Spectral ageing model for the Meteosat First Generation visible band

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Outline

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Main accomplishments
  Spectral ageing model
  Meteosat-7
  Full Meteosat First Generation
  Pre-launch characterisation problem of Meteosat-7 visible spectral response curve

Unpublished work
  Sensitivity study of spectral ageing model
  Regional validation for full MFG

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Introduction – Meteosat First Generation

- Meteosat Visible and Infrared Imager (MVIRI)
  - 6 instruments (02/1982 – 07/2006)
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  - 6 instruments (02/1982 – 07/2006)
  - Temporal frequency of 30 minutes
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- VIS MVIRI data in CM SAF
  - Surface incoming radiation
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  - Fractional cloud cover
  - GERB-like TOA radiation
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  - GERB-like TOA radiation
  - Aerosol optical depth

![Normalized spectral response chart](chart.png)
Introduction – In-flight degradation

Figure: VIS calibration coefficients for Meteosat-7 (Govaerts et al. 2004).
Introduction – In-flight degradation

Figure: VIS calibration coefficients for Meteosat-7 (Govaerts et al. 2004).

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- Saturation of the drift
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  - scene type averaging

![Reflectance ratio](image)
(1) Spectral ageing model – mathematical formula

- Semi-empirical model of spectral response curve \( \phi(\lambda, t) \)
  \[
  \phi(\lambda, t) = \phi(\lambda, 0) \left( e^{-\alpha t} + \beta (1 - e^{-\alpha t}) \right) (1 + \gamma t (\lambda - \lambda_0))
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- Spectral degradation: $1 + \gamma t (\lambda - \lambda_0)$
  - $\gamma$ rate of spectral degradation
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- Parameter fitting
  - Minimisation of the cost function using the Powell method

- Regional validation
  - Unfiltering with all-sky simulations
  - Yearly averages per $100 \times 100$ pixels
  - All-sky images (06/98–06/06): $\sigma = 1.1\%$ yr$^{-1}$
  - All-sky images (01/99–12/05): $\sigma = 0.6\%$ yr$^{-1}$
  - Clear-sky images (06/98–06/06): $\sigma = 0.4\%$ yr$^{-1}$
  - Clear-sky images (01/99–12/05): $\sigma = 0.3\%$ yr$^{-1}$

- Apply linear calibration increase

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(2) Meteosat-7 – spectral ageing correction

- Parameter fitting
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  - Error estimation of parameters through 30 subsets of 100 targets

![Graph showing reflectance ratio r over time for different types of surfaces: Clouds, Ocean, Dark vegetation, Bright vegetation, Dark desert, Bright desert. The graph indicates the reflectance ratio for Meteosat-7 with parameters α=0.000357, β=0.760112, γ=0.000126. The data spans from 1999/01 to 2005/01.]
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(3) Full MFG – spectral ageing correction

- Problems in original time series
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  - volcanic eruptions corrected through least-squares fitting with GACP AOD dataset
(3) Full MFG – spectral ageing correction

- Problems in original time series
  - volcanic eruptions corrected through least-squares fitting with GACP AOD dataset
  - 6-bit digitisation

![Graph showing reflectance ratio over time]

<table>
<thead>
<tr>
<th>Time</th>
<th>Reflectance ratio r</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983/01</td>
<td>0.6</td>
</tr>
<tr>
<td>1987/01</td>
<td>0.7</td>
</tr>
<tr>
<td>1991/01</td>
<td>0.8</td>
</tr>
<tr>
<td>1995/01</td>
<td>0.9</td>
</tr>
<tr>
<td>1999/01</td>
<td>1.0</td>
</tr>
<tr>
<td>2003/01</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Legend:
- Full MFG (with seasonal correction)
- Meteosat-2
- Meteosat-3
- Meteosat-4
- Meteosat-5
- Meteosat-6
- Meteosat-7
- Clouds
- Ocean
- Dark Vegetation
- Bright Vegetation
- Dark Desert
- Bright Desert
3) Full MFG – spectral ageing correction

- Problems in original time series
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  - 6-bit digitisation
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  - normalisation with respect to Meteosat-7 bright desert
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- Long-term stability

<table>
<thead>
<tr>
<th>Surface type</th>
<th>Met-4 – 7 (17 yrs)</th>
<th>Met-2 – 7 (24 yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clouds</td>
<td>0.0123</td>
<td>0.0239</td>
</tr>
<tr>
<td>Ocean</td>
<td>0.0167</td>
<td>0.0611</td>
</tr>
<tr>
<td>Dark vegetation</td>
<td>0.0140</td>
<td>0.0437</td>
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<tr>
<td>Bright vegetation</td>
<td>0.0120</td>
<td>0.0266</td>
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<tr>
<td>Dark desert</td>
<td>0.0142</td>
<td>0.0230</td>
</tr>
<tr>
<td>Bright desert</td>
<td>0.0098</td>
<td>0.0099</td>
</tr>
</tbody>
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(4) Pre-launch characterisation problem

- Using the SEVIRI HRV data of Meteosat-8 in the overlap period 2004–2006
  - Successor channel of MVIRI VIS
  - Comparable spectral response curves

![Normalized flux vs Wavelength](image)

\[ \phi_{\text{Met8}}(\lambda, 0) \quad \phi_{\text{Met7}}(\lambda, 0) \]

Normalized flux
Wavelength (µm)

- Published in August 2013
(4) Pre-launch characterisation problem

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- Validation of spectral ageing model
  - Improvement using Meteosat-8 HRV curve from 4.5% to 2.1% RMS
  - Total error $\sim 1.4\%$

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### Reflectance ratio $r$

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<th>2004/11</th>
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Sensitivity study – $\Delta$ECV

- Simulate degraded radiances after 8 year using both spectral and linear modeled spectral response curves

- Decrease in difference with self-calibration

It is worth to consider the spectral ageing model for most ECVs
(U-1) Sensitivity study – $\Delta$ECV

- Simulate degraded radiances after 8 year using both spectral and linear modeled spectral response curves
- Compute difference for several Essential Climate Variables

![Graph showing spectral response over wavelength with two curves: one for SSCC degraded after 8 years and another for spectrally degraded after 8 years.](image)
Sensitivity study – $\Delta ECV$

- Simulate degraded radiances after 8 year using both spectral and linear modeled spectral response curves
- Compute difference for several Essential Climate Variables
  - Aerosol optical depth over ocean
    - $\Rightarrow \sim$ background aerosols
  - Land surface albedo
    - $\sim 5\%$ over vegetation
  - Cloud optical depth
    - $\sim 10\%$ over ocean
  - TOA outgoing VIS BB-radiation
    - $\sim 4\%$ over vegetation

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\[ \Delta A_{\text{Vegetation}} \]

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- Compute difference for several Essential Climate Variables
  - Aerosol optical depth over ocean ⇒ ∼ background aerosols
  - Land surface albedo ⇒ 5% over vegetation
  - Cloud optical depth ⇒ 10% over ocean

- Decrease in difference with self-calibration ⇒ It is worth to consider the spectral ageing model for most ECVs
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  - TOA outgoing VIS BB-radiation ➞ 4% over vegetation

\[ \Delta L_{BB} \text{ (W m}^{-2}\text{ sr}^{-1}) \]

\begin{tikzpicture}[scale=0.7]
  \begin{axis}[
    xlabel={Broadband radiance $L_{BB}$ (W m$^{-2}$ sr$^{-1}$)},
    ylabel=$\Delta L_{BB}$ (W m$^{-2}$ sr$^{-1}$),
    xmin=-4, xmax=300,
    ymin=-4, ymax=1,
    xtick={-4,-3,-2,-1,0,1,50,100,150,200,250,300},
    ytick={-4,-3,-2,-1,0,1,50,100,150,200,250,300},
    xmajorgrids, ymajorgrids,
    legend style={at={(0.5,0.05)},anchor=south},
    legend cell align=left,
    legend entries={Vegetation}
  \end{axis}
\end{tikzpicture}
(U-1) Sensitivity study – ΔECV

- Simulate degraded radiances after 8 year using both spectral and linear modeled spectral response curves
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  - Aerosol optical depth over ocean
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- Decrease in difference with self-calibration
  $\Rightarrow$ It is worth to consider the spectral ageing model for most ECVs
Outline

Introduction

Main accomplishments
   Spectral ageing model
   Meteosat-7
   Full Meteosat First Generation
   Pre-launch characterisation problem of Meteosat-7 visible spectral response curve

Unpublished work
   Sensitivity study of spectral ageing model
   Regional validation for full MFG

Conclusions

Future prospects
(U-2) Full MFG Regional validation

- All-sky images Meteosat-2 – 7
  \[ \sigma = 0.7\% \text{yr}^{-1} \]
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- All-sky images Meteosat-2 – 7
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- All-sky images Meteosat-4 – 7
  \[ \sigma = 0.5\% yr^{-1} \]
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  \[\sigma = 0.5\%\text{yr}^{-1}\]
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- ECV sensitivity study between spectral and linear degradation
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• Proven pre-launch characterisation problem of Meteosat-7 VIS spectral response curve
• ECV sensitivity study between spectral and linear degradation
• Achievements and accompanying problems were presented:
  ◦ scientific papers in peer-reviewed journals
  ◦ oral presentations at international conferences and meetings
  ◦ personal communication and visit with EUMETSAT team working on calibration of MVIRI VIS channel
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Future prospects – Correcting spectral response curve

- Problems with Meteosat-2 and -3
  - 6-bit digitisation: decrease offset slightly
  - characterisation issue of spectral response curve: replace or mathematically adjust the spectral response curves

- Use of Sciamachy to correct spectral response curve of Meteosat-5, -6, and -7
  - use spectra of Sciamachy and observations from MVIRI to derive spectral response curve
  - based on current response curve or starting from gaussian curve
  - need co-angular data (limited!)
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- Mathematical formula and parameters
  - useful for LUTs of AOD, COD, ...
Thank you