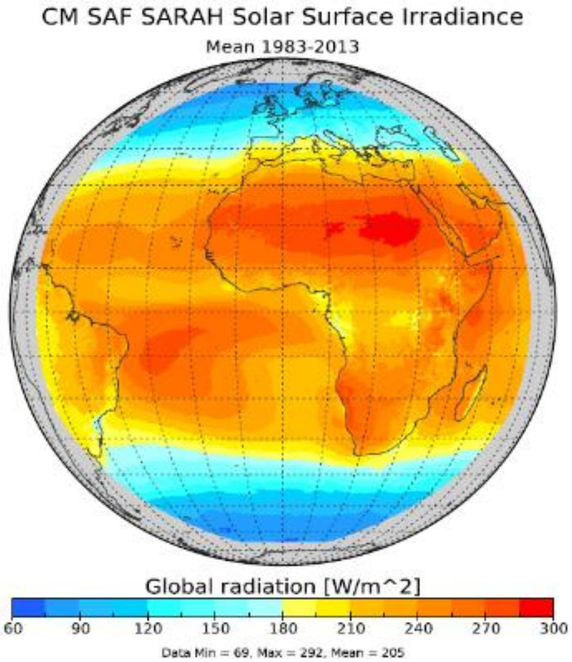
Quality Assessment of SARAH-3:

The new regional satellite-based Surface Solar Radiation data set from the CM SAF



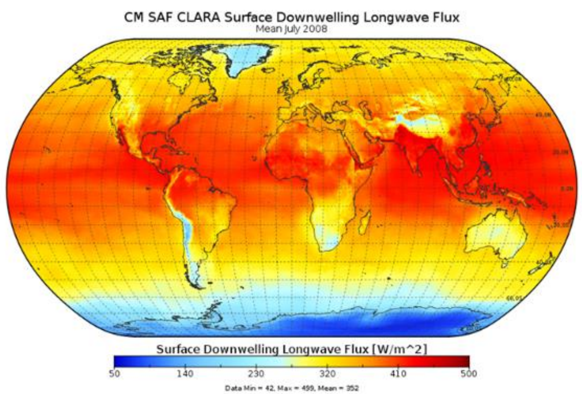
Jörg Trentmann, Uwe Pfeifroth,

Jaqueline Drücke, Roswitha Cremer

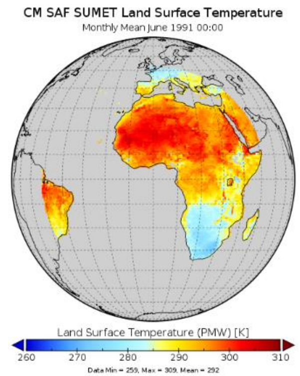
CM SAF Climate Data Records

- CM SAF provides a variety of global and regional climate data records on clouds, radiation, surface parameters (e.g., LST), precipitation (ocean only)
- Availability: 1982 to the day before yesterday
- Resolution: Daily, monthly / 0.05°, 0.25°, 1°
- All data are freely available at www.cmsaf.eu

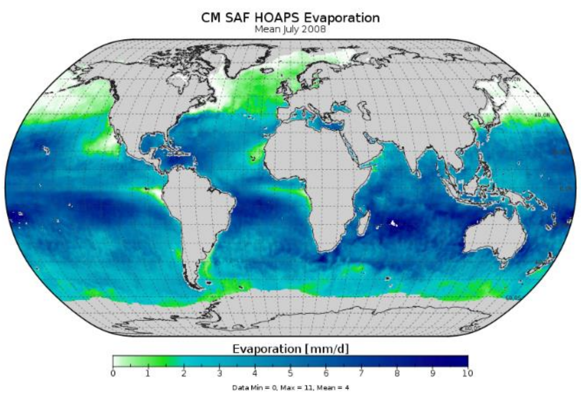
CLARA-A2.1 / ICDR



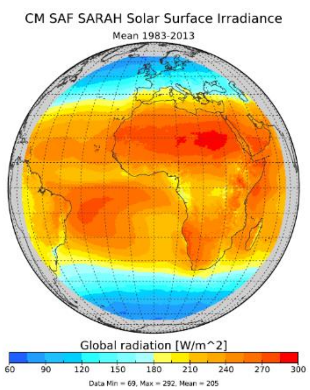
SUMET 1.0



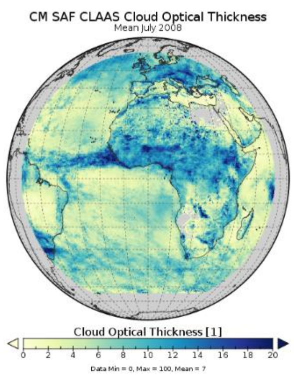
HOAPS 4.0



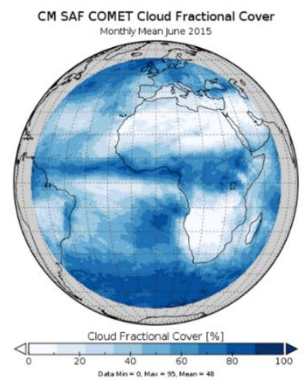
SARAH-2.1 / ICDR



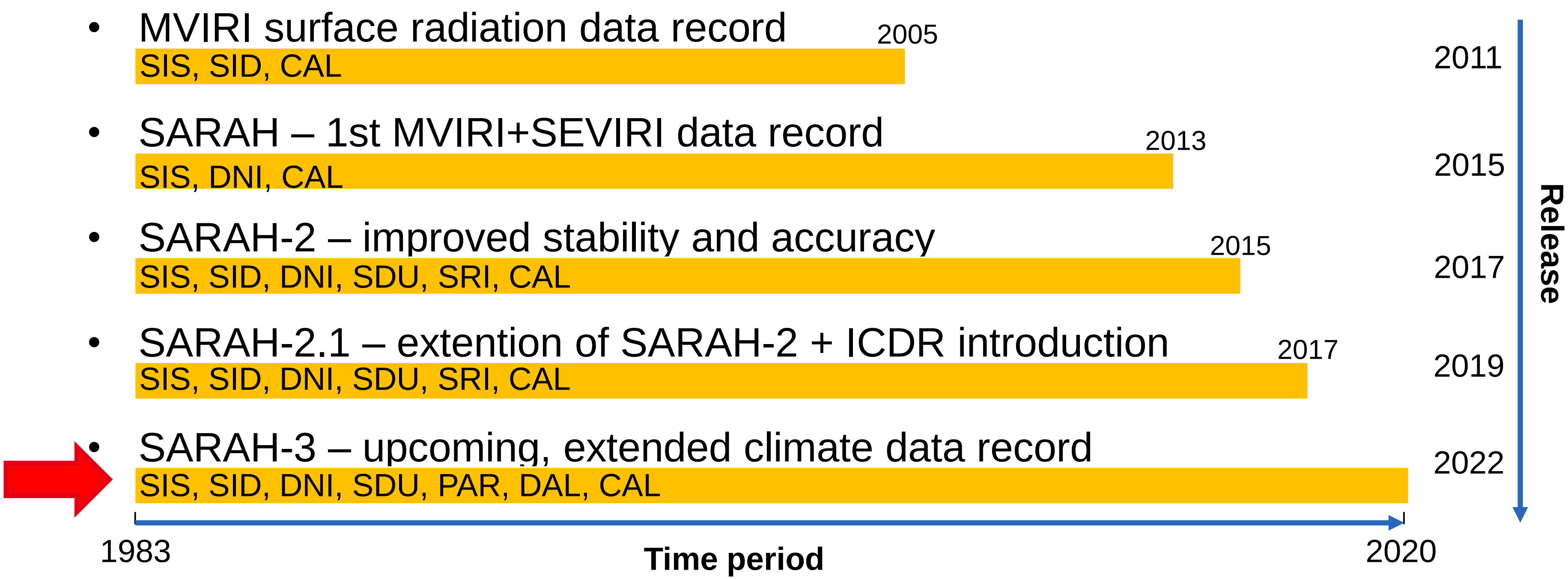
CLAAS-2.1 / ICDR



COMET 1.0



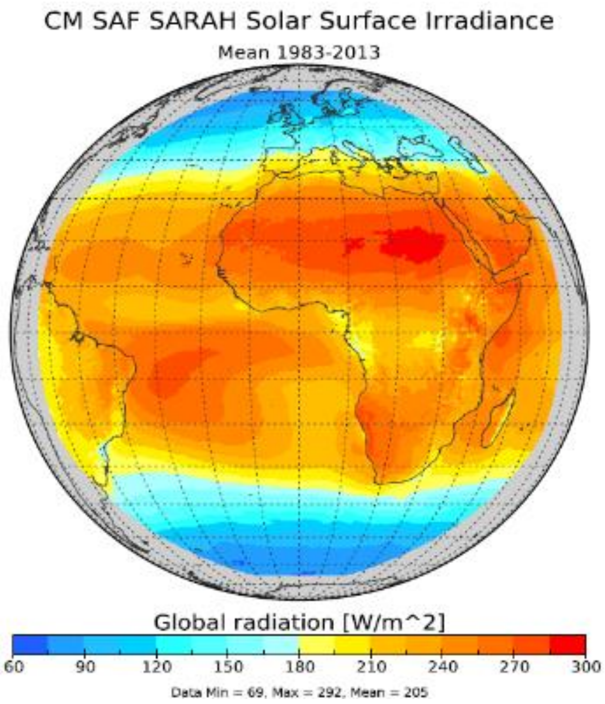
History of METEOSAT-based surface solar radiation climate data records at CM SAF



CM SAF SARAH-3

Surface Solar Radiation Dataset – Heliosat

- **Variables**
  - Surface Solar Irradiance (SIS)
  - Surface Direct Irradiance (SID, DNI)
  - Sunshine Duration (SDU)
  - *Photosynthetic Active Radiation (PAR)*
  - *Daylight (DAL)*
  - Effective Cloud Albedo (CAL)
- **Resolution**
  - Spatial: 0.05° × 0.05°
  - Temporal: 30-min, daily-, monthly mean
- **Coverage**
  - Spatial: regional (±65°)
  - Temporal: 1983 to *2020*



Müller, R. et al. (2015) *Remote Sens., 7*, 8067-8101, doi:10.3390/rs70608067
Pfeifroth, U. et al.. (2018) *J. Geophys, Res., 123,* 1735-1754, doi:10.1002/2017JD027418.

DOI:10.5676/EUM_SAF_CM/SARAH/V003

- Available in late 2022 at www.cmsaf.eu
  currently available via: contact.cmsaf@dwd.de

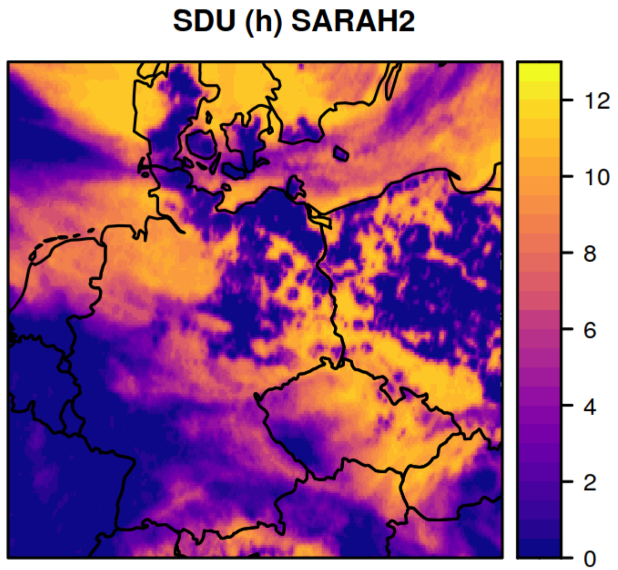
SARAH-3 – What‘s new ?

- Improved estimation of surface radiation over snow-covered surfaces by using internally derived daily snow information
- Updated and improved auxiliary data
  - ERA-5 daily Ozone and Total Column Water Vapor
  - New spectrally-resolved Surface Albedo data based on MODIS (Blanc et al.)
- Improved estimation of sunshine duration (based on DNI)
- Covering 1983 to 2020
- New spectral parameters:
  - Photosynthetic active radiation (PAR)
  - Daylight (DAL)

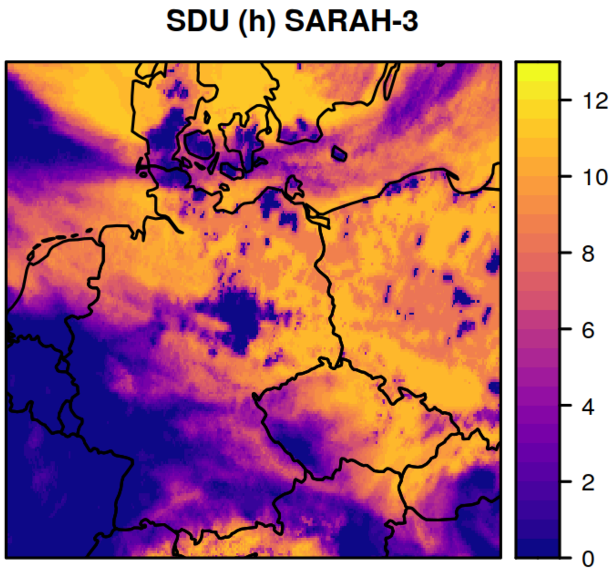
SARAH-3: Snow Coverage

Sunshine Duration, 23 March 2013

SARAH-2

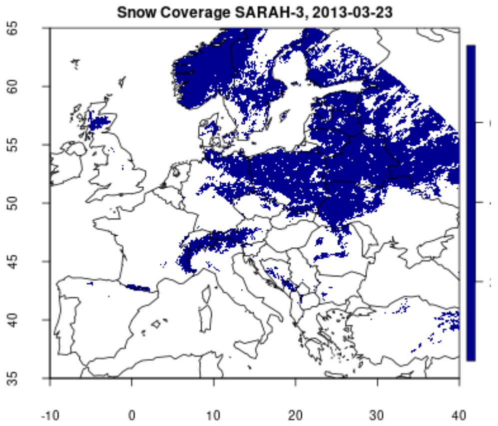


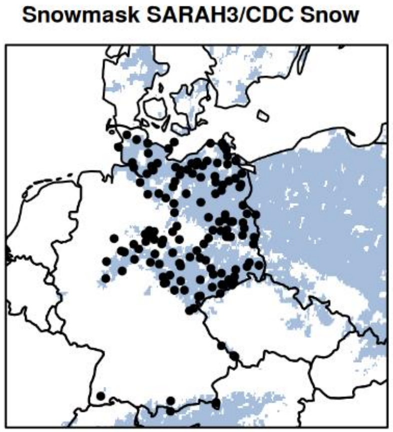
SARAH-3



Snow Mask

SARAH-3





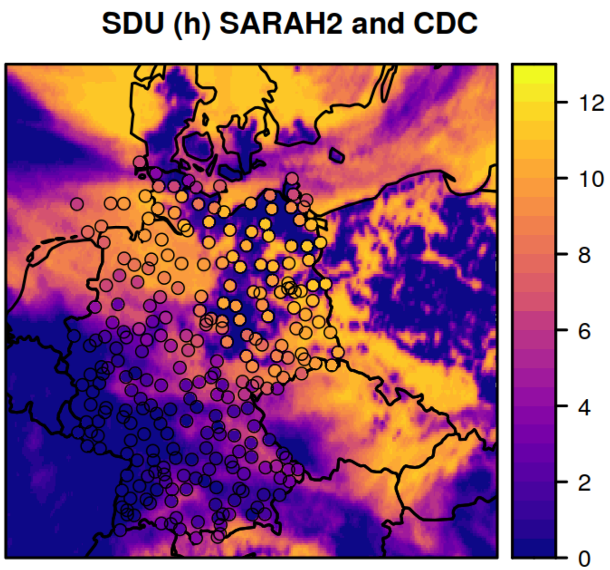
➔ Substantially enhanced surface irradiance under snow-covered conditions

SARAH-3: Snow Coverage

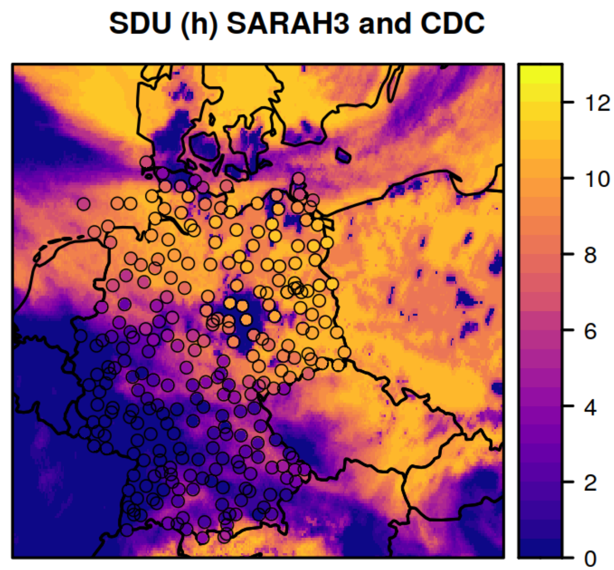
Snow Mask

Sunshine Duration, 23 March 2013

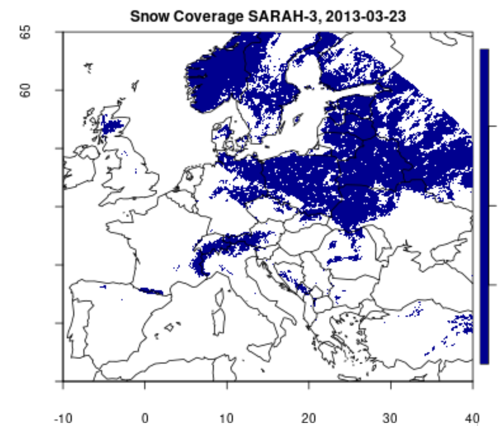
SARAH-2

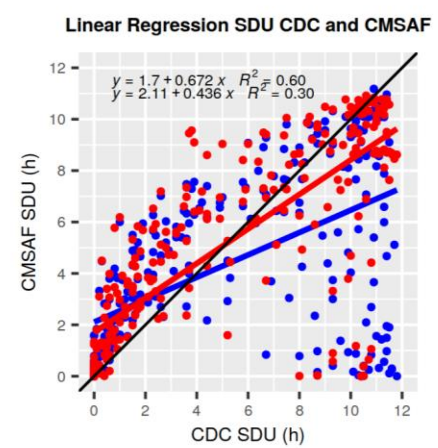


SARAH-3



SARAH-3



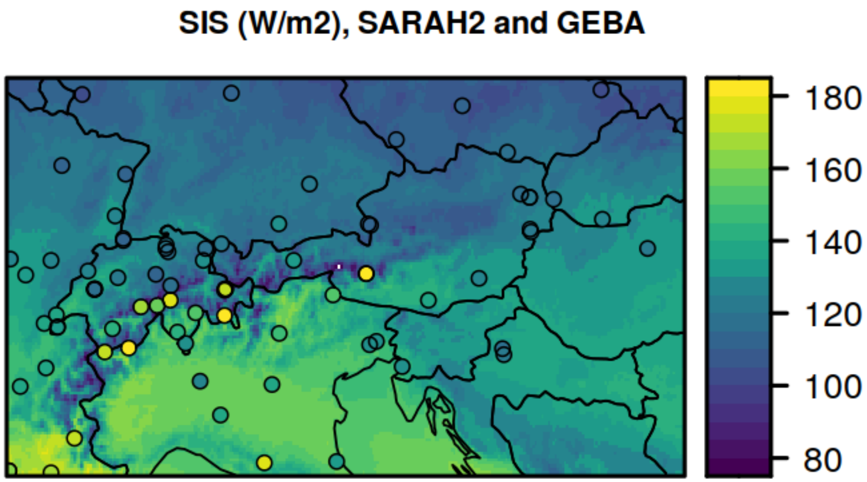


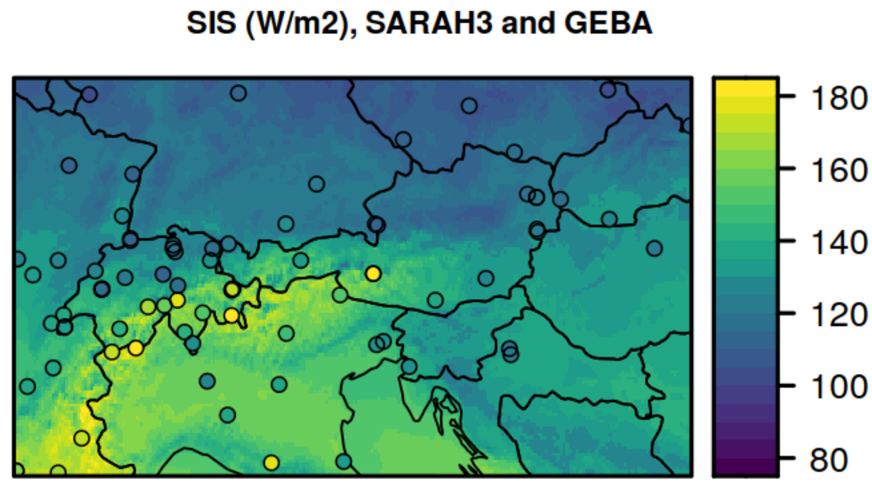
- ➔ Improved comparison to surface measurements
- ➔ Snow-covered situations remain challenging!

SARAH-3: Snow Coverage

Surface Radiation, Climatology, March 1991 - 2020

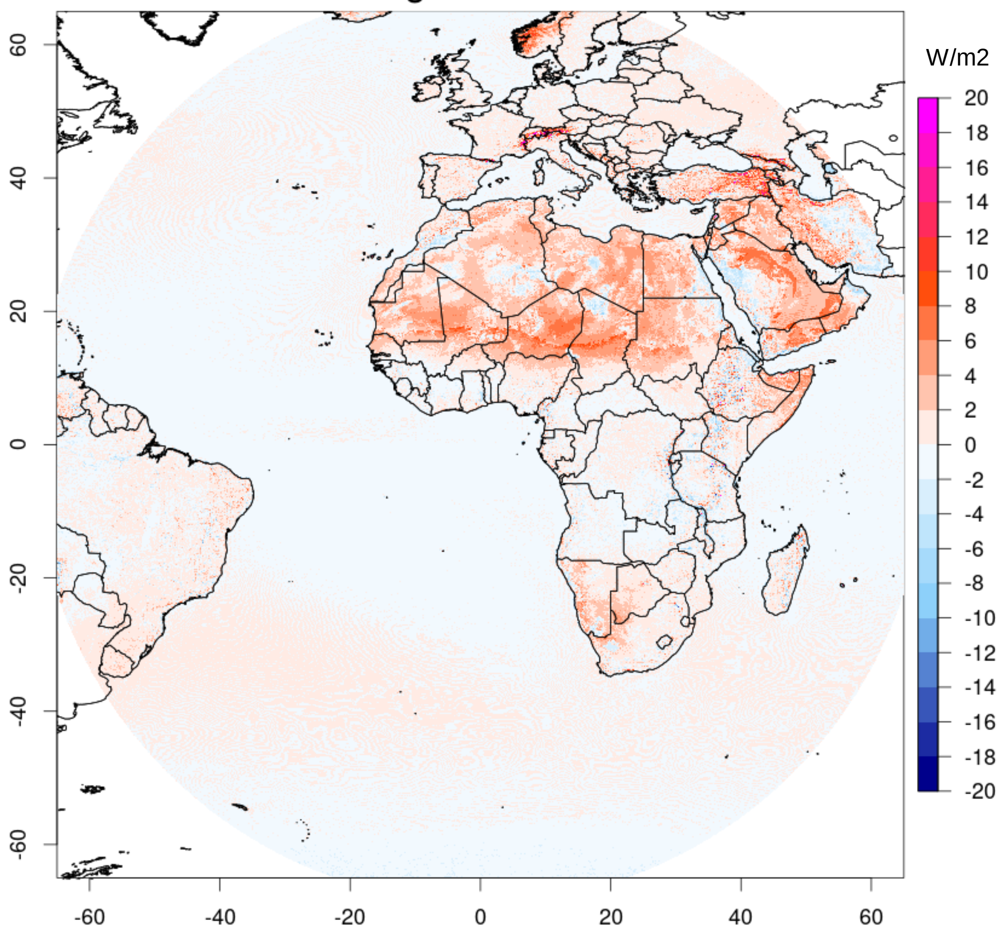
- ➔ Substantially enhanced surface radiation in the Alpine region in SARAH-3
- ➔ SARAH-3 compares much better with surface measurements





SARAH-3 – Comparison with SARAH-2

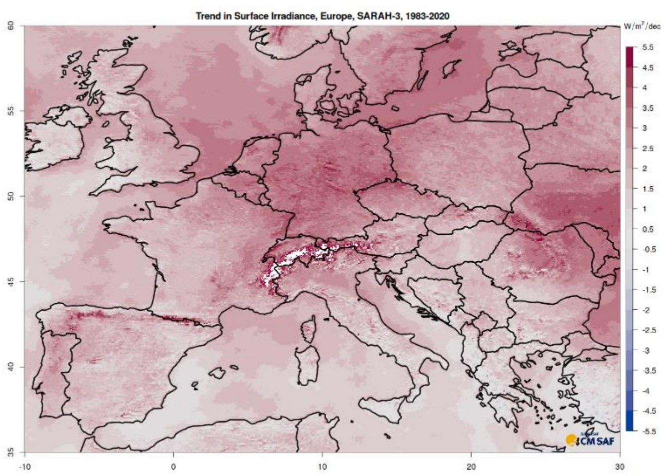
Difference in Climatologies SARAH-3 minus SARAH-2.1

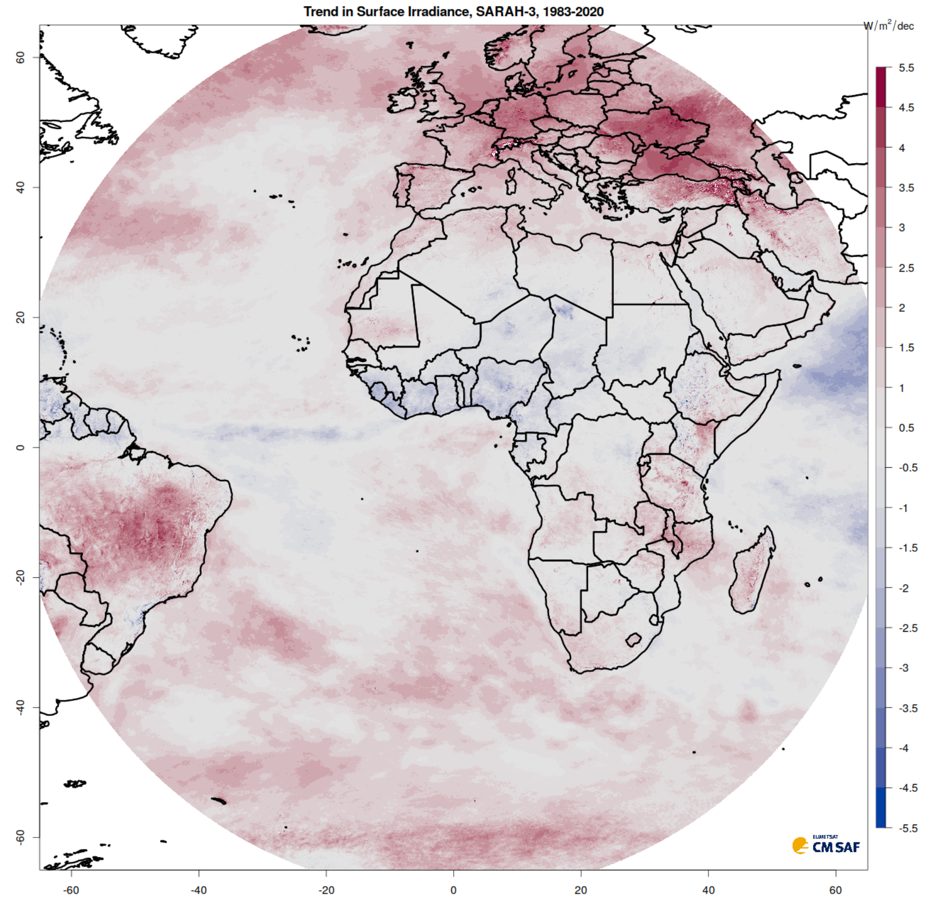


- ➔ In general, only small changes
- ➔ SARAH-3 irradiance is higher in **alpine** regions (snow) and most of the **subtropics** (albedo)

Surface Irradiance, Decadal Trend

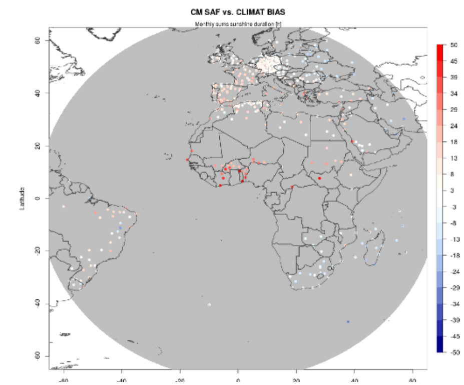
- ➔ Reasonable linear trends in SARAH-3
- ➔ General 'brightening' in Europe
- ➔ Unrealistic large brightening in Alpine region, likely due to improved snow detection after 1994



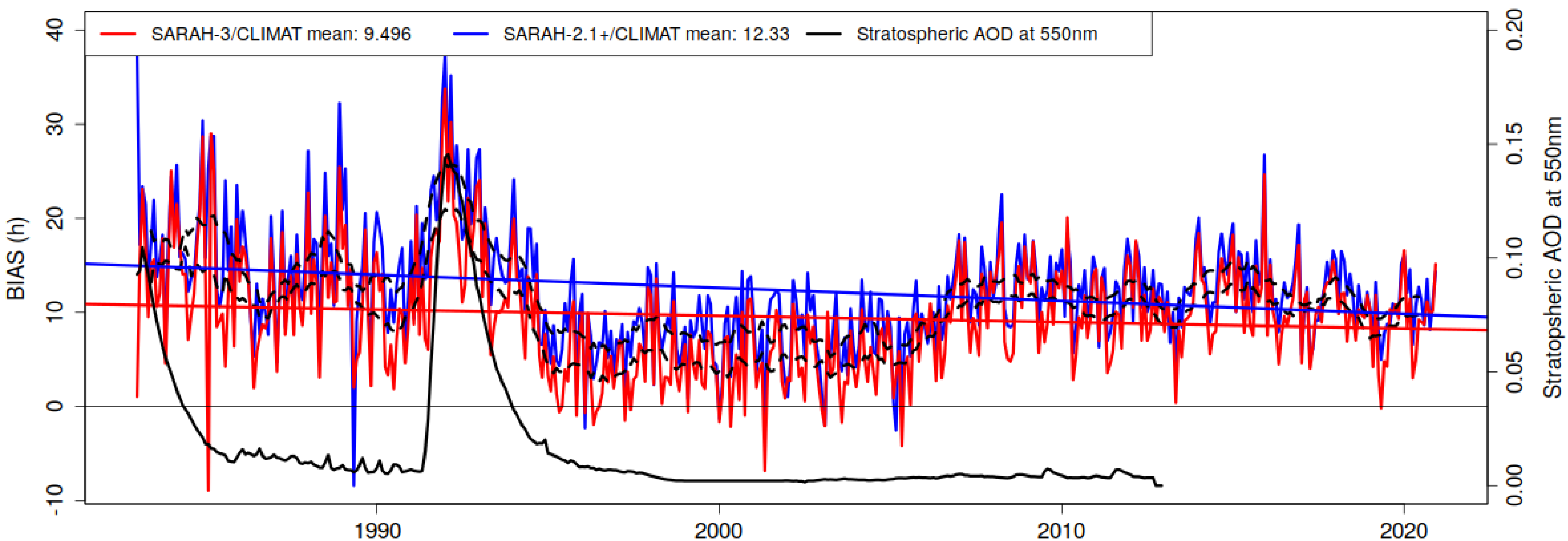


Sunshine Duration, Evaluation, CLIMAT

- Long-term observations of sunshine duration available
- Time Series of the bias as a measure for stability
- Analysis of aerosol impact possible

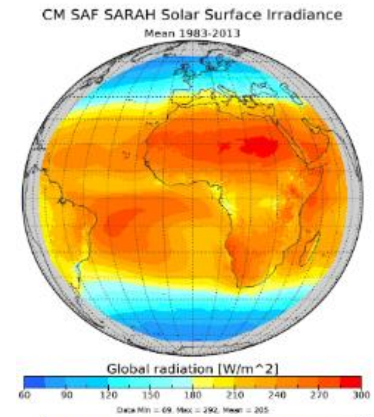


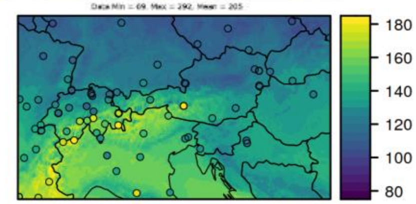
BIAS, SDU (1983-2020)

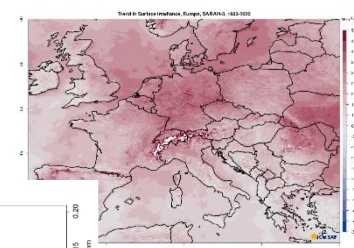


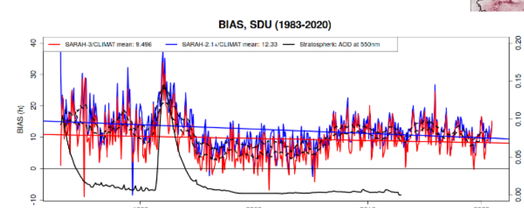
Summary

- SARAH-3: The next editon of the CM SAF SARAH climate data records
- Includes improved consideration of snow coverage, surface albedo, water vapor, ozone
- New parameters: DAL, PAR
- Improved performance best detectable in daily data and sunshine duration
- Currently available via: contact.cmsaf@dwd.de









Extra Slides

Validation Results, SARAH-3

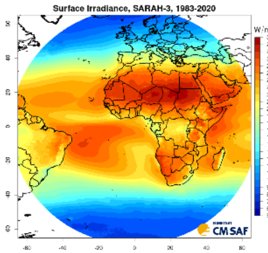
EUMETSAT CM SAF CLIMATE MONITORING

Deutscher Wetterdienst
Wetter und Klima aus einer Hand
DWD

Surface Incoming Solar Radiation (SIS)

Monthly Mean

SIS	N_{mon}	Bias [W/m²]	MAD [W/m²]	SD [W/m²]	StMAD [W/m²]	AC	$Frac_{mon}$ > threshold accuracy [%]
SARAH-3	2863	2.25	5.32	6.75	5.83	0.93	12.2 (>10 W/m²)
SARAH-2.1+ICDR	2863	1.6	5.15	6.87	5.46	0.92	11.1 (>10 W/m²)
SARAH-2.1	2453	1.59					
SARAH-2	1909	2.03					
SARAH	1672	1.27					
MVIRI	878	4.24					



	SIS [W/m²]			
accuracy	Th	Ta	Op	T
monthly	5	4	3	
daily	12	11	10	1
Inst.	20	15	12	4
stability	1	0.5	0.3	

Daily Mean

SIS	N_{day}	Bias [W/m²]	MAD [W/m²]	SD [W/m²]	StMAD [W/m²]	AC	$Frac_{day}$ > threshold accuracy [%]
SARAH-3	84789	2.18	10.9	15.8	11.32	0.96	19.6 (>17 W/m²)
SARAH-2.1 + ICDR	84815	1.52	11.5	16.8	11.99	0.95	21.4 (>17 W/m²)
SARAH-2.1	72087	1.51	11.70	17.2	11.92	0.95	16.8 (>20 W/m²)
SARAH-2	57128	1.7					
SARAH	48605	1.1					
MVIRI	29790	4.4					

30-min

SIS	N	Bias [W/m²]	MAD [W/m²]	SD [W/m²]	StMAD [W/m²]	Cor	$Frac_{mon}$ > threshold [%]	
SARAH-3 tot	3,941,018	2.3	24.5	59.4	25.3	/	22.0 (> W/m²)	30
SARAH-3 day	2,146,546	4.2	44.9	80.3	47.1	0.97	40.4 (> W/m²)	30

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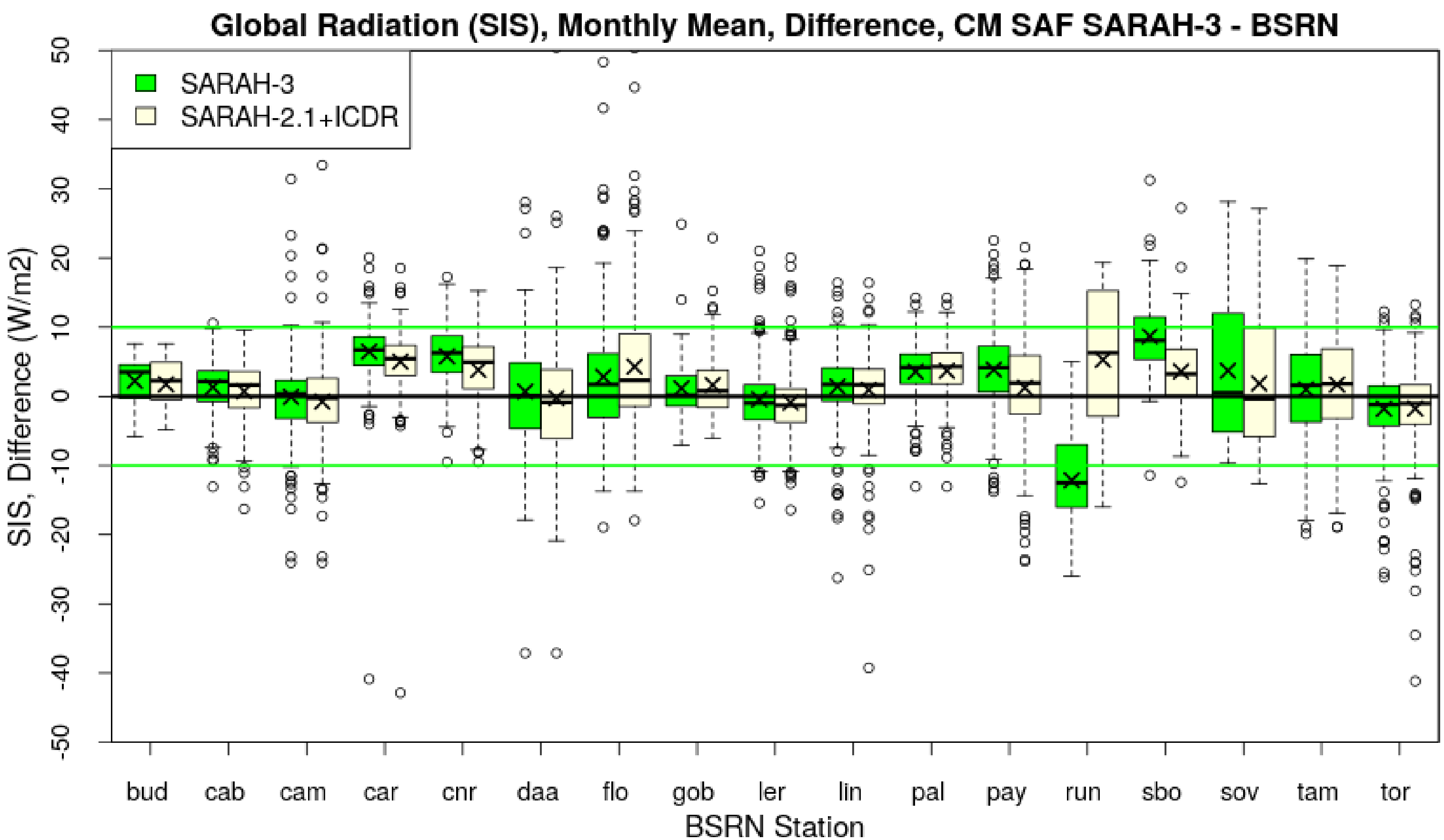
Surface Incoming Solar Radiation (SIS) Individual stations



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DWD

Surface Incoming Direct Radiation (SID)

Monthly Mean

SID	N_{mon}	Bias [W/m²]	MAD [W/m²]	SD [W/m²]	StMAD [W/m²]	AC	$Frac_{mon}$ > threshold accuracy [%]
SARAH-3	2708	0.99	7.84	11.2	9.09	0.90	19.0 (>13W/m²)
SARAH-2.1+ICDR	2708	0.70	7.78	11.2	8.54	0.90	18.2 (>13W/m²)
SARAH-2.1	2347	0.87	7.8	11.3	8.70	0.89	7.7 (>20W/m²)
SARAH-2	1828	1					
SARAH	1587	(					
MVIRI	805	(					

	SID [W/m²]		
accuracy	Th	Ta	Op
monthly	8	7	5
daily	18	15	12
Inst.	40	30	20
stability	5	3	2

Daily Mean

SID	N_{day}	Bias [W/m²]	MAD [W/m²]	SD [W/m²]	StMAD [W/m²]	AC	$Frac_{day}$ > target W/m² [%]
SARAH-3	76512	0.92	16.0	24.0	17.58	0.93	25.3 (>20W/m²)
SARAH-2.1+ICDR	76537	0.63	17.0	25.5	18.70	0.92	27.2 (>20W/m²)
SARAH-2.1	65697	0.79	17.2	25.9	18.85	0.92	19.3 (>30W/m²)
SARAH-2	51929	0.89	17.6	26.			
SARAH	43549	0.77	17.9	26.			
MVIRI	26614	0.74	20.73	31.			

30-min

SID	N	Bias [W/m²]	MAD [W/m²]	SD [W/m²]	StMAD [W/m²]	Cor	$Frac_{mon}$ > threshold [%]
SARAH-3 tot	3,762,519	0.53	25.7	67.0	28.0	/	15.9 (> 50 W/m²)
SARAH-3 day	2,026,608	0.94	47.8	91.28	53.1	0.98	29.5 (> 50 W/m²)

Surface Normal Direct Radiation (DNI)

	DNI [W/m²]		
accuracy	Th	Ta	Op
monthly	17	15	12
daily	34	30	25
Inst.	50	40	30
stability	5	3	2

Monthly Mean

DNI	N_{mon}	Bias [W/m²]	MAD [W/m²]	SD [W/m²]	StMAD [W/m²]	AC	$Frac_{mon}$ > threshold [%]
SARAH-3	2627	-0.89	16.7	22.1	18.84	0.89	18.5 (>27 W/m²)
SARAH-2.1+ICDR	2627	-1.78	16.5	21.9	17.50	0.88	17.5 (>27 W/m²)
SARAH-2.1	2263	-1.82	16.4	21.9	17.97	0.88	14.7 (>30 [illegible]
SARAH-2	1794	-0.89	16[illegible]				
SARAH-1	1541	3.25	17[illegible]				

Daily Mean

DNI	N_{day}	Bias [W/m²]	MAD [W/m²]	SD [W/m²]	StMAD [W/m²]	AC	$Frac_{day}$ > threshold [%]
SARAH-3	71331	0.33	31.1	43.3	32.92	0.93	26.1 (>44W/m²)
SARAH-2.1+ICDR	71354	-0.69	33.0	46.2	34.83	0.92	28.3 (>44W/m²)
SARAH-2.1	60528	-0.82	33.4	46.8	35.71	0.91	32.3 (>40W/m²)
SARAH-2	49075	-0.81					
SARAH	41253	3.8					

DNI	N	Bias [W/m²]	MAD [W/m²]	SD [W/m²]	StMAD [W/m²]	Cor	$Frac_{mon}$ > threshold [%]
SARAH-3 tot	3,789,081	0.13	51.0	117.6	53.2	/	24.4 (> 60 W/m²)
SARAH-3 day	1,995,311	0.22	96.8	162.01	103.3	0.92	46.3 (> 60 W/m²)

30-min data

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Photosynthetic Active Radiation (PAR)

Monthly Mean

PAR	N_{mon}	Bias [µmol/m²/s]	MAD [µmol/m²/s]	SD [µmol/m²/s]	StMAD [µmol/m²/s]	AC	$Frac_{mon}$ > target [%]
SARAH-3	1064	14.5	19.7	24.1	18.84	0.89	3.8 (>46 µmol/m²/s)

	PAR [µmol/m²s]		
accuracy	Th	Ta	Op
monthly	46	37	23
daily	92	69	46
Inst.	138	92	69
stability	1	0.5	0.3

Daily Mean

PAR	N_{day}	Bias [µmol/m²/s]	MAD [µmol/m²/s]	SD [µmol/m²/s]	StMAD [µmol/m²/s]	AC	$Frac_{mon}$ > target [%]
SARAH-3	31532	14.7	26.5	32.7	27.25	0.98	3.48 (>78 µmol/m²/s)

Based on data from 10 stations, all with different temporal coverage

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Daylight (DAL)

Monthly Mean

DAL	N_{mon}	Bias [kLux]	MAD [kLux]	SD [kLux]	StMAD [kLux]	AC	$Frac_{mon}$ > threshold [%]
SARAH-3	584	2.92	2.92	1.6	3.0	0.87	48.5 (>2.7 kLux)

Daily Mean

DAL	N_{mon}	Bias [kLux]	MAD [kLux]	SD [kLux]	StMAD [kLux]	AC	$Frac_{mon}$ > threshold [%]
SARAH-3	17775	2.87	3.04	2.3	3.08	0.95	19.2 (>4.8 kLux)

DAL [kLux]			
accuracy	Th	Ta	Op
monthly	1.4	1.0	0.7
daily	3.4	2.7	2.1
Inst.	6.8	5.5	3.4
stability	1	0.5	0.3

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Sunshine Duration (SDU)

	SDU [h]		
accurac	Th	Ta	Op
monthly	20	15	10
daily	1.5	1	0.75
Inst.			
stability	0.8	0.5	0.3

Monthly Sum

SDU	N_{mon}	Bias [h]	MAD [h]	SD [h]	stMAD	AC	$Frac_{mon}$ > threshold [%]
SARAH-3	139786	6.24	15.40	20.37	15.43	0.88	26.6 (>20h)
SARAH-2.1+ICDR	139786	8.49	16.59	21.28	16.54	0.88	29.5 (>20h)
SARAH-2.1	137811	8.45	16.6	21.3	/	0.88	13.7 (>30h)
SARAH-2	117373	7.23					

Daily Sum

SDU	N_{day}	Bias [h]	MAD [h]	SD [h]	AC	$Frac_{day}$ > 1.5 h [%]
SARAH-3	4,579,221	0.25	1.05	1.64	0.91	23.5
SARAH-2.1+ICDR	4,575,907	0.30	1.07	1.64	0.91	23.8
SARAH-2.1	2,642,777	0.37	1.01	1.45	0.93	22.8
SARAH-2	2,484,980	0.44	1.35	1.97	0.87	32.7

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Deutscher Wetterdienst
Wetter und Klima aus einer Hand
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Summary, SARAH-3 Validation

	SIS	SID	DNI	PAR	DAL	SDU	Cal
Monthly	5 W/m²	8 W/m²	17 W/m²	20 umol/m²/s	2.6 kLux	15 h	0.1
Daily	11 W/m²	16 W/m²	31 W/m²	27 umol/m²/s	3.4 kLux	1 h	0.2
30-min	24 W/m²	26 W/m²	50 W/m²	NA	NA	-	
Stability	-0.6 W/m²/dec	based on SIS	based on SIS	based on SIS	based on SIS	based on SIS	based on SIS

EUMETSAT CM SAF CLIMATE MONITORING

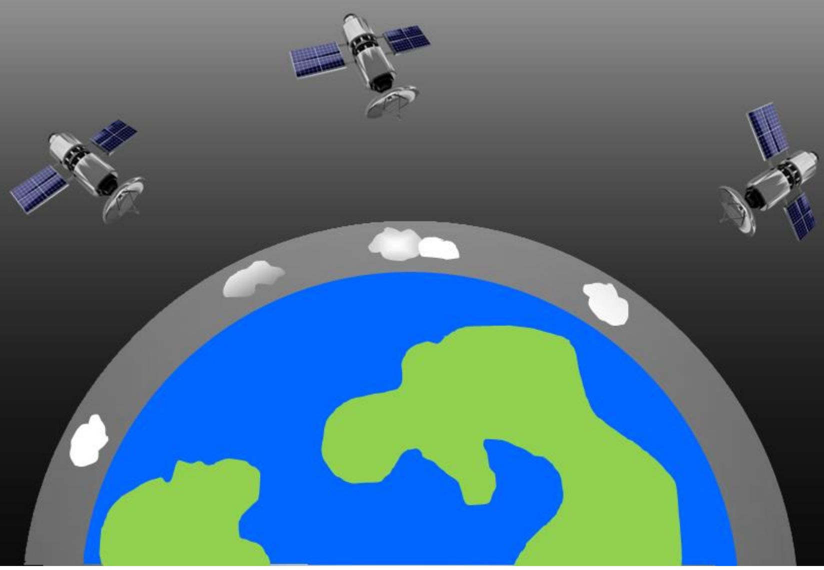
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

General CM SAF

Satellite Application Facility on Climate Monitoring

What we do → Satellite-derived Products of Energy & Water Cycle → Why we do it

What we do
- Develop
- Generate
- Archive
- Distribute



Why we do it
- Monitor
- Understand
- Adapt

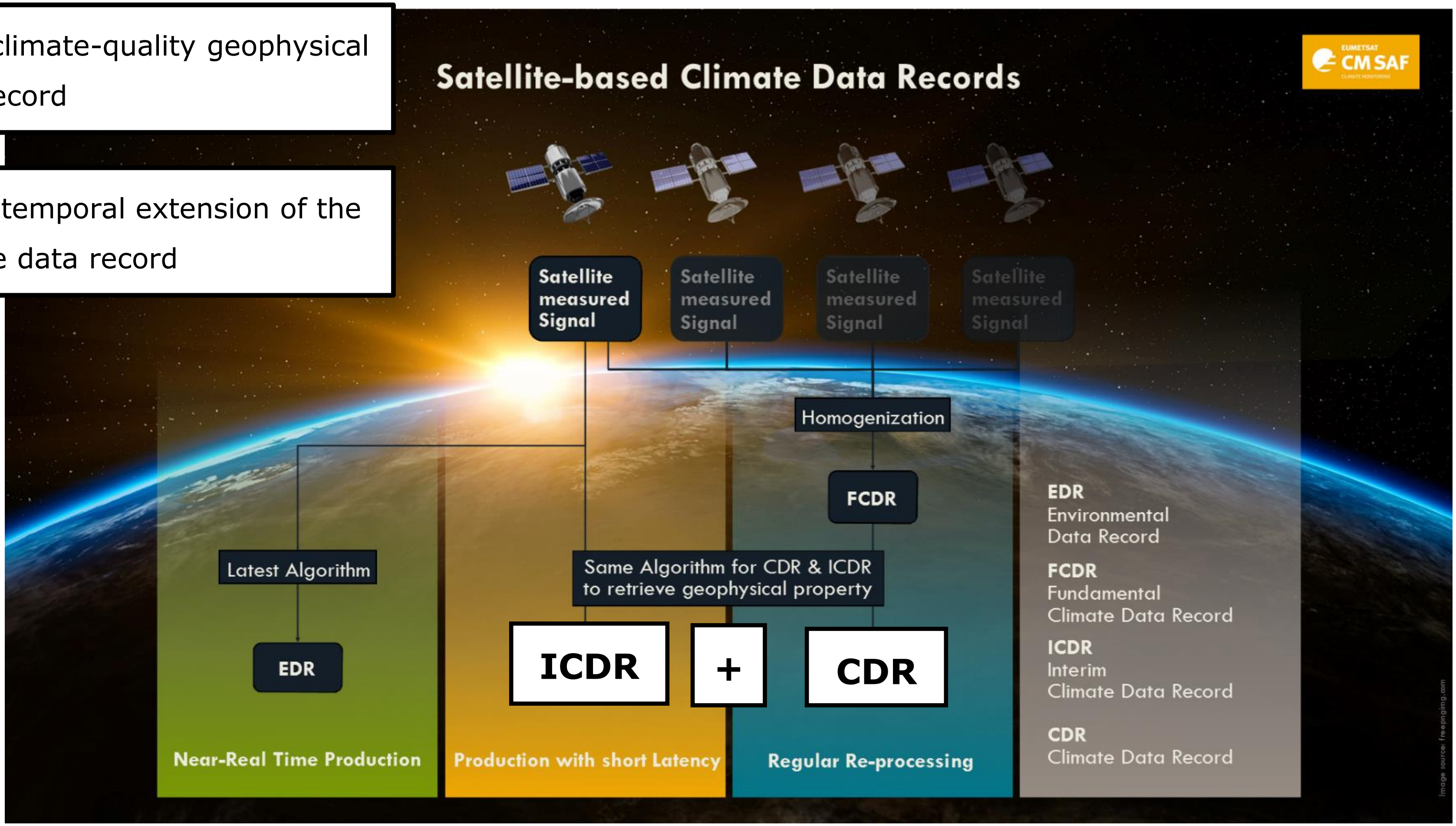
Climate Variability
&
Climate Change

Image source: freepngimg.com

Climate Data Record + Interim Climate Data Record

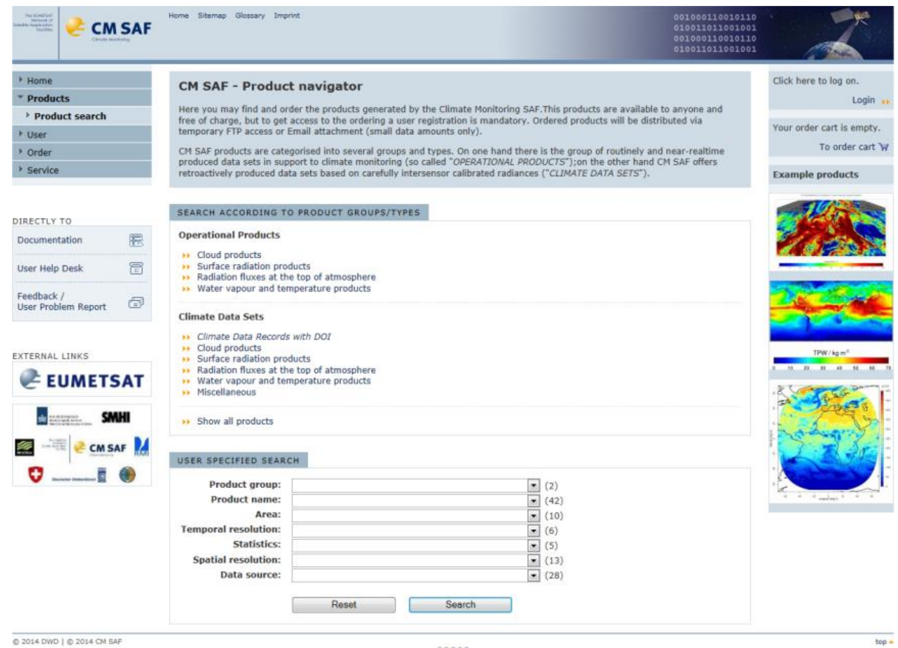
CDR: climate-quality geophysical data record

ICDR: temporal extension of the climate data record



Data Access

- ➔ **Web User Interface**
  - ➔ Easy selection and online ordering
  - ➔ Possibility of regular data delivery
  - ➔ Postprocessing
    - ➔ Spatial, temporal selection
  - ➔ Data format (NetCDF)
  - ➔ Download via https or sftp
  - ➔ All data free of charge
- ➔ **EUMETCast**
- ➔ **User Help Desk**

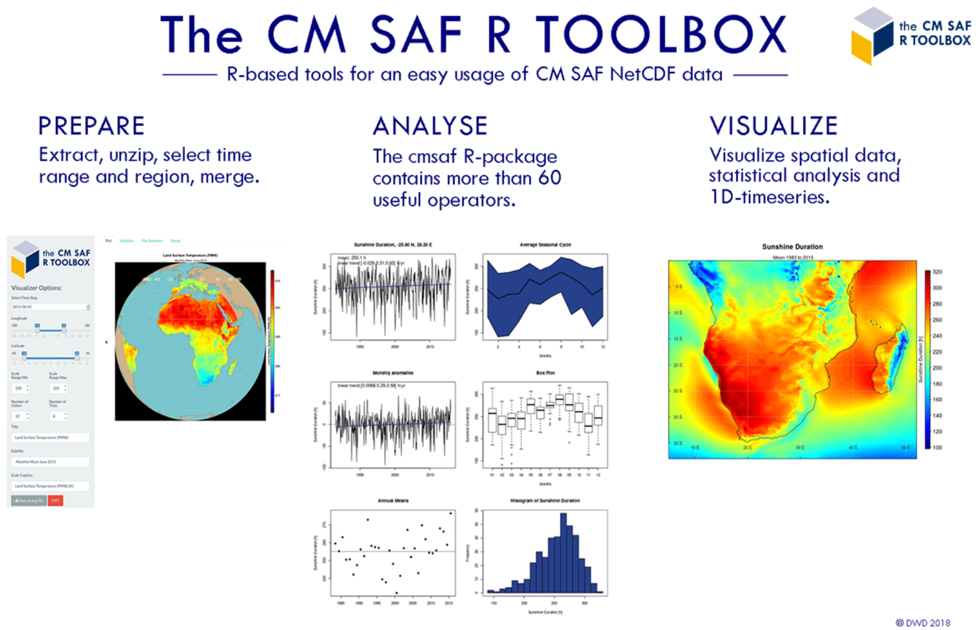


https://wui.cmsaf.eu

CM SAF R Toolbox

www.cmsaf.eu/R_toolbox

- ➔ CM SAF provides the CM SAF R Toolbox (based on the open source software R)
- ➔ Designed to access, analyse, and visualize CM SAF (and other SAF) data
- ➔ No programming skills required
- ➔ Can be used within scripts or as a stand-alone GUI
- ➔ (Video-)Tutorials available

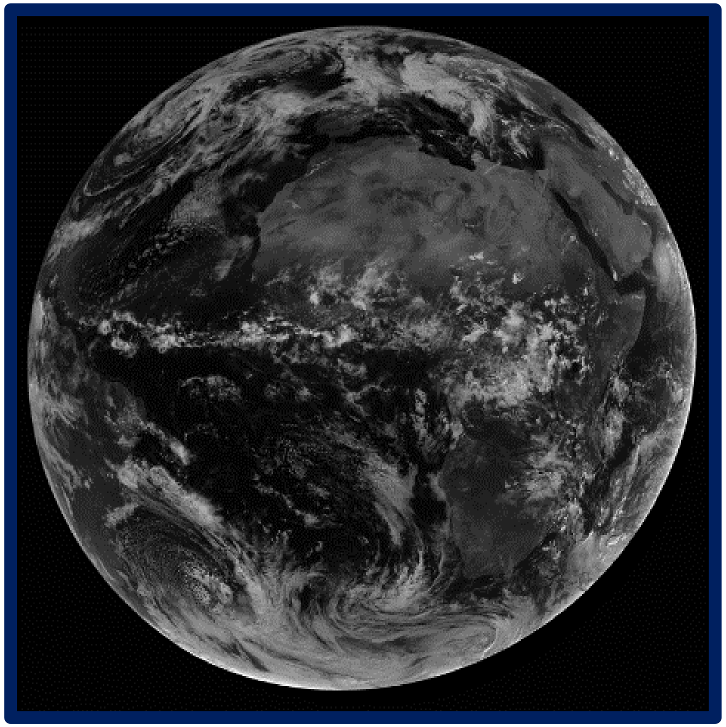


Heliosat + HelSnow method

Surface Irradiance / Sunshine Duration

➢Spatial and temporal information of surface radiation can accurately be derived from satellite observations, because…

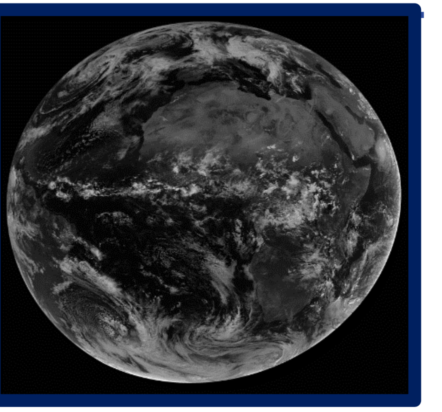
- … satellites can well detect clouds (= bright) during daytime
- … clear-sky solar radiative transfer is well simulated assuming auxiliary data (e.g., water vapor, aerosol) is available



SARAH-3 Algorithm Basics

R the reflection observed by satellite, **strong signal from clouds in the visible.**

R: Meteosat VIS image



Eff. Cloud Albedo

$$\text{CAL} = \frac{R - Rmin}{Rmax - Rmin}$$

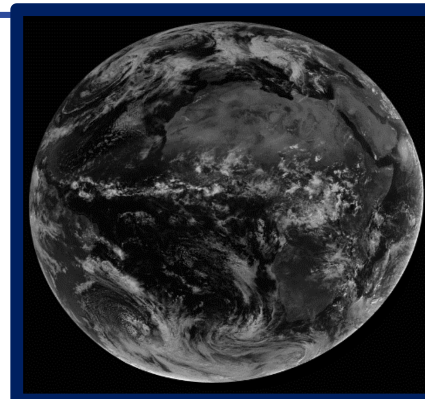
Cano et al. (1986), Beyer et al. (1996), Hammer et al. (2003), Mueller et al. (2011)

SARAH-3 Algorithm Basics

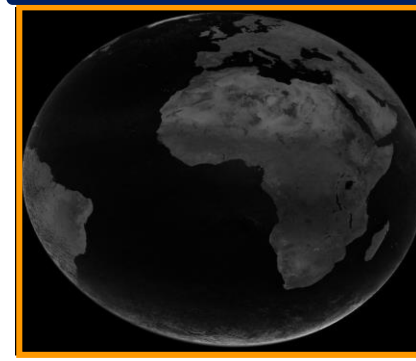
R the reflection observed by satellite, **strong signal from clouds in the visible.**

Rmin, monthly minimum per slot & pixel, corrects (filters) the clear sky reflection

R: Meteosat VIS image



Rmin:
„clear sky reflection“



Eff. Cloud Albedo

$$\text{CAL} = \frac{R - Rmin}{Rmax - Rmin}$$

Cano et al. (1986), Beyer et al. (1996), Hammer et al. (2003), Mueller et al. (2011)

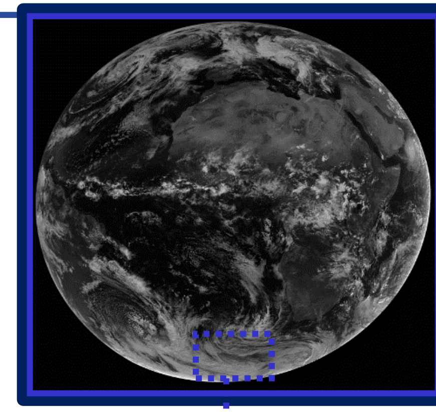
SARAH-3 Algorithm Basics

R the reflection observed by satellite, **strong signal from clouds in the visible.**

Rmin, monthly minimum per slot & pixel, corrects (filters) the clear sky reflection

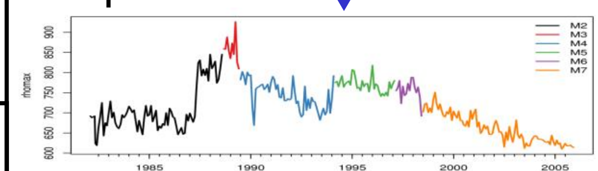
Rmax corrects changes in sensitivity and aging of optical instruments.

R: Meteosat VIS image



Rmin: „clear sky reflection“

Rmax: „monthly maximum reflection“



Eff. Cloud Albedo

$$\text{CAL} = \frac{R - Rmin}{Rmax - Rmin}$$

Cano et al. (1986), Beyer et al. (1996), Hammer et al. (2003), Mueller et al. (2011)

SARAH-3 Algorithm Basics

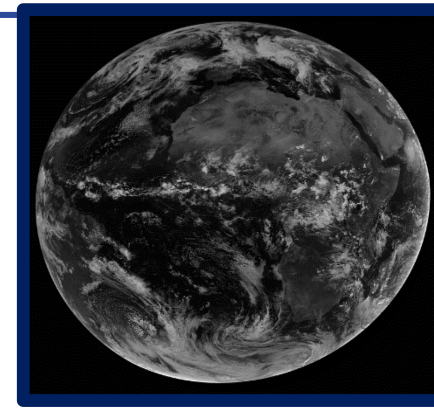
R the reflection observed by satellite, **strong signal from clouds in the visible.**

Rmin, monthly minimum per slot & pixel, corrects (filters) the clear sky reflection; Rmin_snow

Rmax corrects changes in sensitivity and aging of optical instruments.

Effective Cloud Albedo (CAL) provides the amount of reflected solar radiation relative to clear sky

R: Meteosat VIS image



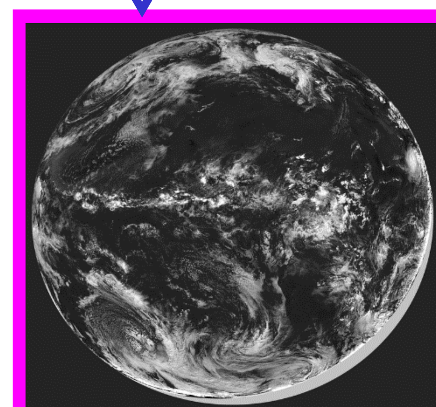
Rmin:

Observable

Rmax“

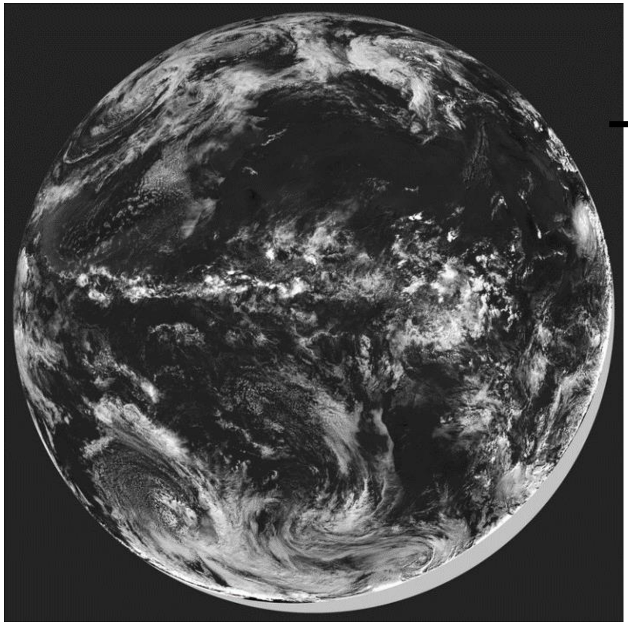
Eff. Cloud Albedo

$$\text{CAL} = \frac{R - Rmin}{Rmax - Rmin}$$



Cano et al. (1986), Beyer et al. (1996), Hammer et al. (2003), Mueller et al. (2011)

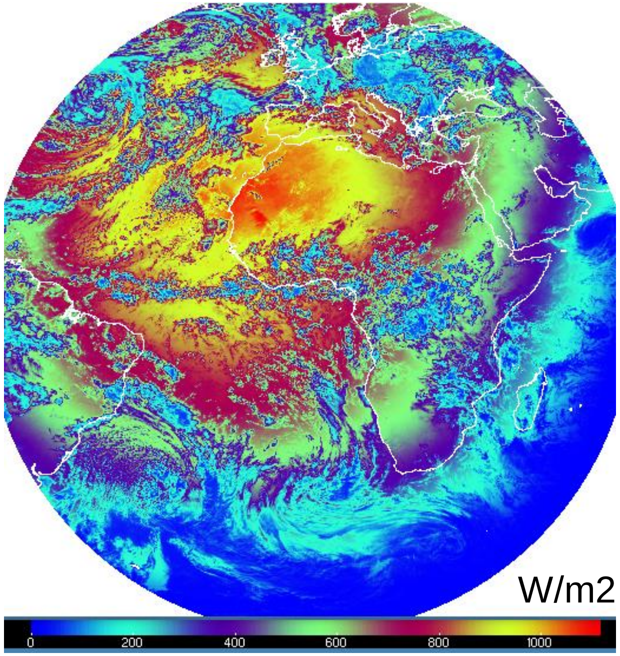
SARAH-3 Algorithm Basics



CAL

$$\text{CAL}-1 \sim \frac{\text{SIS}}{\text{SIS}clear}$$

Clear-sky model
SPECMAGIC



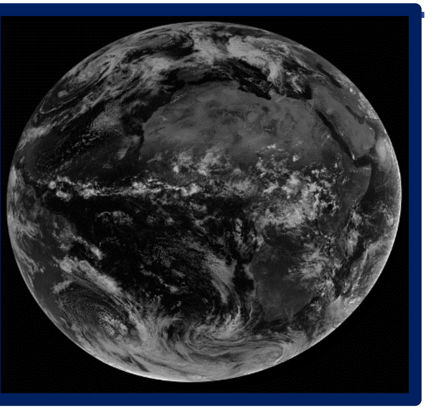
SIS (global irradiance)

http://sourceforge.net/projects/gnu-magic/

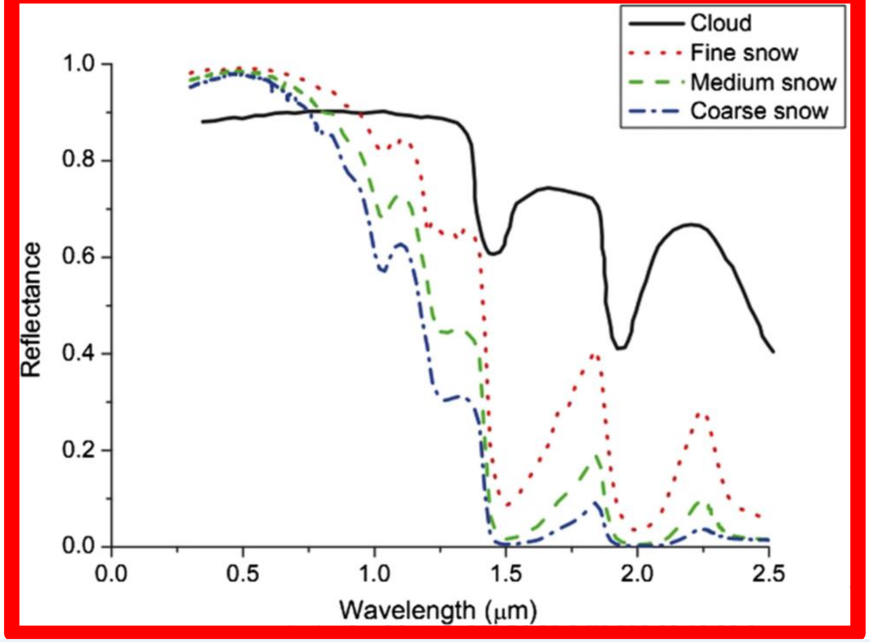
SARAH-3 Algorithm Basics

R the reflection observed by satellite, **strong signal from clouds in the visible.**

R: Meteosat VIS image



Issue: Snow vs. Clouds



Source: Application of moderate resolution imaging spectroradiometer snow cover maps in modeling snowmelt runoff process in the central Zab basin, Iran

J. Appl. Remote Sens. 2014;8(1):084699. doi:10.1117/1.JRS.8.084699

Cano et al. (1986), Beyer et al. (1996), Hammer et al. (2003), Mueller et al. (2011)

Issue: Snow vs. Clouds

→ *Status quo:*

Separation between cloud and snow problematic (only 3 spectral channels available from historic satellites)

Solution: HELSNOW

→ *Approach:*

Separation between Cloud and Snow based on ‚motion'

→ Efficient programming (OpenCV: ‚optical flow') allows the processing of long time series

Raw Observation → Optical Flow (analyze motion) → Detecting potential Snow → Generate Daily snow mask / snow reflectivity (Rmin_snow)