METEOSAT SURFACE ALBEDO

Y. Govaerts\textsuperscript{(1)}, A. Lattanzio\textsuperscript{(1)} and B. Pinty\textsuperscript{(2)}

govaerts@eumetsat.de

(1) EUMETSAT : www.eumetsat.de
(2) JRC/IES
EUMETSAT OBJECTIVES

THE INITIAL CONVENTION:
"The primary objective ... is to establish, maintain and exploit European systems of operational meteorological satellites...."

THE NEW CONVENTION:
"A further objective ... is to contribute to the operational monitoring of the climate and the detection of global climate change..."
The development of the Meteosat Surface Albedo product has been triggered by EUMETSAT in collaboration with the JRC as a demonstration activity to better understand the implications of its new mandate on operational climate monitoring in terms of:

- Climate product design, development and generation;
- Data quality control;
- Climate user's community activities and requirements.
OUTLINE

- Meteosat spacecraft
- Meteosat VIS band calibration
- Meteosat VIS band calibration evaluation
- Meteosat Surface Albedo Algorithm
- MSA product description
- MSA product evaluation
- MSA applications
**METEOSAT INSTRUMENT CHARACTERISTICS**

### Channels
- **Visible (VIS)**: 0.4 - 1.0 µm
- **Water Vapour**: 5.7 - 7.1 µm
- **Infrared**: 10.5 - 12.5 µm

- **2 VIS detectors**
- **Image repeat cycle**: 30 min
### METEOSAT INSTRUMENT CHARACTERISTICS

<table>
<thead>
<tr>
<th>Year</th>
<th>Meteosat-1</th>
<th>Meteosat-2</th>
<th>Meteosat-3</th>
<th>Meteosat-4</th>
<th>Meteosat-5</th>
<th>Meteosat-6</th>
<th>Meteosat-7</th>
</tr>
</thead>
<tbody>
<tr>
<td>77</td>
<td>DCS by GOES-4</td>
<td>DCS only after 1979</td>
<td></td>
<td></td>
<td>Support to INDOEX at 63°E since July 1998</td>
<td>Launch, 20 November 1993</td>
<td>Launch, 2 September 1997</td>
</tr>
<tr>
<td>78</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>79</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>81</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>82</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>83</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>84</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>85</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>86</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>87</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>88</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>89</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>91</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>92</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>93</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>94</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>95</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>96</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>97</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>98</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>99</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>02</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Meteosat-1**: DCS only after 1979, DCS by GOES-4
- **Meteosat-2**: De-orbiting Nov 1995
- **Meteosat-3**: Operational at 0° since June 1998
- **Meteosat-4**: Rotating lens problem
- **Meteosat-5**: Operational at 0° since June 1998
- **Meteosat-6**: Back-up at 10°W (IR gain change problem corrected on ground)
- **Meteosat-7**: Operational at 0° since June 1998
RADIOMETRIC ACCURACY

The radiometric accuracy is essentially controlled by the “crude” signal digitalisation (8 or 6 bits) when radiometric anomalies are not present (e.g., M6).
OUTLINE

• Meteosat spacecraft
• Meteosat VIS band calibration
• Meteosat VIS band calibration evaluation
• Meteosat Surface Albedo Algorithm
• MSA product description
• MSA product evaluation
• MSA applications
The absolute vicarious calibration of remote sensing data requires the definition of an independent “calibration reference”.

This reference relies on simulated TOA radiances generated with 6S in the 0.3 - 1.8 µm spectral region over bright desert and clear ocean targets using a data set of surface and atmospheric properties.

The reliability of this reference is established comparing simulated radiances with calibrated spaceborne observations acquired by ERS2/ATSR-2, SeaStar/SeaWiFS, VEGETATION and Envisat/MERIS.
Desert targets X  Sea search areas □
Each target is characterised by 6 state variables $\chi_p$:
- 3 state variables ($\lambda$) of the surface BRF model (Hapke)
- Total aerosol amount (TOMS AI, AERONET)
- Total column water vapour (ECMWF)
- Total column ozone (TOMS)
Each variable is estimated with an associated error $\varepsilon_p$. 
Bright sandstone spectra from the ASTER spectral data base
VIS BAND CALIBRATION

Surface: spectral properties (example for 1 target)
VIS BAND CALIBRATION

Example of surface BRF over one target
Example of atmospheric properties over one target

<table>
<thead>
<tr>
<th></th>
<th>H$_2$O</th>
<th>OZONE</th>
<th>AEROSOL LOAD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ECMWF</td>
<td>TOMS O$_3$</td>
<td>TOMS AI, AERONET</td>
</tr>
<tr>
<td></td>
<td>10%</td>
<td>15%</td>
<td>50%</td>
</tr>
</tbody>
</table>
Mean annual aerosol optical thickness from AVHRR
Algorithm overview

10 days Data Acquisition

Target Identification

Pixel Extraction

RTM

QC Calibration

$C_f, \delta C_f$
**VIS BAND CALIBRATION**

**Calibration error**

The calibration accuracy is determined by

- The target description uncertainties
- The VIS band response uncertainties

![Graphs showing calibration accuracy for METEOSAT 7 and METEOSAT 5](image)
VIS BAND CALIBRATION

Meteosat 7

YEARLY DRIFT: 2.59% ±0.047% (RMSE=0.014)

Launch time

Today
VIS BAND CALIBRATION

Meteosat 5

YEARLY DRIFT: 1.44% ± 0.008% (RMSE=0.011)
• Meteosat spacecraft
• Meteosat VIS band calibration
• Meteosat VIS band calibration evaluation
• Meteosat Surface Albedo Algorithm
• MSA product description
• MSA product evaluation
• MSA applications
CALIBRATION EVALUATION

Concept

Calibration estimation is based on the comparison between calibrated observations acquired by polar orbiting instruments and simulation of these observations.

\[ \tilde{R}_f = \frac{\int R(\lambda)\xi(\lambda)d\lambda}{\int \xi(\lambda)d\lambda} \]

\[ \tilde{R}_f^* \]

Observation

Simulation

\[ \chi_p, \varepsilon_p \]

\[ \chi_p, \varepsilon_p \]
Spectral response of the radiometric bands used in the comparison.

SEVIRI   ATSR-2   SeaWiFS   MERIS   VGT
CALIBRATION EVALUATION

1. Observation acquisition

![Graph showing relative error and radiance vs wavelength](image)

- **Mean observed BRF:**
- **Standard deviation:**

**Illumination and viewing geometry:**

**Radiance:**

**BRF:**

**BRF error:**

The theoretical maximum error is estimated accounting for the contribution of each state variable error.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2O</td>
<td>10%</td>
</tr>
<tr>
<td>OZONE</td>
<td>15%</td>
</tr>
<tr>
<td>AEROSOL LOAD</td>
<td>50%</td>
</tr>
<tr>
<td>SINGLE SCATTERING ALBEDO</td>
<td>30%</td>
</tr>
<tr>
<td>ASYMMETRY PHASE FUNCTION</td>
<td>&gt;100%</td>
</tr>
<tr>
<td>POROSITY (HOT SPOT)</td>
<td>&gt;100%</td>
</tr>
</tbody>
</table>
Error contribution of each parameter over one des. target

Atmosphere
- AOT
- TCO3
- TCWV

Surface
- \( \omega \)
- \( \theta \)
- \( h \)

TOTAL
3. **Comparison between obs.** \( \tilde{r}_f^* \) **and sim.** \( \tilde{r}_f \)

**Monthly mean relative bias averaged over all targets:**

Relative bias

\[
\beta = \frac{\tilde{r}_f^* - \tilde{r}_f}{\tilde{r}_f}
\]

Bias error

\[
\varepsilon_\beta = \beta \cdot \left( \sigma_{\tilde{r}_f^*} + \sigma_{\tilde{r}_f} \right)
\]

Monthly mean weighted relative bias

\[
\bar{\beta} = 100 \frac{1}{18} \sum_{\text{target}} \frac{1}{W_t} \sum_{\text{month}} \frac{\tilde{r}_f^* - \tilde{r}_f}{\tilde{r}_f} \frac{1}{\varepsilon_\beta^2}
\]
Monthly mean relative difference (bias + std. dev.) between simulations and observations (BRF) over all targets
Seasonal trend of the monthly relative difference over all targets
• Meteosat spacecraft
• Meteosat VIS band calibration
• Meteosat VIS band calibration evaluation
• Meteosat Surface Albedo Algorithm
• MSA product description
• MSA product evaluation
• MSA applications
The Meteosat Surface Albedo (MSA) algorithm derives the surface albedo in the Meteosat VIS band every days at the pixel resolution using all the available images during daytime. One final product is generated every 10 days in order to minimise the effects of the clouds.

The algorithm accounts for:
- water vapour and ozone gaseous absorption;
- aerosol scattering and absorption;
- surface anisotropy (coupled with aerosols).

Surface albedo definition

Directional Hemispherical Reflectance (DHR)

\[
DHR(Z_0, \mu_0) = \frac{1}{\pi} \int_{2\pi}^{\pi} \rho_{sfc}(z_0, \Omega' \to \Omega) \mu' d\Omega'
\]
Surface albedo definition

Daily averaged Directional Hemispherical Reflectance (DDHR)

\[ DDHR(Z_0) = \frac{1}{\int_{\mu_1}^{\mu_2} DHR(z_0, \mu_0) d\mu} \]

\[ \int_{\mu_1}^{\mu_2} DHR(z_0, \mu_0) d\mu \]

\[ \int_{\Omega'}^{\mu_2} \]

\[ \Omega' \]

\[ \Omega ' \]

\[ \mu_1, \mu_2 \]
Surface anisotropy
Coupled with atm.
Surface anisotropy: the RPV model

\[ \rho_{\text{sfc}} (z, \Omega_0 \rightarrow \Omega) = \rho_0 M_i (k) F_{HG} (\Omega) H (\rho_0) \]

- \( \rho_0 \) - controls amplitude level
- \( k \) - controls bowl/bell shape
- \( \Theta \) - controls forward/backward scattering
- \( \rho_0 \) - controls hot spot peak

Ref: Rahman et al. (1993) JGR
Atmospheric scattering

MISR ToA observations of the Appalachian Mountains, USA, true colors

14 June 2000

**METEOSAT SURFACE ALBEDO**

**Assumptions**
- Atmosphere is composed of one absorbing gas layer and one scattering layer
- US62 atmospheric profile
- Continental aerosol type
- Atmospheric and surface scattering properties are constant along the day
- Surface scattering properties can be represented by the RPV BRF model

**Parameters**
- Model:
  - ozone (TOMS)
  - Total column water vapour (ECMWF)

- Retrieved:
  - Equivalent aerosol optical thickness (1)
  - surface anisotropy (3)

One final product is generated every 10 days in order to minimise the cloud effects.
Sun position during the course of the day

Meteosat position
DCP: Cloud filtering (South Italy, Day=121)

METEOSAT SURFACE ALBEDO

Daily TOA fit

Rejected slots
1. Removal gas absorption

2. Inversion of the scattering layer
   \[ k = \{0.5, 0.6, 0.7, 0.8, 0.9, 1.0\} \]
   \[ \Theta = \{-0.3, -0.2, -0.1, 0.0\} \]
   \[ \tau = \{0.1, 0.2, 0.4, 0.6, 1.0\} \]

\[ \rho_0 = 0.146 \]
\[ k = 0.8 \]
\[ \Theta = -0.1 \]
\[ \tau = 0.2 \]
\[ \text{DHR} = 0.232 \]
**METEOSAT SURFACE ALBEDO**

Daily inversion (South Italy, Day=121)

**DAILY TIME SERIES M7**

- Simulated TOA BRF with best solution
- Surface BRF
Daily “Best Solution” are accumulated during a 10 day compositing period.

The selected final solution is the one with the $\rho_0$ the closest to the $\langle \rho_0 \rangle$ with the smallest cost function
• Meteosat spacecraft
• Meteosat VIS band calibration
• Meteosat VIS band calibration evaluation
• Meteosat Surface Albedo Algorithm
• MSA product description
• MSA product evaluation
• MSA applications
## FINAL PRODUCT FIELDS

<table>
<thead>
<tr>
<th>Name</th>
<th>V1.x</th>
<th>V2.0</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDHR</td>
<td>X</td>
<td>X</td>
<td>Daily averaged DHR (1 byte)</td>
</tr>
<tr>
<td>DHR</td>
<td>X</td>
<td>X</td>
<td>Directional Hemispherical Reflectance (1 byte)</td>
</tr>
<tr>
<td>QI</td>
<td>X</td>
<td></td>
<td>Overall Quality product</td>
</tr>
<tr>
<td>Nbr Solution</td>
<td></td>
<td>X</td>
<td>Number of solutions</td>
</tr>
<tr>
<td>Nbr Input Slot</td>
<td></td>
<td>X</td>
<td>Number of cloud free input slots</td>
</tr>
<tr>
<td>Surface Index</td>
<td></td>
<td>X</td>
<td>Value of k and Θ</td>
</tr>
<tr>
<td>AOT index</td>
<td></td>
<td>X</td>
<td>Aerosol optical thickness</td>
</tr>
<tr>
<td>Rho_0</td>
<td></td>
<td>X</td>
<td>Value of $\rho_0$</td>
</tr>
<tr>
<td>StdDevRho_0</td>
<td>X</td>
<td>X</td>
<td>Standard deviation of $\rho_0$</td>
</tr>
<tr>
<td>StdDevRho_0 10D</td>
<td>X</td>
<td>X</td>
<td>Standard deviation of $\rho_0$ during 10 days</td>
</tr>
<tr>
<td>Nbr days</td>
<td></td>
<td>X</td>
<td>Number of cloud free days</td>
</tr>
<tr>
<td>Best day</td>
<td></td>
<td>X</td>
<td>Best day number within the 10 days</td>
</tr>
<tr>
<td>Chi2ASM</td>
<td>X</td>
<td>X</td>
<td>Cost of the Atmospheric scattering module</td>
</tr>
<tr>
<td>Chi2DCP</td>
<td>X</td>
<td>X</td>
<td>Cost of the Data Consistency module</td>
</tr>
<tr>
<td>Latitude</td>
<td></td>
<td>X</td>
<td>Pixel latitude</td>
</tr>
<tr>
<td>Longitude</td>
<td>X</td>
<td>X</td>
<td>Pixel longitude</td>
</tr>
<tr>
<td>More ...</td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
K

Modified Minnaert Contribution

- k > 1.6: bell shape
- k = 1.6: Lambertian
- k < 1.6: GOE-shape

View Zenith Angle (degrees)

MSA (K THETA)
Period: 2001 121 - 130
METEOSAT SURFACE ALBEDO

METEOSAT ALBEDO VERSUS BROAD BAND ALBEDO
METEOSAT SURFACE ALBEDO

BROADBAND ALBEDO

MSA

SARB

EUMETSAT
OUTLINE

• Meteosat spacecraft
• Meteosat VIS band calibration
• Meteosat VIS band calibration evaluation
• Meteosat Surface Albedo Algorithm
• MSA product description
• MSA product evaluation
• MSA applications
METEOSAT SURFACE ALBEDO

Legend:
- **Flooded area**
- **Non-flooded area**
METEOSAT SURFACE ALBEDO

EVALUATION

Calib: ±5%

METEOSAT-7

Calib: ±9%

METEOSAT-5
METEOSAT SURFACE ALBEDO

TOA BRF COMPARISON

METEOSAT-7  METEOSAT-5
OUTLINE

- Meteosat spacecraft
- Meteosat VIS band calibration
- Meteosat VIS band calibration evaluation
- Meteosat Surface Albedo Algorithm
- MSA product description
- MSA product evaluation
- MSA applications
APPLICATIONS

1996

Early January

Early March

Early April

APPLICATIONS

SURFACE ALBEDO SEASONAL DYNAMICS

Surface albedo change in the Meteosat VIS band as a function of the vegetation amount over different soil types.

Monsoon-induced cycle of surface albedo

Surface albedo seasonal cycle vs precipitation for one Meteosat pixel located in northern Nigeria
Charney's Feedback Loop

decreased vegetation cover

albedo increase

less precipitation

decreased cumulus convection

reinforced sinking motion

surface air cools and contracts

Well recognized but poorly quantified

△?
APPLICATIONS

2 Climate Model Simulations
(1) Meteosat Albedo
(2) Albedo = 0.35
Simulated Precipitation over North Africa

JJA Precipitation [mm/d] MAX Albedo = 0.35

JJA Precipitation [mm/d] METEOSAT Albedo


SURFACE ALBEDO CHANGE

B024: FIRE

LAT = 9.56  LON = 26.02

0.25

Amount of Vegetation

Brown Leaves
Green Leaves

Surface Albedo (unitsless)

Leaf Area Index (m²/m²)

Dry season
FIRE IMPACT ON SURFACE ALBEDO

North Hemisphere

DAYS OF 1996

Dry season

DHR(30)

0.25

0.20

0.15

0.10

LON = 26.02  LAT = 9.56

B024: FIRE

Vegetation re-growth

Fire-induced perturbation

Vegetation re-growth
December 1996

Relative decrease