Modeling of the ageing effects on Meteosat First Generation Visible Band

Ilse Decoster, N. Clerbaux, Y. Govaerts, P. J. Baeck, E. Baudrez, S. Dewitte, A. Ipe, S. Nevens, A. Velazquez

Royal Meteorological Institute of Belgium (RMIB)
Satellite Application Facility on Climate Monitoring (CM-SAF)
Free University of Brussels (VUB)

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Outline

Background

- Part of the GERB team at the RMI Belgium, supported by Climate Monitoring SAF (CM-SAF)
- Since 2004, the Meteosat Second Generation (MSG) satellites carry next to the narrow band (NB) imager SEVIRI also a broad band (BB) instrument called GERB
- In a geostationary orbit, GERB measures the Earth Radiation Budget through two broad band channels
- Next to doing operational work, the GERB team at RMIB has experience in creating GERB-like data from SEVIRI through a NB-to-BB conversion

Background (2)

- Working on the generation of GERB-like data for Meteosat First Generation (MFG) satellites
- Only a narrow band imager onboard of the satellites: Meteosat Visible and Infrared Imager (MVIRI)

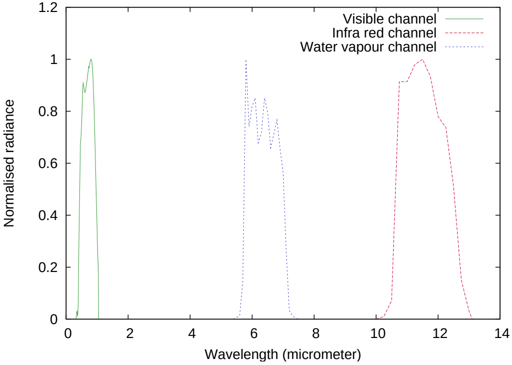

Figure: *Normalised spectral response curves for MVIRI channels.*

Background (3)

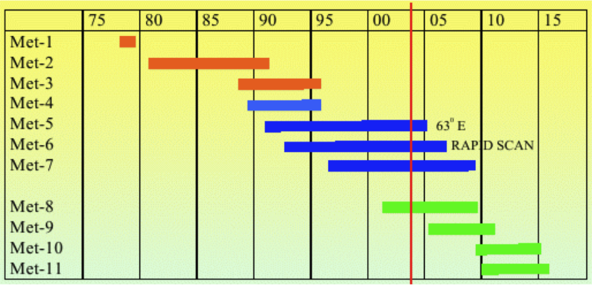

Figure: *Operational time for Meteosat satellites.*

- To create GERB-like data for MFG satellites, we will use overlap between MVIRI data from last MFG satellite without GERB instrument (Meteosat-7) and SEVIRI data from the first MSG satellite with GERB instrument (Meteosat-8).

Background (4)

- However, MFG satellites seem to have bigger ageing problem than MSG satellites
- First need to try to correct for this
- Only visible (VIS) band data used from:
  Meteosat-2 (1982/02/05 - 1987/05/12)
  Meteosat-7 (1998/06/03 - 2006/06/14)

Outline

Ageing process on MFG detectors and optics

Degradation of the silicon detectors and the mirror optics leads to decrease in spectral response of the radiometer which can be seen as a decreasing trend in the time series

$\Rightarrow$ Need to remove the trend by correcting for the ageing effect

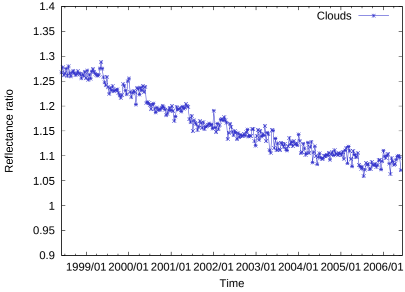

Figure: *Cloud time series for Meteosat-7.*

Ageing process on MFG detectors and optics (2)

- EUMETSAT uses a constantly increasing calibration coefficient in time to correct for ageing.

  ⇒ For Meteosat-7 this leads to an increase of about 2.2% per year (Results from Y.Govaerts et al. 2004)

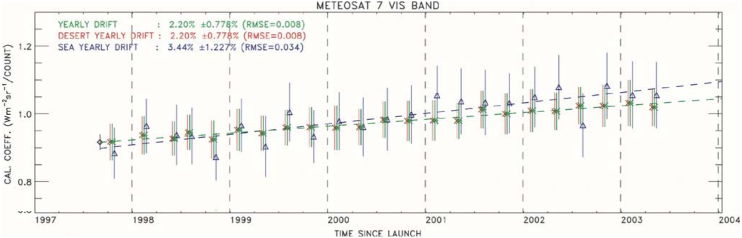

Figure: *Calibration coefficient Meteosat-7 (Govaerts et al. 2004).*

- In my work the calibration coefficient will be kept constant (value at launch) and the possibility of a non constant decrease in time will be investigated.

Outline

Preparation of time series

Requirements:

- Both cloudy and clear sky time series
  - Clear sky images were created every 10 days through a pixel to pixel analysis of a series of 30 images before and 30 images after the original one
- Time series as constant as possible
  - Look for stable sites:
    $\Rightarrow$ stable clear sky sites have lowest standard deviation in the total series of images
    $\Rightarrow$ stable cloudy sites are chosen amoungst the highly convective clouds, so the highest reflectance values
  - Averageing was done in space
- Clear sky time series for different scene types
  - Scene types used: bright vegetation, dark vegetation, bright desert, dark desert and ocean

Preparation of time series (2)

Time series are expressed in reflectance ratio:

- Value of original images in counts $[DC]$
- **Radiance** obtained using a constant calibration:
  rad = calibration * (value - offset) $[W/(m^2\,sr)]$
- **Reflectance** obtained as:
  refl = rad / (irr * cos(SZA) * π * $(\text{dist})^2$)
- **Reflectance ratio** obtained by dividing the reflectance with a simulated reflectance and multiplying with a narrow band (NB) to broad band (BB) correction
  - NB to BB correction through a NB to BB fit of simulated reflectance values: $refl_{BB} = a + b\, refl_{NB}$

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Preparation of time series (3)

- Obtain 6 time series: 1 for cloudy sky and 5 for clear sky with obvious decrease in reflectance ratio

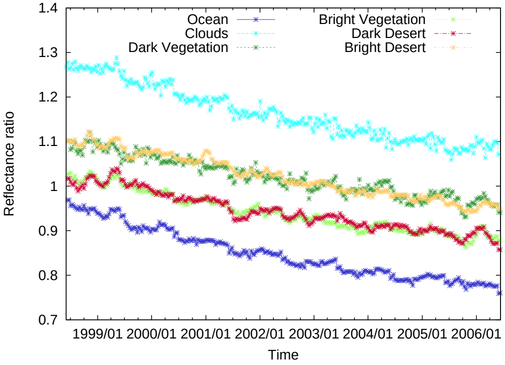

Figure: *Original time series for Meteosat-7.*

Ageing model

- Modeling decrease of spectral response curve $\phi(\lambda, t)$
- At time t_0, spectral response curve $\phi(\lambda, t_0) = \phi_0(\lambda)$
- Linear or exponential decrease of $\phi(\lambda, t)$ in time?
- Is decrease of $\phi(\lambda, t)$ in time wavelength dependent?

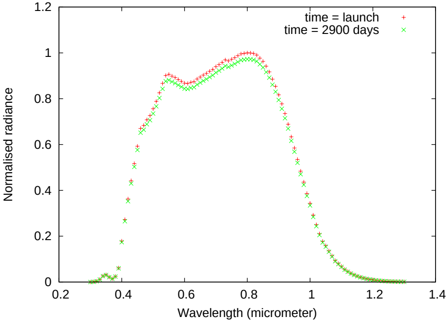

Figure: *Spectral Response curve for Meteosat-7 at launch and how it could look after 2900 days.*

Ageing model - linear decrease in time

Linear decrease of spectral response in time, no wavelength dependence: $\phi(\lambda, t) = \phi_0(\lambda)\,(1 - \alpha t)$

Translating to filtered reflectance:

$$L_{NB} = \int_0^\infty L(\lambda)\,\phi(\lambda, t)\,d\lambda = (1 - \alpha t)\,\int_0^\infty L(\lambda)\,\phi_0(\lambda)\,d\lambda$$

Linear decrease of spectral response in time, wavelength dependent: $\phi(\lambda, t) = \phi_0(\lambda)\,(1 - \alpha t)\,\mathbf{(1 + \beta t\,(\lambda - \lambda_0))}$

Translating to filtered reflectance:

$$L_{NB} = \int_0^\infty L(\lambda)\,\phi(\lambda, t)\,d\lambda = (1 - \alpha t)\,\int_0^\infty L(\lambda)\,\phi_0(\lambda)\,d\lambda$$

$$\mathbf{+(1 - \alpha t)\,\beta t\,\int_0^\infty L(\lambda)\,\phi_0(\lambda)\,(\lambda - \lambda_0)\,d\lambda}$$

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Translating to filtered reflectance:

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Linear decrease of spectral response in time, **wavelength dependent**: $\phi(\lambda, t) = \phi_0(\lambda)\,(1 - \alpha t)\,\boldsymbol{(1 + \beta t\,(\lambda - \lambda_0))}$

Translating to filtered reflectance:

$$L_{NB} = \int_0^\infty L(\lambda)\,\phi(\lambda, t)\,d\lambda = (1 - \alpha t)\int_0^\infty L(\lambda)\,\phi_0(\lambda)\,d\lambda$$
$$\boldsymbol{+ (1 - \alpha t)\,\beta t\int_0^\infty L(\lambda)\,\phi_0(\lambda)\,(\lambda - \lambda_0)\,d\lambda}$$

Ageing model - linear decrease - Example

Meteosat-7 time series for ocean, clouds, dark vegetation, bright vegetation, dark desert and bright desert without narrow band to broad band correction:

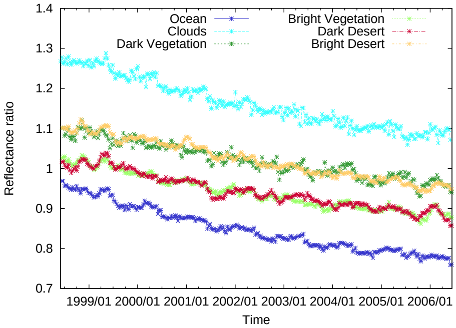
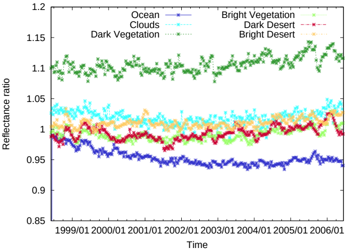


Figure: *Original time series for Meteosat-7.*

Ageing model - linear decrease - Example (2)

Meteosat-7 time series after linear ageing correction of the spectral response curve: $\phi(\lambda, t) = \phi_0(\lambda)\,(1 - \alpha t)$



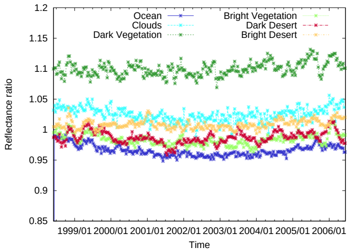
Best $\alpha = 0.000055$ days^{-1}, which corresponds to a linear decrease of the spectral response curve of 2.0% per year.

RMS error of the residual drift is 0.95% over the full period.

Figure: *Time series with linear ageing model for Meteosat-7 (ageing parameter $\alpha = 0.000055$ days^{-1}).*

Ageing model - linear decrease - Example (3)

Met-7 time series after ageing correction of the spectral response curve: $\phi(\lambda, t) = \phi_0(\lambda)\,(1 - \alpha t)\,(1 + \beta t\,(\lambda - \lambda_0))$



Best $\alpha = 0.000050$ days^{-1} and $\beta = 0.000105$ days^{-1} μm^{-1} which corresponds to a decrease of the spectral response curve of 1.8% per year.

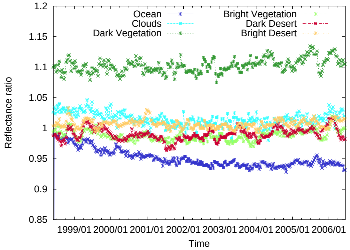
RMS error of the residual drift is 0.49% over the full period.

Figure: *Time series with linear ageing model for Meteosat-7 (ageing parameters $\alpha = 0.000050$ days^{-1}, $\beta = 0.000105$ days^{-1} μm^{-1}).*

Ageing model - exponential decrease in time

Exponential decrease of spectral response in time:

$$\phi(\lambda, t) = \phi_0(\lambda)\, exp(-t/t_0)$$



Translating to filtered reflectance:

$$L_{NB} = \int_0^\infty L(\lambda)\, \phi(\lambda, t)\, d\lambda = exp(-t/t_0) \int_0^\infty L(\lambda)\, \phi_0(\lambda)\, d\lambda$$

Figure: *Time series with exponential ageing model for Meteosat-7 (ageing parameter $t_0 = 18000$ days).*

Best $t_0 = 18000$ days. RMS error of the residual drift is 0.48% over the full period.

Meteosat-2 - Original time series

Meteosat-2 time series for ocean, clouds, dark vegetation, bright vegetatiaon, dark desert and bright desert without narrow band to broad band correction:

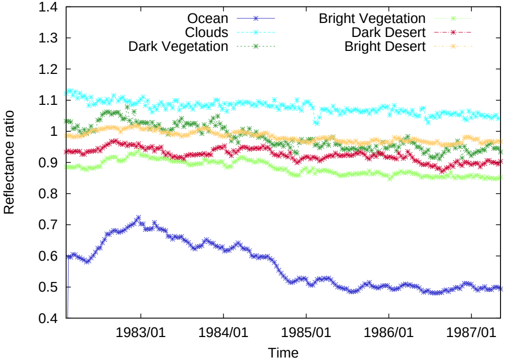
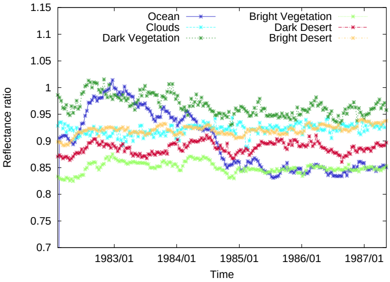


Figure: *Original time series for Meteosat-2.*

Meteosat-2 - Linear ageing model

Meteosat-2 time series after linear ageing correction of the spectral response curve.



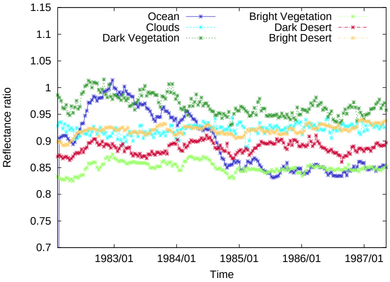


Figure: *Time series with linear ageing model for Meteosat-2. Left figure ageing parameter $\alpha = 0.000035$ days^{-1}. Right figure ageing parameters $\alpha = 0.000035$ days^{-1}, $\beta = 0.000001$ days^{-1}.*

Meteosat-2 - Ocean curve

Bump in ocean curve could be caused by El Chichon eruptions in Mexico during end of 1982/03 and beginning of 1982/04.

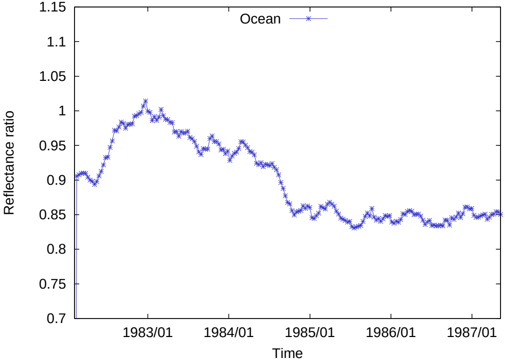


Figure: *Meteosat-7 ocean time series after linear ageing correction (ageing parameter* $\alpha = 0.000035$ *days*$^{-1}$*).*

Outline

Conclusions

- Goal to create GERB-like data for MFG
- First creating ageing models to correct for the degradation of the instruments
- Meteosat-7 data can be corrected well using a linear wavelength dependent model (stability of 0.49%), except for a slight curve in the time series which still needs to be removed (perhaps exponential model instead)
- Meteosat-2 data correction is probably hindered by the volcanic eruptions of El Chichon
- Stronger wavelength dependent ageing in Meteosat-7 than Meteosat-2 due to different shape of the spectral response curve