On the spatiotemporal variability of solar radiation and its consequences for the accuracy of satellite-based products of solar surface irradiance

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Motivation

• Clouds introduce significant spatio-temporal variability in the solar radiation field
• Limited representativeness of single point observation for extended spatial domains
• => Large instantaneous differences between ground-based observations and satellite retrievals (here: global surface irradiance)
• Complicates attribution of deviations to physical mechanisms (cloud structure, 3D effects, retrieval shortcomings, … )
Goals

• Use observations from a unique network of 99 autonomous pyranometer stations to investigate spatial averaging effects

• Compare these ground-based observations with global irradiance retrieved from METEOSAT SEVIRI

• Quantify improvements from using HRV channel from SEVIRI (1x1 vs. 3X3 km²) and 5min Rapid Scan Service in retrievals
The HOPE Field Campaign

- HOPE (HDCP2 Observational Prototype Experiment): major field campaign performed around Jülich, Germany, in spring/summer 2013
- Collection of reference data for evaluation of the German high-resolution atmospheric model ICON
- Focus on onset of clouds and precipitation in the convective boundary layer
- See Macke et al., ACP, 2017, for details
Pyranometer Network I.

- Autonomous stations recording temperature, rel. humidity and global irradiance
- Operated as part of HOPE in Apr.-Jul. 2013 around Juelich, DE
- New battery / cleaning / read-out of storage every 7-10 days
- See Madhavan et al., AMT, 2016, for more info.
Pyranometer Network II.

Fig.: Ridge- or joyplot of the timeseries of global irradiance recorded the pyranometer network on 24th of May 2013 comprising 64 high-quality stations.
Multi-Resolution Analysis I.

• Wavelet-based MRA used to separate time series into frequency sub-bands
• Split signal into wavelet smooths/details
• Haar wavelet: smooths are running mean
• Scales $J=3\ldots8 \Rightarrow$ running mean of $1/2^J$ days $\Rightarrow$ 3h … 5.6min
• See Whitcher et al., JGR, 2000; Deneke et al., JGR, 2009, for details

Fig.: Wavelet/scaling function and their frequency response (from Deneke et al., 2009).
Multi-Resolution Analysis II.

**Fig.** Wavelet smooths and details of the MRA for scales $J=3\ldots8$ (running mean of length $3h\ldots5.6\text{min}$), obtained from the time series of the mean global transmittance from all pyranometer obs. on 2013-05-24.
Representativeness Error I.

**Fig.:** Representativeness of point obs. under broken cloud conditions, as function of temporal frequency and domain size. (a) Variance of transmittance details. (b) Explained variance of point obs. and domain avg. (c) Expected deviation between point obs. and domain avg. (adapted from Madhavan et al., ACP, 2017).
Representativeness Error II.

- 32 pyranometers located in standard resolution pixel
- 9 pyranometers located in southerly HRV resolution pixel
- Combination of pyranometers allows more accurate estimate of spatial average!

**Fig.:** Map of pyranometer stations and collocation with closest standard and HRV-resolution MSG SEVIRI pixels.
Optimal Averaging I.

- Determination of optimal weights for estimating spatial average from multiple point measurements
- Main factor: spatial auto-correlation, assumed to depend only on distance
- Provides estimates of reduction in variance, averaging accuracy
- (Method closely related to Kriging interpolation)
Optimal Averaging II.

Fig.: Pixel-area estimates for broken cloud conditions (2013-05-24), as function of temporal frequency and pixel resolution. (a) Variance of transmittance. (b) Explained variance of pixel estimate and domain average. (c) Expected deviation between pixel estimate and domain average.
Optimal Averaging III.

**Fig.**: Time series of global irradiance obtained by optimal averaging of pyranometer observations for the domain of a MSG standard and a HRV-resolution pixel on day 2013-05-24.
Cloud Properties @ HRV Resolution

- Based on standard MSG-CPP retrieval (Roebeling et al., 2006, developed at KNMI, used for CM SAF CLARA/CLAAS climate data records), method of Nakajima and King, JAS, 1992
- Use HRV for resolution enhancement of VIS006/VIS008 channels / cloud optical depth (see Deneke & Roebeling, ACP, 2010)
- Threshold-based HRV cloud mask (see Bley & Deneke, AMT, 2013), pixel sharpening
- Consider local covariance of COT&Reff, 1.6um channel
Cloud Properties @ HRV Resolution II.

\[ \delta r_h = a \delta r_{06} + b \delta r_{08} \]

1. Fit linear model between visible channels
2. Extract hi.-freq. variation of HRV channel
   (see Deneke & Roebeling, ACP, 2010)
**SICCS**: SURFACE INSOLATION IN CLOUDY CONDITIONS FROM METEOSAT SEVIRI IMAGERY - ALGORITHM

**Fig**: Flowchart of SICCS algorithm.

- Clear-sky model estimates aerosol radiative effects, water vapor absorption
- Cloudy-sky model estimates cloud transmissivity from CPP cloud properties

See Deneke et al., 2005/2008; Greuell et al., 2013, for details
SICCS @ HRV Resolution

**Fig.**: Time sequence of TOA broadband albedo retrieved with SICCS algorithm for std.(left) and HRV (right) resolution for a 20x20km² domain centered on the pyranometer network for 2013-05-24.
Finding my pixel...

Fig.: Pixel map of autocorrelation function for std. (left) and HRV (right) resolution and for a 20x20km² domain centered (?) on the pyranometer network for 2013-05-24.
Variability MSG vs. Ground

Fig.: Wavelet-based variance spectrum for standard and HRV resolution global irradiance retrievals (solid) and for corresponding pyranometer averages (dashed) for 2013-05-24.

Variability MSG vs. Ground

Fig.: Explained variance of wavelet details of satellite retrievals and pyranometer averages for 2013-05-24.
Variability MSG vs. Ground

Fig.: Root mean square error for std. and HRV retrievals vs. pyranometer averages (solid) for smoothing with different running means and for 2013-05-24.
Conclusions

• High spatial density pyranometer network used to address limited representativeness of single point observations
• Introduced novell HRV-resolution cloud and solar irradiance datasets from MSG SEVIRI
• Demonstrated its benefits for solar irradiance products

*We do not have to wait for MTG to achieve 1km resolution!*
Outlook

• Longer-term comparison, classification according to cloud type
• Account for wind speed, anisotropy of spatial autocorrelation
• Within MetPVNet project:
  – Benefits for grid integration of PV power generation
  – Direct irradiance/irradiance on inclined planes
• Publically available CPP/SICCS dataset@HRV / 5min resolution for selected years/Central Europe will be released by early 2019
• Investigate effects of increased temporal/spatial resolution with MTG for Copernicus Radiation Service