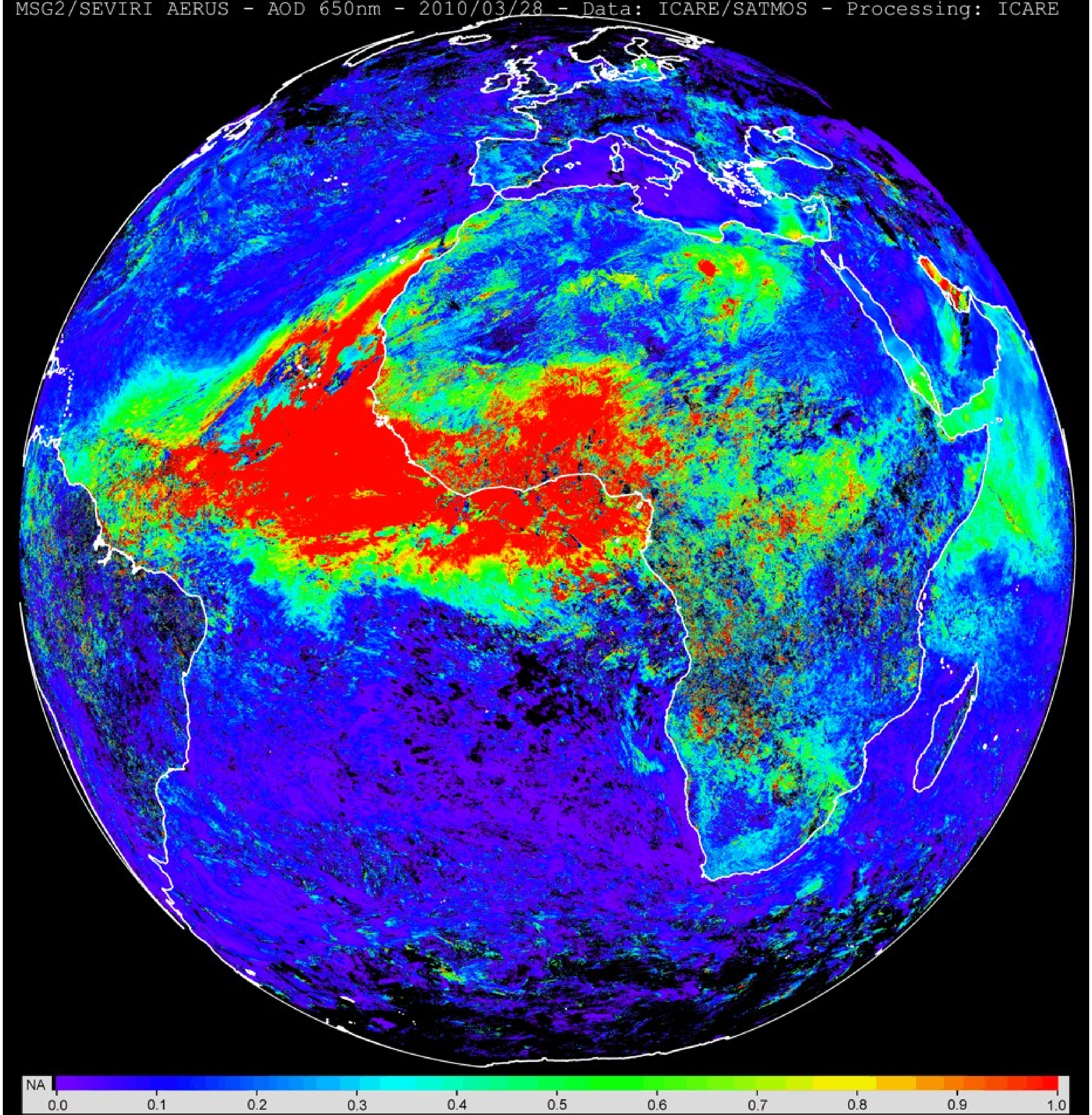
2010/03/25


MSG2/SEVIRI AERUS - AOD 650nm - 2010/03/26 - Data: ICARE/SATMOS - Processing: ICARE
NA
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

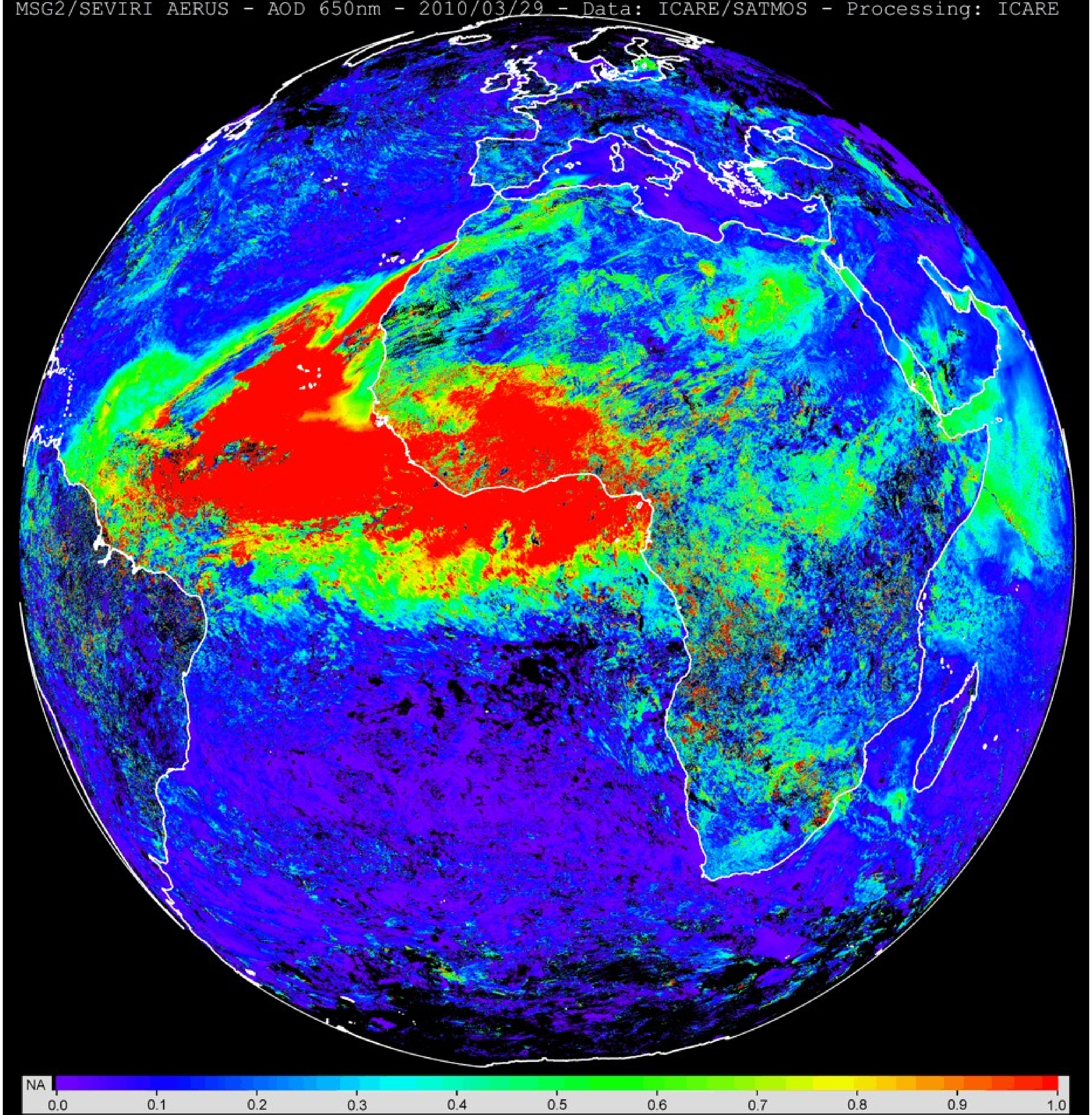
2010/03/26


MSG2/SEVIRI AERUS - AOD 650nm - 2010/03/27 - Data: ICARE/SATMOS - Processing: ICARE
NA
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

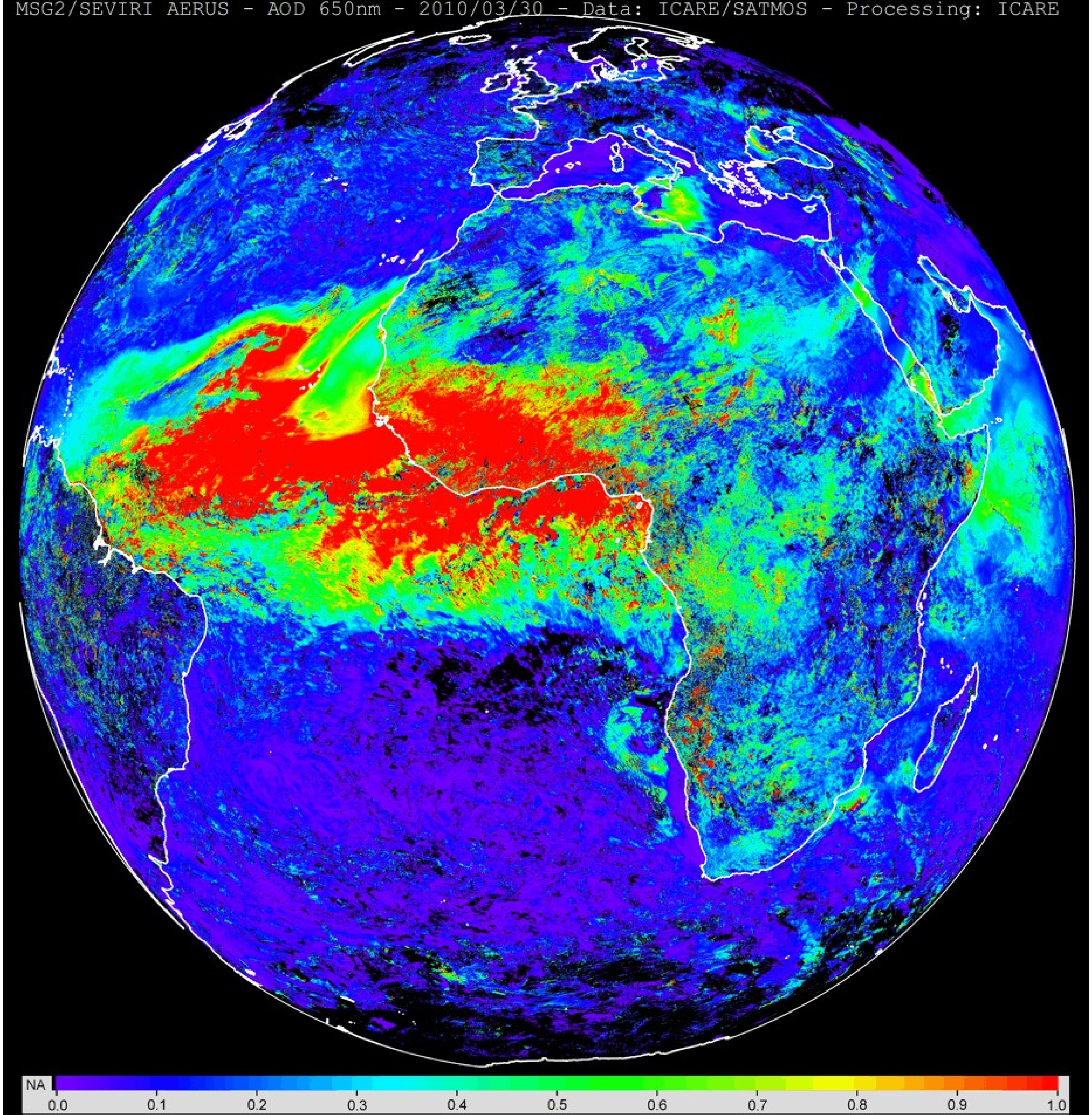
2010/03/27


MSG2/SEVIRI AERUS - AOD 650nm - 2010/03/28 - Data: ICARE/SATMOS - Processing: ICARE
NA
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

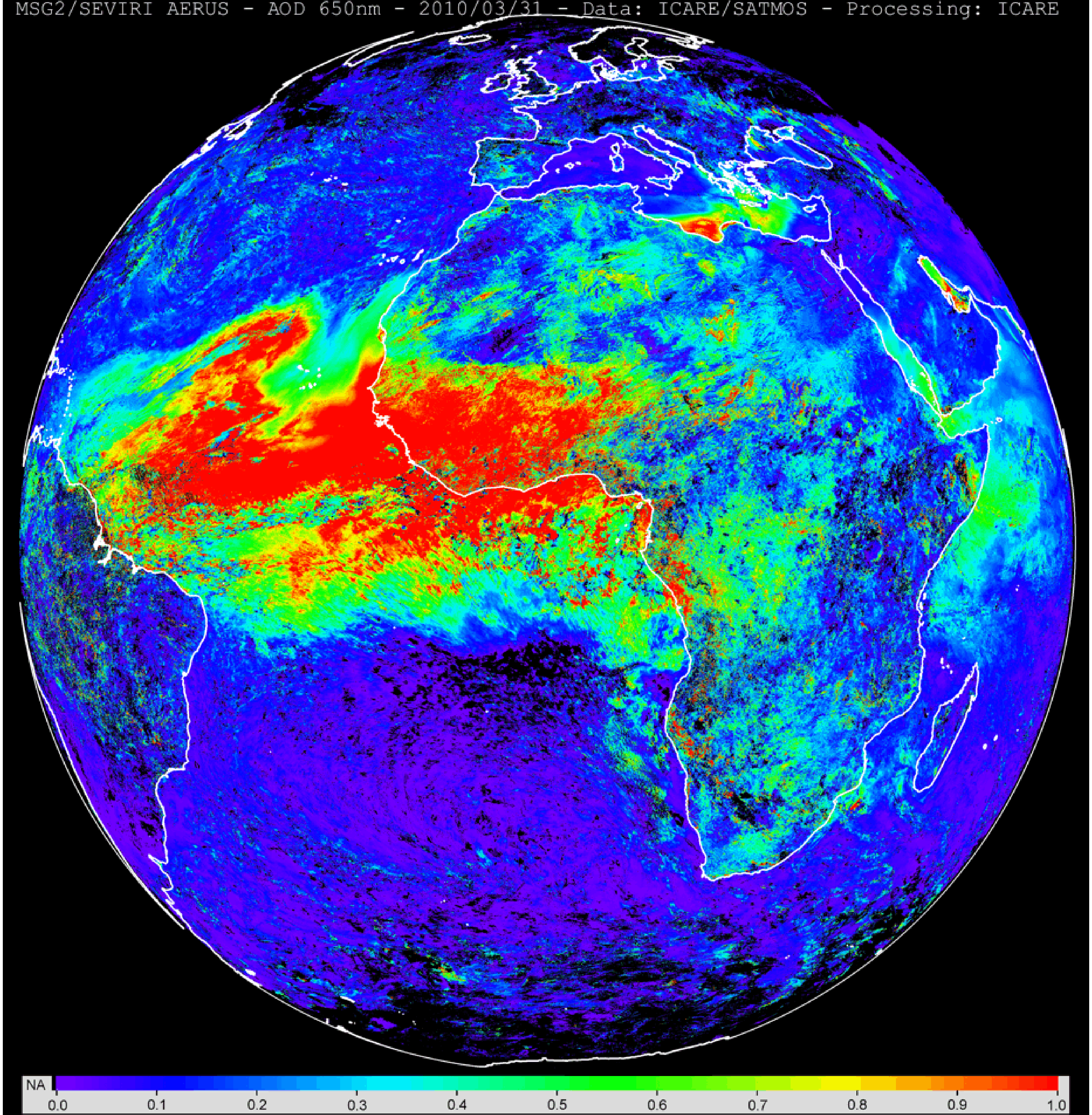
2010/03/28


MSG2/SEVIRI AERUS - AOD 650nm - 2010/03/29 - Data: ICARE/SATMOS - Processing: ICARE
NA
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

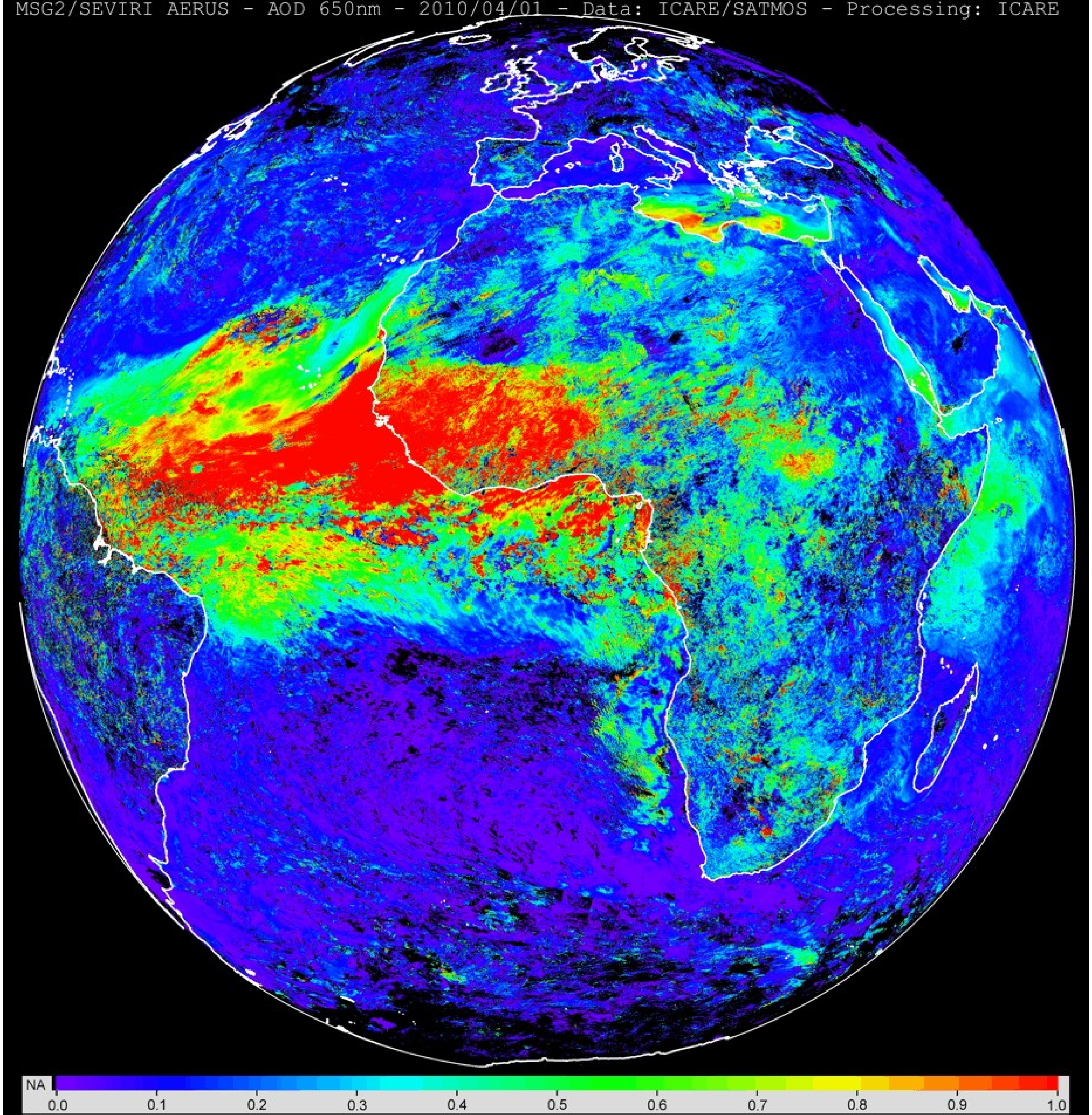
2010/03/29


MSG2/SEVIRI AERUS - AOD 650nm - 2010/03/30 - Data: ICARE/SATMOS - Processing: ICARE
NA
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

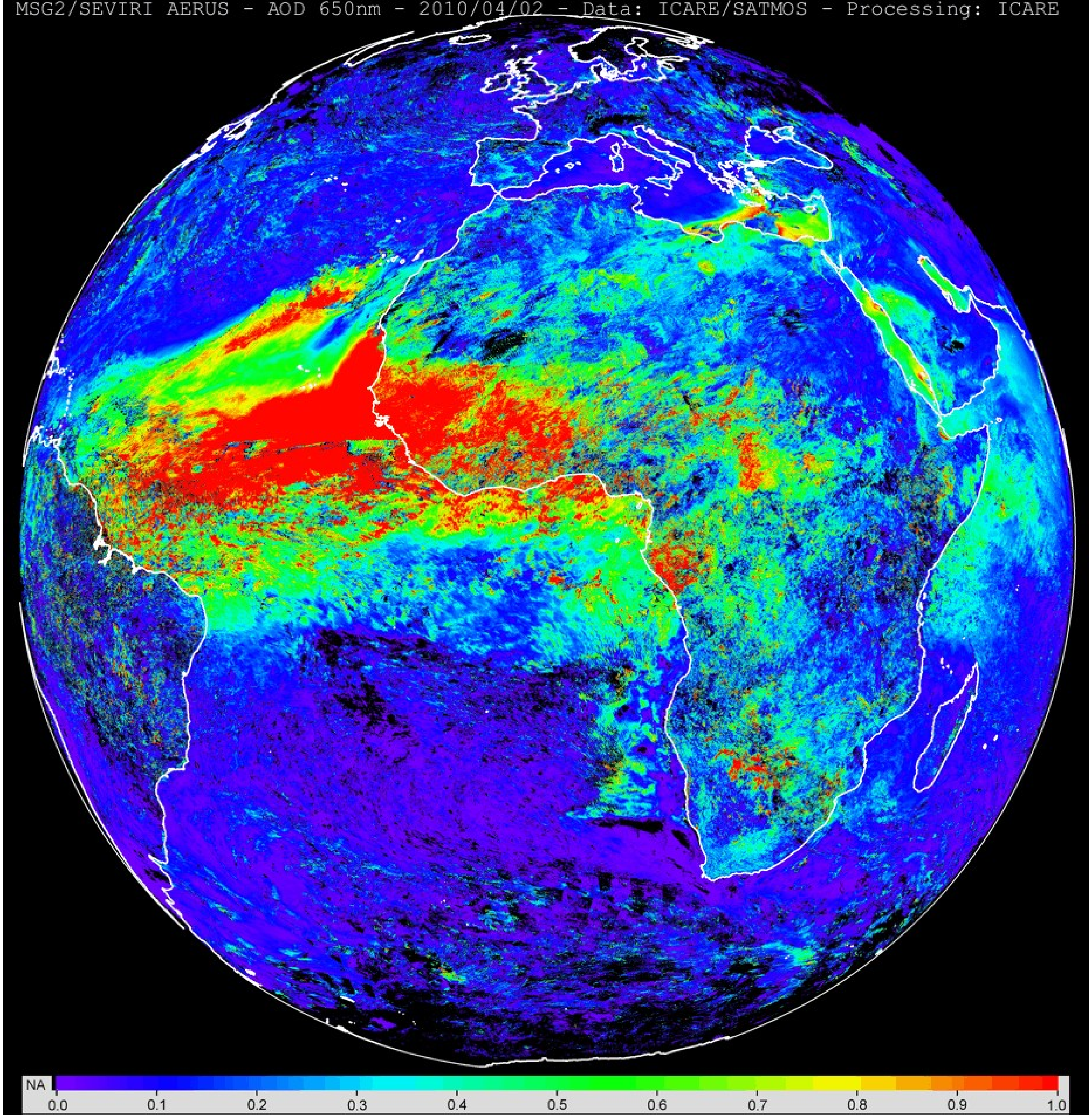
2010/03/30


MSG2/SEVIRI AERUS - AOD 650nm - 2010/03/31 - Data: ICARE/SATMOS - Processing: ICARE
NA
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

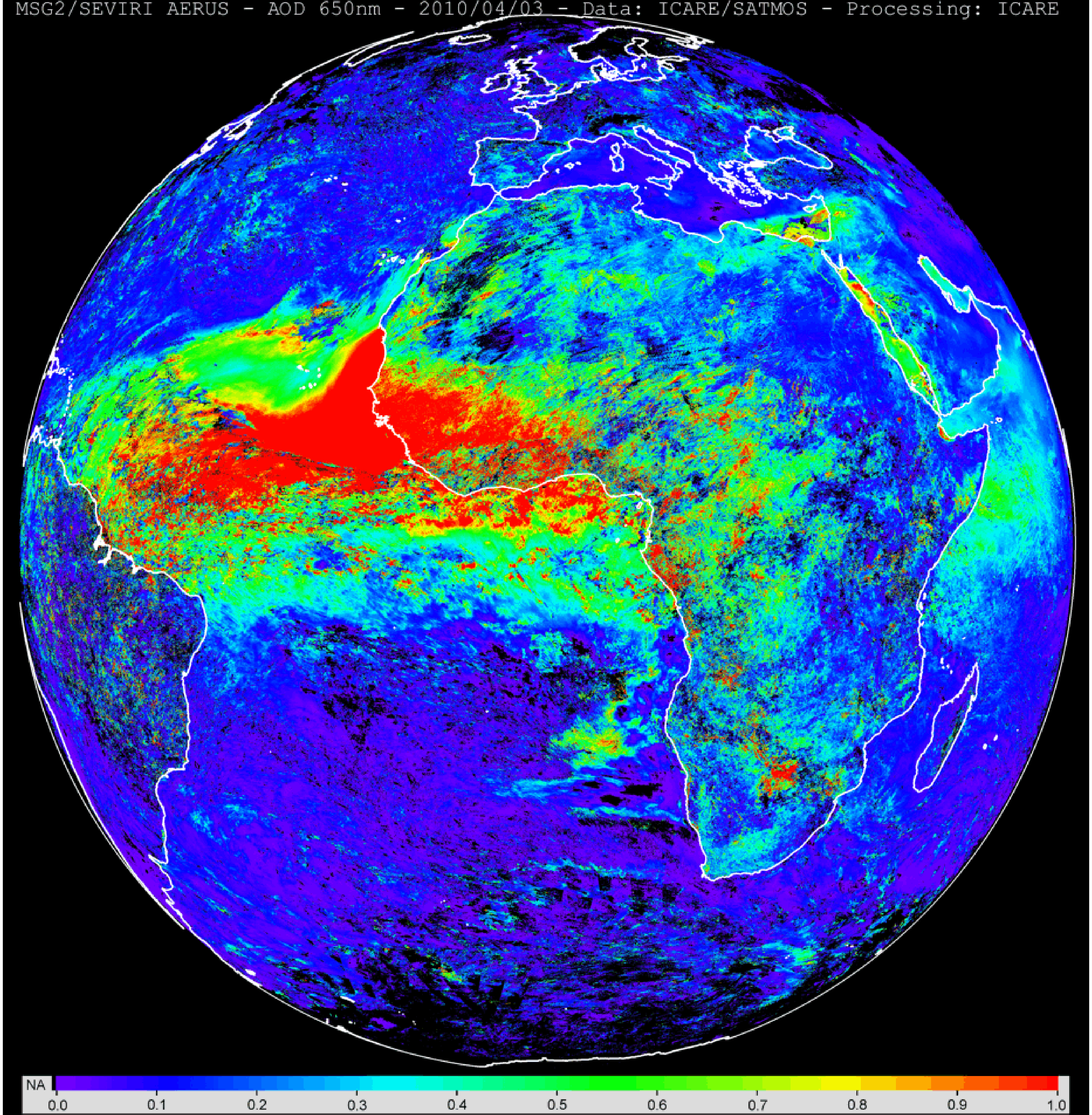
2010/03/3


MSG2/SEVIRI AERUS - AOD 650nm - 2010/04/01 - Data: ICARE/SATMOS - Processing: ICARE
NA
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

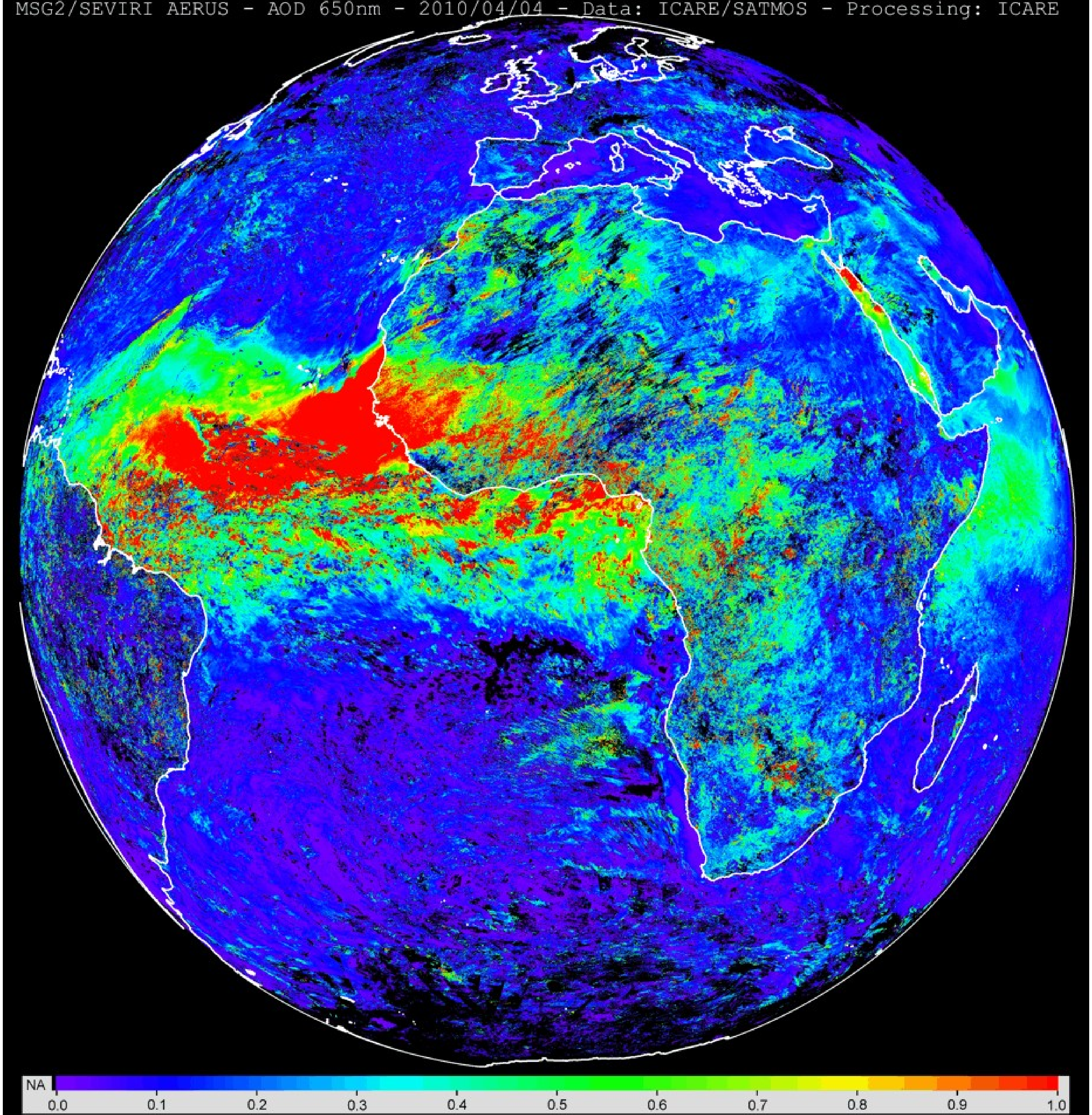
2010/04/01


MSG2/SEVIRI AERUS - AOD 650nm - 2010/04/02 - Data: ICARE/SATMOS - Processing: ICARE
NA
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

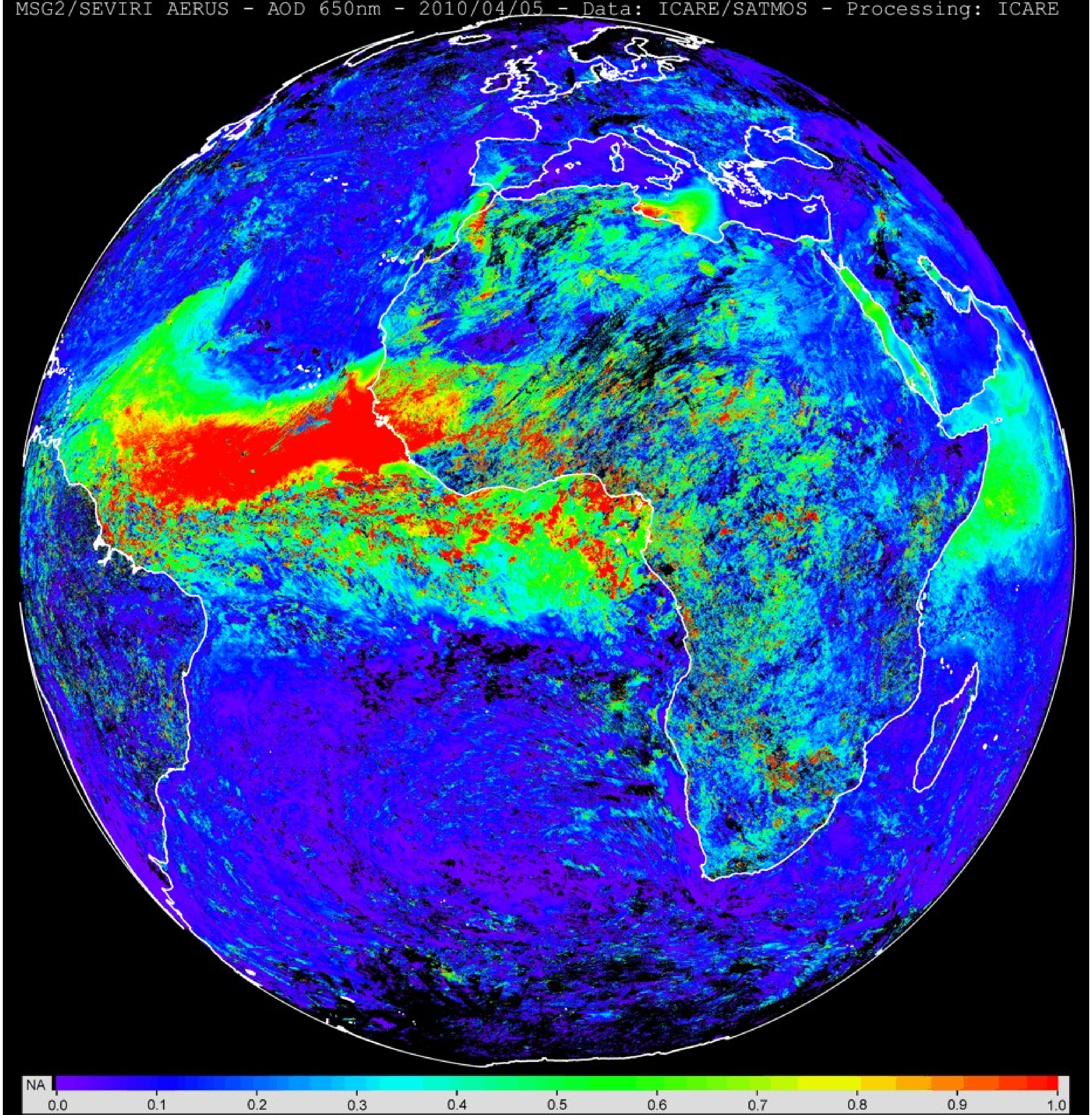
2010/04/0


MSG2/SEVIRI AERUS - AOD 650nm - 2010/04/03 - Data: ICARE/SATMOS - Processing: ICARE
NA
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

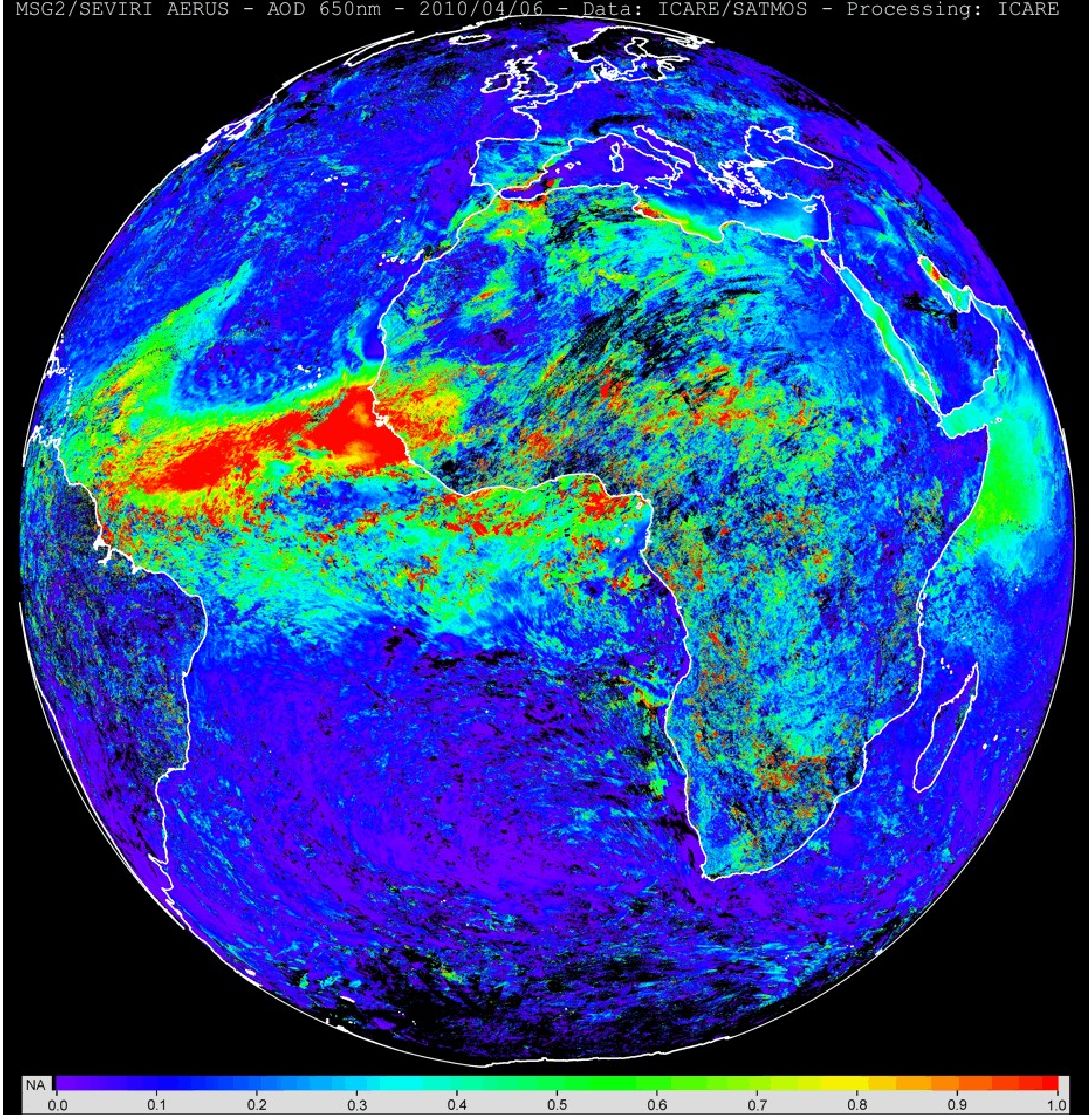
2010/04/03


MSG2/SEVIRI AERUS - AOD 650nm - 2010/04/04 - Data: ICARE/SATMOS - Processing: ICARE
NA
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

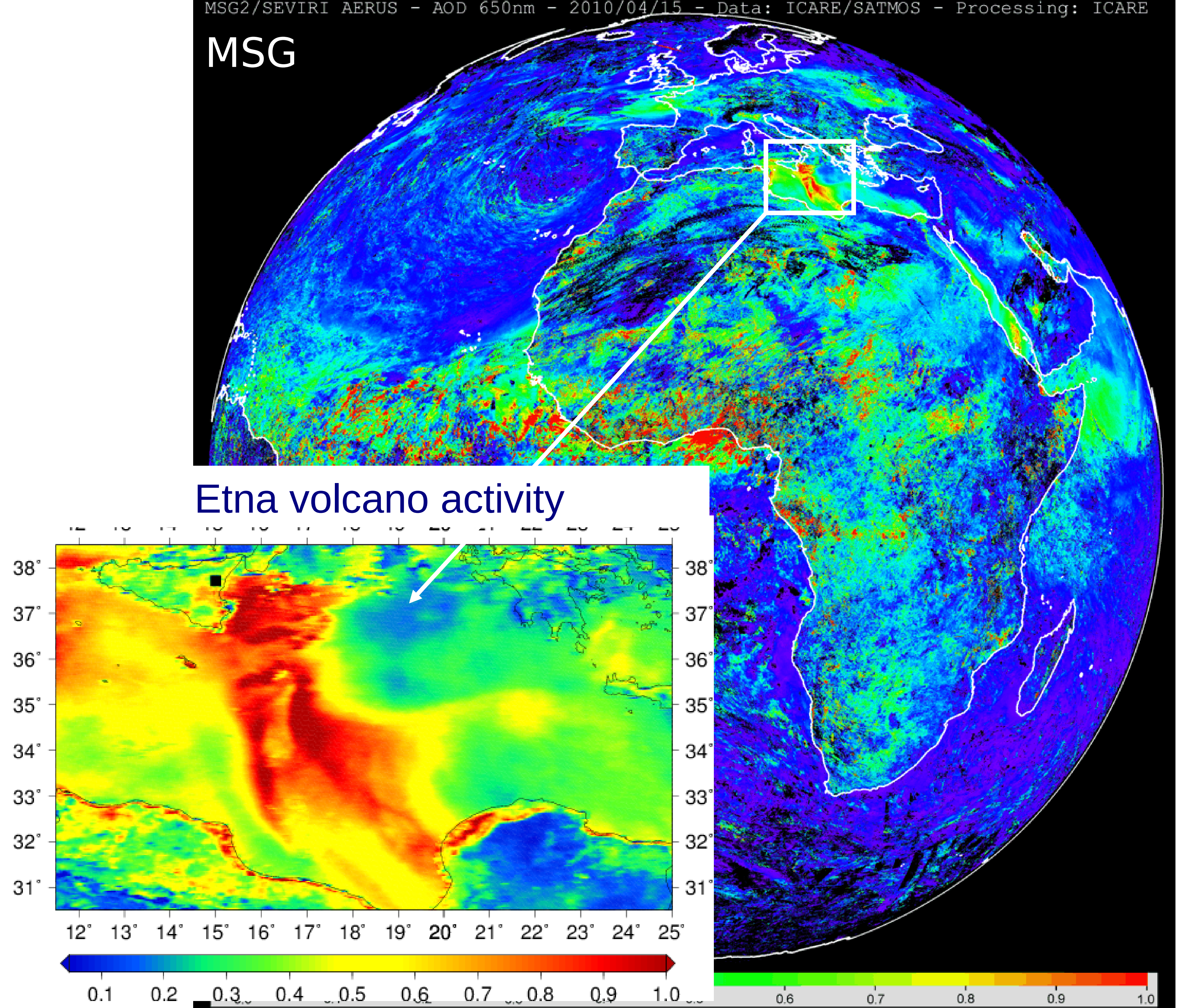
2010/04/04


MSG2/SEVIRI AERUS - AOD 650nm - 2010/04/05 - Data: ICARE/SATMOS - Processing: ICARE
NA
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

2010/04/05


MSG2/SEVIRI AERUS - AOD 650nm - 2010/04/06 - Data: ICARE/SATMOS - Processing: ICARE
NA
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

2010/04/0



MSG2/SEVIRI AERUS - AOD 650nm - 2010/04/15 - Data: ICARE/SATMOS - Processing: ICARE
MSG
Etna volcano activity
38° 37° 36° 35° 34° 33° 32° 31°
12° 13° 14° 15° 16° 17° 18° 19° 20° 21° 22° 23° 24° 25°
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
0.6 0.7 0.8 0.9 1.0

Thank you !