Detection of aerosols and other climatological effects by remote sensing using GERB/SEVIRI

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Outline

Introduction

GERB
  Instrument
  Products

Aerosol Detection
  Motivation
  Algorithm Presentation
  Ocean Reflectance
  Land Minimum Reflectance
  AOD Retrieval
  Validation
  Examples

Aerosol Radiative Forcing

Conclusions
Main interest GERB team at RMIB.
SERVIRI

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Introduction

GERB Instrument

Products

Aerosol Detection

Aerosol Radiative Forcing

Conclusions

- Spinning Enhanced Visible and Infrared Imager.
- Main instrument aboard MSG satellite (2004-...).
- Spectral properties:
  - 12 narrow-band channels
  - chosen for specific detection purposes.
- Temporal resolution: 15 minutes interval
- Spatial resolution: 3km × 3km at nadir (1km HRVIS)
Detection of aerosols and other climatological effects by remote sensing using GERB/SEVIRI

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Introduction

GERB Instrument Products

Aerosol Detection Aerosol Radiative Forcing

Conclusions

➤ Geostationary Earth Radiation Budget instrument.
➤ Announcement of opportunity instrument on MSG.

➤ Spectral properties:
  ➤ 2 broad-band channels
  ➤ Short wave: 0.32 - 4 μm
  ➤ → solar channel
  ➤ Total: 4 - 30 μm
  ➤ Longwave: by subtraction
  ➤ → thermal channel
  ➤ Temporal resolution: 15 minutes interval
  ➤ Spatial resolution: 44.5km × 39.3km at nadir (NS × EW)
  → Upsampling using SEVIRI: 9km × 9km
Detection of aerosols and other climatological effects by remote sensing using GERB/SEVIRI

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Introduction
GERB Instrument Products
Aerosol Detection Aerosol Radiative Forcing Conclusions

GERB High Resolution Example

Reflected solar radiation.

20070809 07:15 20070809 14:15

Emitted thermal radiation.
Top Of Atmosphere Products (TOA)

- We provide three TOA products (CM-SAF) from 2004 on:
  - Total Incoming Solar radiation (TIS).
  - Total Reflected Solar radiation (TRS).
  - Total Emitted Thermal radiation (TET).
- Daily mean, monthly mean diurnal cycle and monthly mean.
- To get these (and much more):
  - http://www.cmsaf.eu
  - http://cmsaf.oma.be
Total Incoming Solar Radiation (TIS)

- Computed from TSI (Total Solar Irradiance)

\[ TSI = \frac{TIS \cos(\theta_{\text{sol}})}{d^2} \]

where,
- \( d \) = distance pixel sun (astronomical units).
- \( \theta_{\text{sol}} \) = solar zenith angle
- TSI measured over 3 decades:
Detection of aerosols and other climatological effects by remote sensing using GERB/SEVIRI

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Introduction
GERB
Instrument
Products
Aerosol Detection
Aerosol Radiative Forcing
Conclusions

Example TIS

TOA Incoming Solar (TIS) [W/m²]
Detection of aerosols and other climatological effects by remote sensing using GERB/SEVIRI

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Introduction

GERB Instrument Products

Aerosol Detection

Aerosol Radiative Forcing

Conclusions

TRS and TET

- Obtained from GERB instrument
  - GERB field of view.
  - ADM to correct for angles.
  - Spatial upsampling.

+ CERES experiment → polar region.

+ SEVIRI
  - If no GERB data available.
    → narrow to broadband conversion: GERB-like data.
  - The future: no GERB instrument on MTG.
  - And the past: no GERB instrument on MFG.
Detection of aerosols and other climatological effects by remote sensing using GERB/SEVIRI

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Introduction

GERB

Instrument

Products

Aerosol Detection

Aerosol Radiative Forcing

Conclusions
Detection of aerosols and other climatological effects by remote sensing using GERB/SEVIRI

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Introduction
GERB
Instrument
Products
Aerosol Detection
Aerosol Radiative Forcing
Conclusions
Example with Netto Irradiance at TOA
Motivation

Tropospheric aerosol particles originate from:

- Urban/industrial activities.
- Biomass burning associated with land use processes.
- Wind-blown dust.
- Natural sources.

Global observations from space required due to:

- Short lifetime (a few days).
- High spatial variability in aerosol optical and radiative properties.
Motivation (bis)

Major uncertainty in predicting climate change due to:
- **Direct radiative forcing** → radiation is scattered or absorbed by the aerosols.
- **Indirect radiative forcing** → influence on cloud microphysics.
- Modify concentration of climate-influencing constituents such as greenhouse gases through heterogeneous chemistry.
Detection of aerosols and other climatological effects by remote sensing using GERB/SEVIRI

Stijn Nevens

Introduction

GERB

Aerosol Detection

Motivation

Algorithm

Presentation

Ocean Reflectance

Land Minimum Reflectance

AOD Retrieval

Validation

Examples

Aerosol Radiative Forcing

Conclusions

Input

- SEVIRI level 1.5 images at wavelengths 600, 800 and 1600 nm.
- CM SAF cloud mask, based on NWC SAF software.
  planned replacement for current inadequate cloudmask.
- Cloud shadows also need to be implemented.
Reflectance (Rescaled BRDF)

- Single scatter approximation → separation
  \[ \mathcal{R}(\lambda, \mu_i, \mu_o) = \mathcal{R}_{surface} + \mathcal{R}_{rayleigh} + \mathcal{R}_{aerosol} \]

- The aerosol reflectance is given by,
  \[ \mathcal{R}_{aerosol} = \frac{\tau \tilde{\omega} P(\theta)}{4 \cos(\omega_i) \cos(\omega_o)} \]

  where,
  - \( \tau \) = aerosol optical depth (AOD).
  - \( \tilde{\omega} \) = aerosol single scatter albedo.
  - \( P(\theta) \) = aerosol phase function.

- \( \mathcal{R}_{rayleigh} \) is calculated using RTE.
Ocean Reflectance

- \( R_{surface} \leftarrow \) a fixed value chosen according to statistics on marine reflectance synthesis.

→ works far away from sun glint region, where:
  - \( R_{surface} \) peaks.
  - Depends on wind speed.

- Upgrade to LUT from Cox-Munk surface model planned.
Land Minimum Reflectance

\(R_{\text{surface}}\) calculated assuming

- \(R_{\text{surface}}\) constant over sufficiently long period (15d).
- \(\tau\) (AOD) reaches its background value in this period.
- \(R(\lambda = 600\,\text{nm})\) increases with increasing AOD.

→ only true when \(R_{\text{surface}}\) is small (dark surface).

Background aerosol day = day in the period under consideration when

\[ R(\lambda = 600\,\text{nm}) - R_{\text{rayleigh}}(\lambda = 600\,\text{nm}) \]

reaches its minimum.
The surface reflectance (for all $\lambda$) is then given by:

$$R_{surface} = \tilde{R} - \tilde{R}_{rayleigh} - \tilde{R}_{aerosol}$$

where,

- the RHS is taken on the background day.
- $\tilde{R}_{aerosol}$ = aerosol background reflectance
  fixed background value for AOD = 0.03
AOD Retrieval

- $R_{\text{surface}}$ is now known.
- Retrieval performed for 6 different aerosol classes:
  - Derived from an analysis of AERONET retrieval.
  - Maritime model WMO, moderately absorbing, continental WMO, urban-industrial, smoke and spherical dust.
  - All are spherical and some are too similar.
  - Introduction of different (non-spherical) aerosol models.
- AOD is calculated from a best fit using the 3 solar channels with simulated reflectances using LUT.
Based on comparison with AERONET observations.

July 2006: > 200 co-registrations with Cabauw.

slope = 0.96 intercept = 0.02.
Observation Temporal Changes in Aerosol Load

- Dust event Dakar with AOD varying from $>2.0$ till 0.3 in 7 days.

- Same trends AERONET and SEVIRI.
- SEVIRI tends to underestimate the aerosol load.

→ Background day: assumed AOD = 0.03 + high AOD during the reference period ⇒ systematic bias.
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Stijn Nevens

Introduction

GERB

Aerosol Detection

Motivation
Algorithm
Presentation
Ocean Reflectance
Land Minimum Reflectance
AOD Retrieval
Validation
Examples

Aerosol Radiative Forcing

Conclusions

Dust storm across Central and West Africa

08/03/2004 Aqua Satellite
Detection of aerosols and other climatological effects by remote sensing using GERB/SEVIRI

Stijn Nevens

Introduction
GERB
Aerosol Detection
Motivation
Algorithm
Presentation
Ocean Reflectance
Land Minimum Reflectance
AOD Retrieval
Validation
Examples
Aerosol Radiative Forcing
Conclusions

Example AOD (08/03/2004)
Methodology

With low AOD there is a linear relation between (clear sky) radiative forcing and AOD.

LLoeb, Norman G., Seiji Kato, 2002)
Methodology (bis)

- Use this relation to calculate slope and intercept in a TRS (or TET) - AOD graph.
- Slope: radiative forcing corresponding with give AOD.
Conclusions

- GERB: provides many interesting products (both direct and derived).
- Aerosols algorithm: constant background AOD of 0.03 unrealistic in high AOD periods.
  → Use different algorithm to improve estimation of background AOD.
- Aerosol retrieval works only when $R_{surface}$ is small (dark surface).
  → Use different algorithm for bright surfaces (desert).
- We can combine our products to calculate aerosol radiative forcing.