Remote Sensing and Climate Diagnostics

summer semester 2026
Goethe University Frankfurt

Day 1 (R. Hollmann)

- Content and structure of lecture
- Motivation and background
- The physics of remote sensing
- Radiative transfer und retrieval basics
- Satellite orbits and instruments
- Satellite-based climatologies and its application

Day 2 (U. Pfeifroth, M. Stengel, A. Niedorf)

- Radiation in the solar und thermal range
- Clouds
- Water vapor and Precipitation
- Coursework

Bemerkung zur PDF-Version

Dieses PDF ist ein PDF des Vorlesungsvortrages aus der Vorlesung „Fernerkundung und Klimadiagnostik“ gehalten im Sommersemester 2026 an der Universität Frankfurt.

Teile in diesem Dokument sind anderen Vorlesungen, Büchern, Zeitschriften, Internet- oder anderen Quellen entnommen worden, ohne dass diese in jedem Fall durch entsprechende Zitate kenntlich gemacht wurden.

Aus diesem Grund sollte aus diesem PDF nicht ohne weitere Rückfrage/Recherche zitiert werden.

Radiation in the solar und thermal range

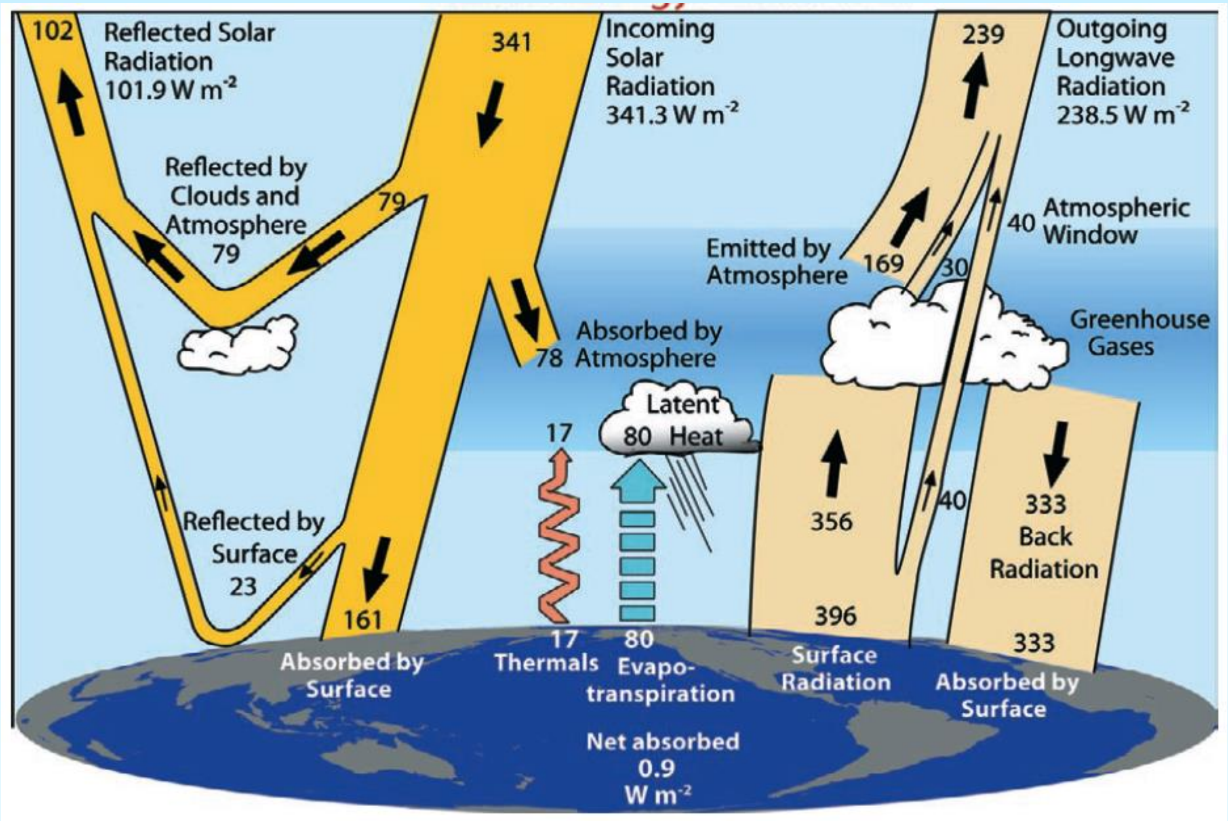
Outline

- **Motivation: satellite data as valuable data source**
- Surface Solar Radiation (SSR)
  - Methods to derive SSR
  - Validation and comparisons
  - Applications
  - Climate analysis
- Surface albedo
- Longwave downward radiation at the surface
- Radiation budget at the top of atmosphere

Motivation

Our climate is controlled by radiative fluxes !

It is important to monitor the **Earth radiation budget** and its single **components** to better understand the climate system and potental changes !

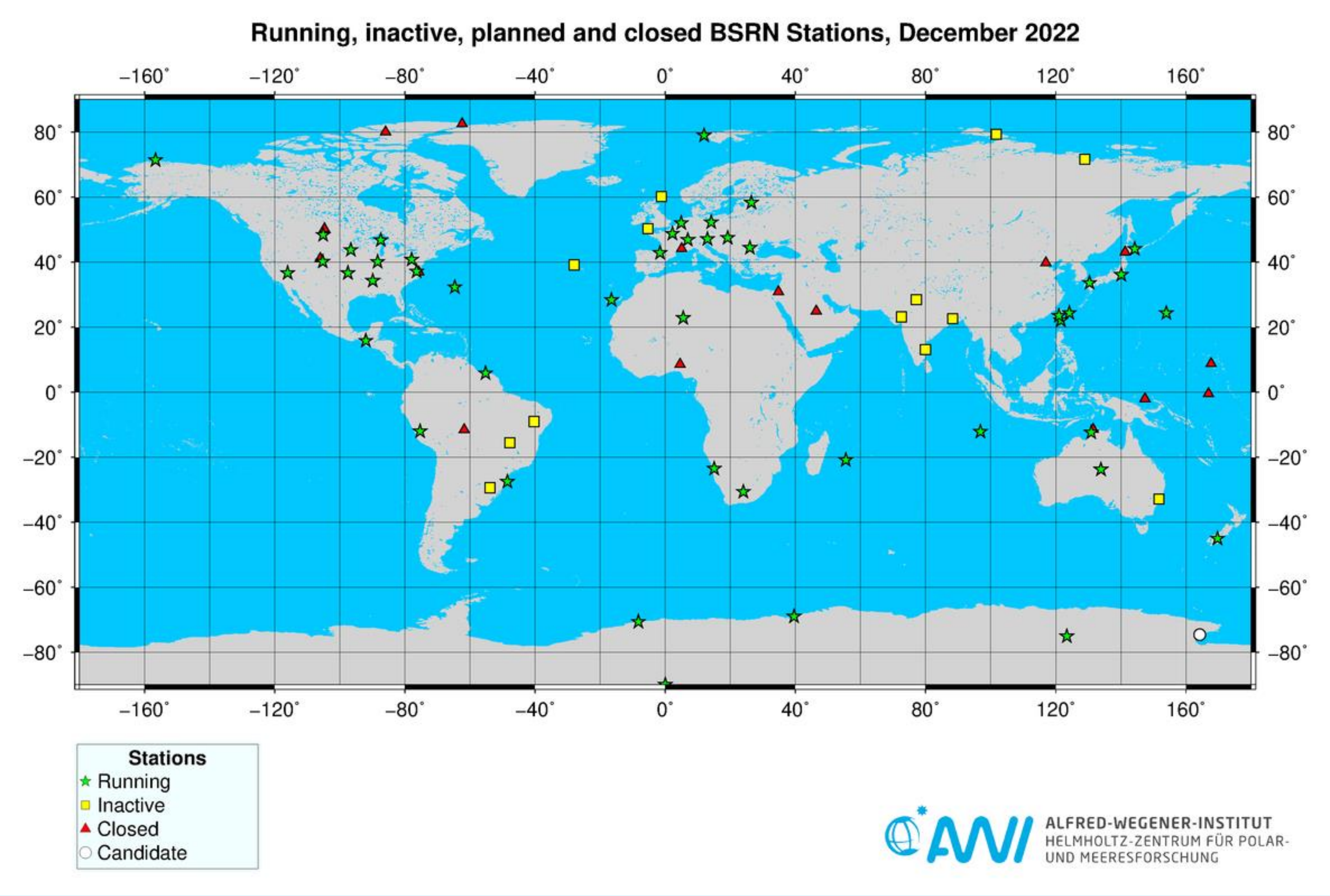


Source: Trenberth et al. (2009)

Motivation

BSRN (Baseline Surface Radiation Network)

High quality, but few stations and relatively short time series (since 1994)



GEBA/WRDC:

More stations, some long records (since 1950s);
Medium quality, monthly means only

604 M. Wild et al.: The Global Energy Balance Archive (GEBA)

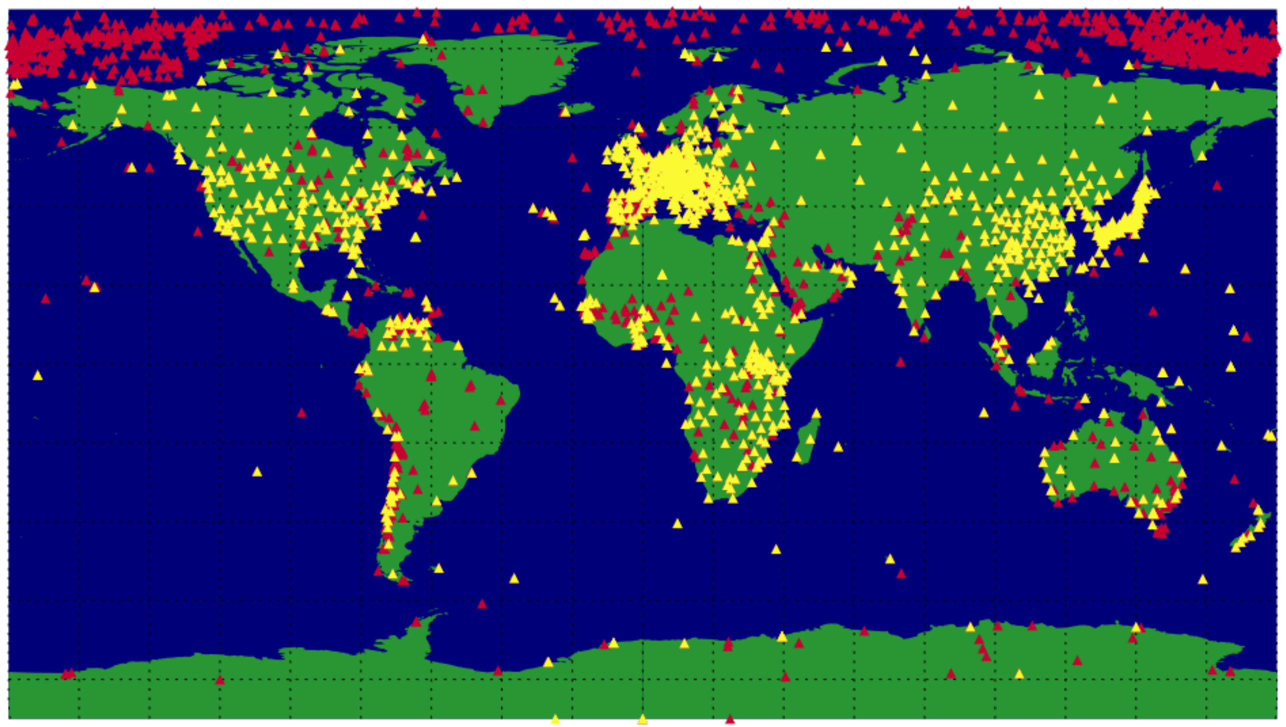


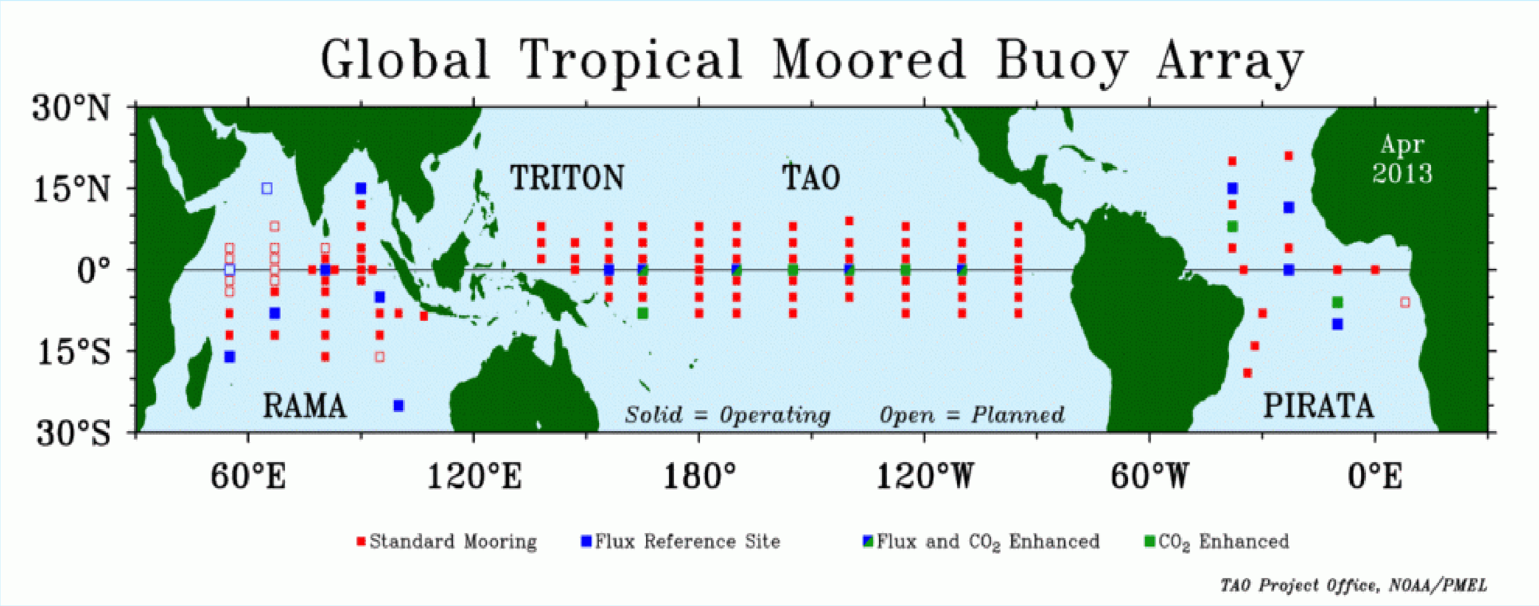
Figure 1. Distribution of the 2500 locations with observational data contained in GEBA. Red symbols indicate locations with at least one monthly entry in GEBA; yellow symbols signify locations with multiyear records (at least 3 years of data).

Motivation

Buoy measurements:

Global Tropical Moored Buoy System *(TAO, TRITON, PIRATA, RAMA (TOGA))*

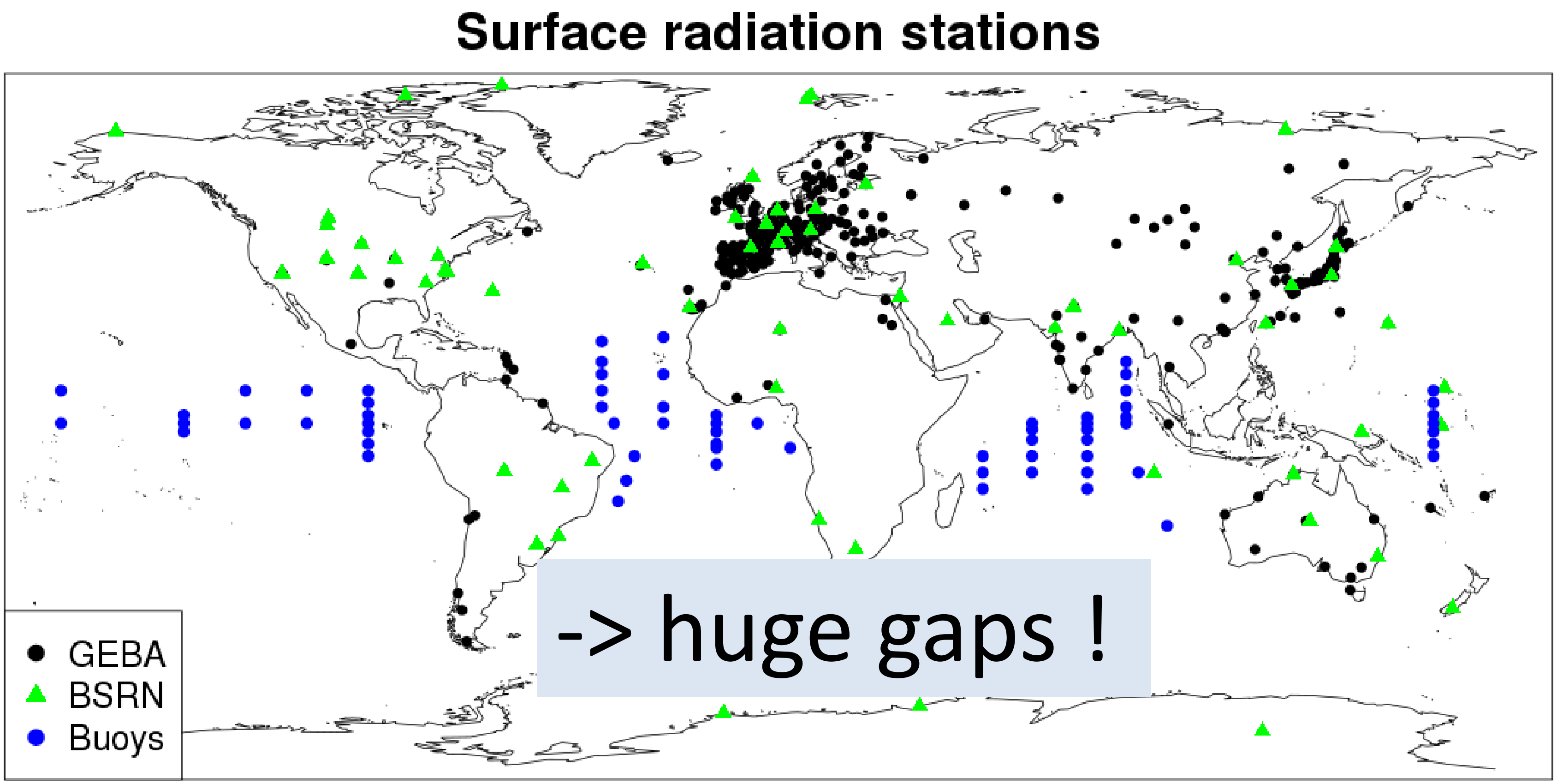
Daily and monthly data



Source: https://globalocean.noaa.gov/Research/Global-Tropical-Moored-Buoy-Array

Combination of BSRN + GEBA + Buoys

(filtered for „long“, up-to-date surface solar radiation records)



Motivation

-> reflection and emission by clouds are variable

-> clouds have a cooling effect (of ~ 20 to 30 W/m²)*

-> Satellite data is an important observational data source !

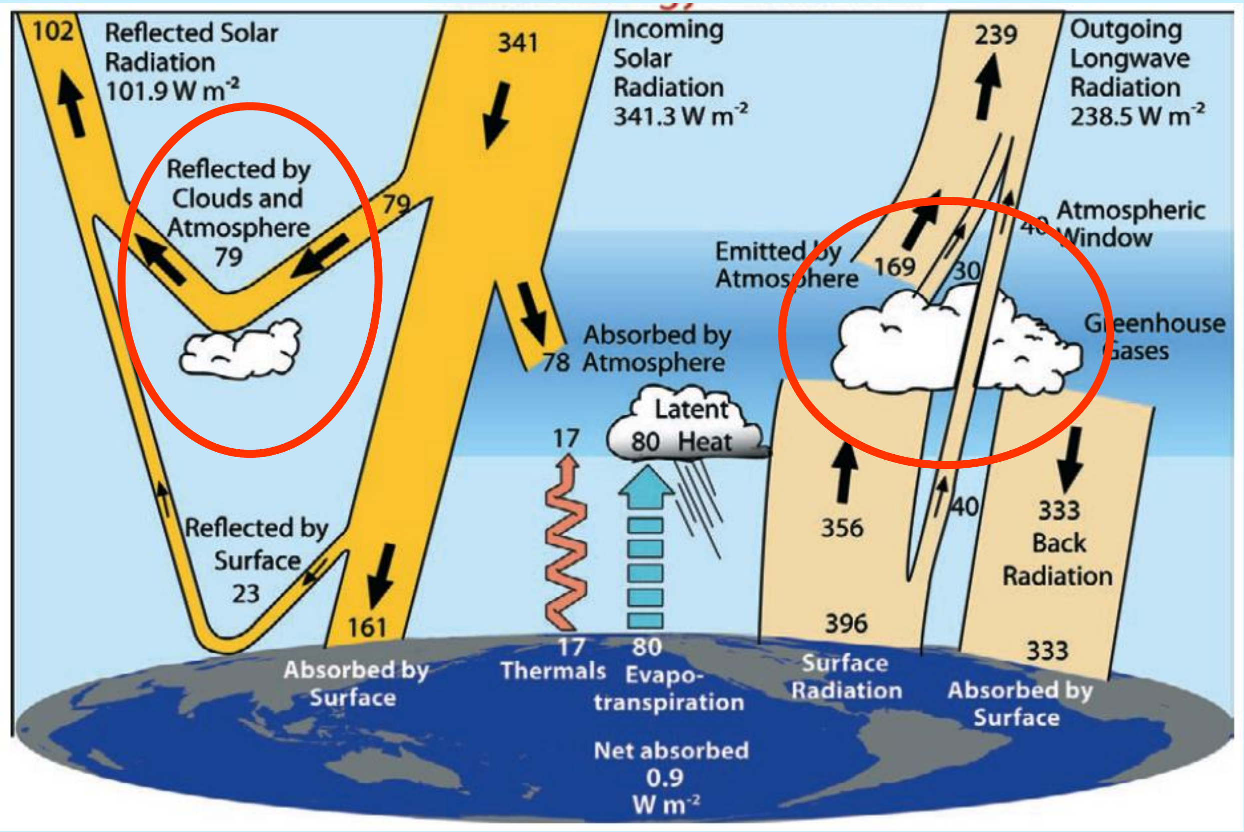


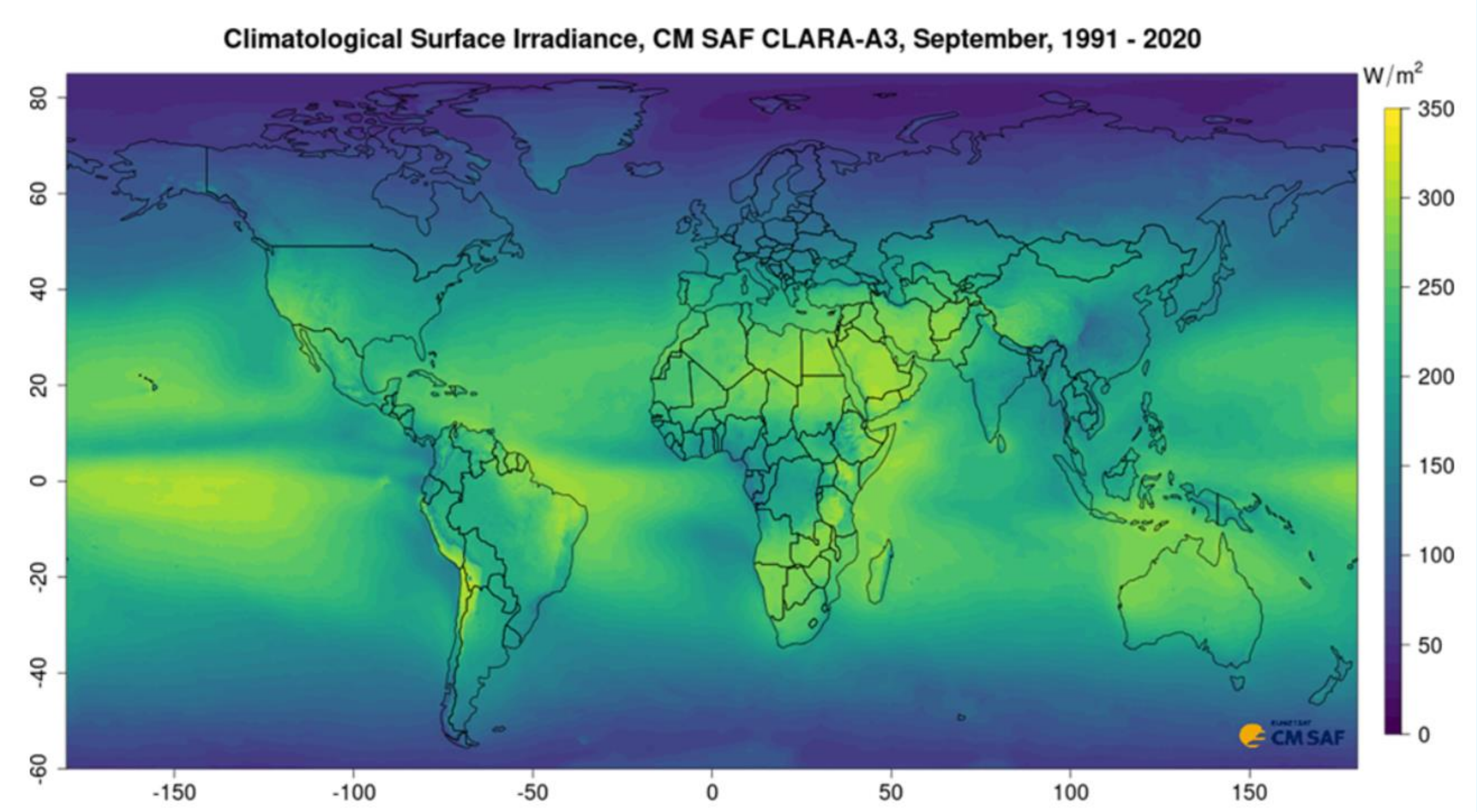
Figure from Trenberth et al. (2009)

*See e.g. Stuhlmann et al. 1995, Raschke et al. 2005, Loeb et al. 2009

Radiation in the solar und thermal range

Outline

- → Motivation: satellite data as valuable data source
- → **Surface Solar Radiation (SSR)**
    - → **Methods to derive SSR**
    - → Validation and comparisons
    - → Applications
    - → Climate analysis
- → Surface albedo
- → Longwave downward radiation at the surface
- → Radiation budget at the top of atmosphere



Source: Karlsson et al., 2023, ESSD.

global energy fluxes

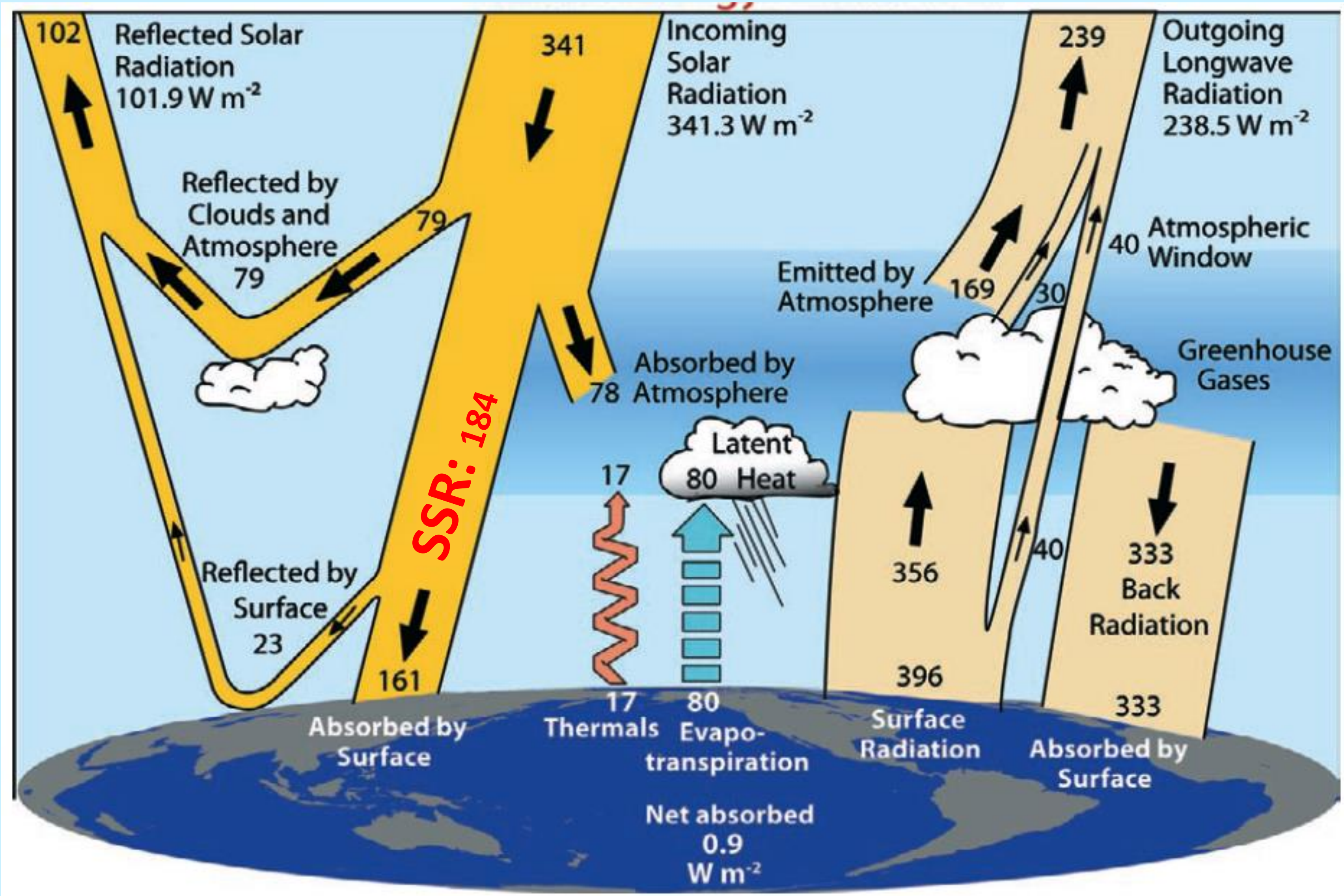
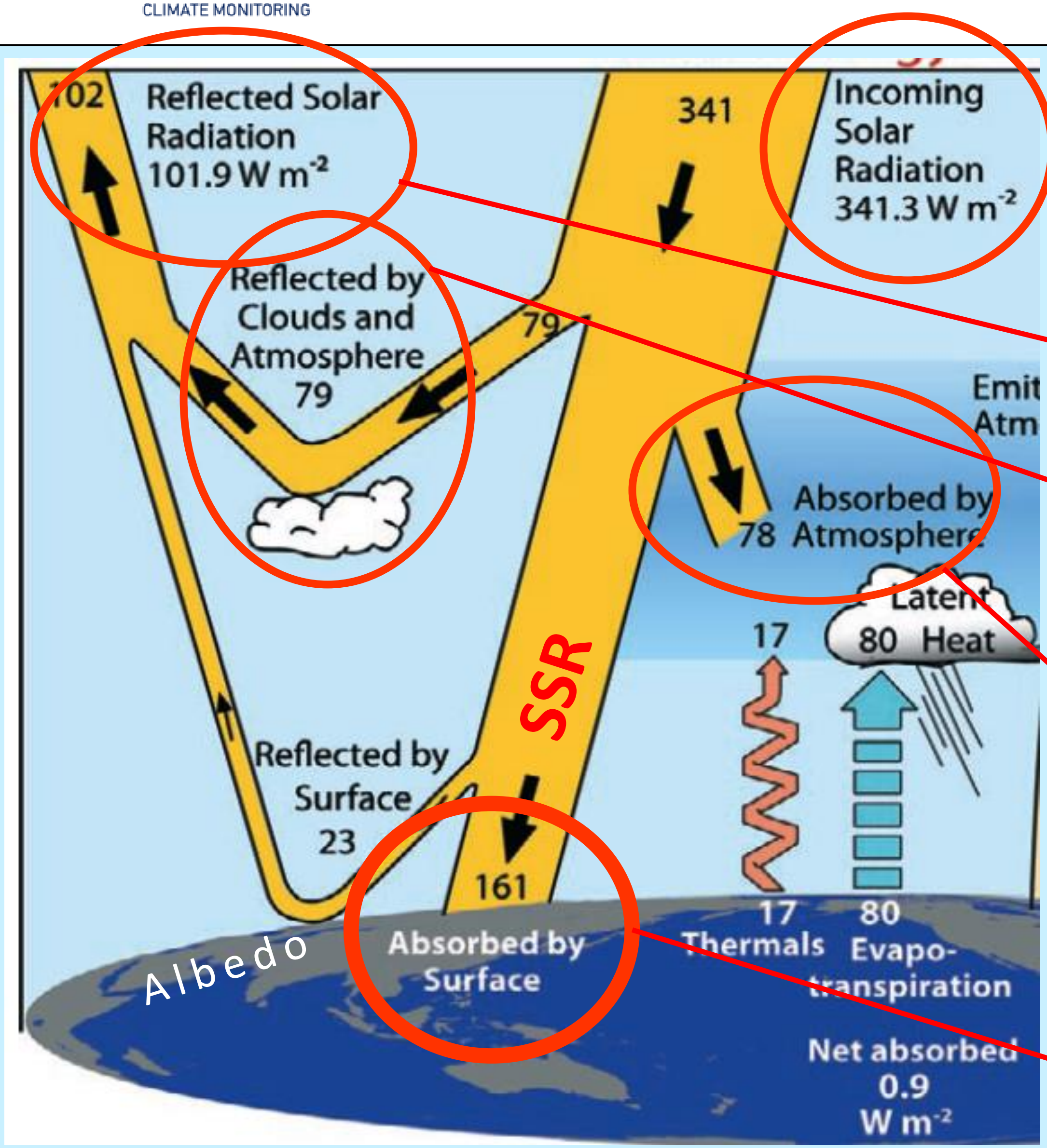


Figure from Trenberth et al. (2009)

global energy fluxes - shortwave



well observable („**Solar constant**“) G_{ext}

Measured by satellite (VIS channels) G_r

Clouds well visible from satellite images (VIS + IR channels)

Absorption in the atmosphere not observable in the VIS spectral range, yet important G_a

Net **Surface solar radiation** G_n

Figure from Trenberth et al. (2009)

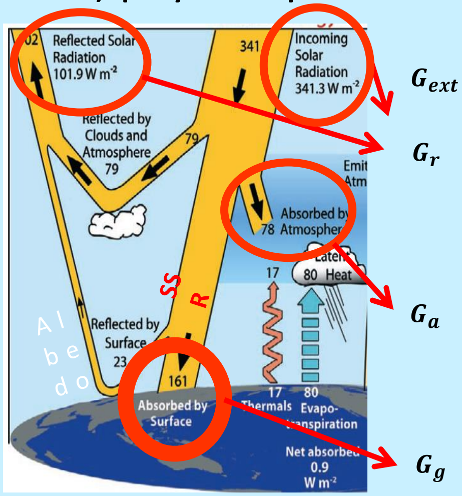
Methods to derive surface solar radiation

Statistical algorithm

based on statistical (and physical) relations

Physical algorithm

based on physical relations and observations by considering (any/most) physical processes



Basis of all methods: Treating interactions of **extraterrestrial radiation** and **the Earth-Atmosphere system**

Principle: Energy conservation

$$G_{ext} = G_r + G_a + G_n$$

G_{ext} Extraterrestrial radiation

G_r Reflected radiation at Top-of-Atm

G_a Atmosphere-absorbed radiation

G_n Surface-absorbed radiation (net surface)

$$G_n = (1 - \beta) * SSR$$

β Surface albedo

SSR Surface Solar Radiation (Global radiation)

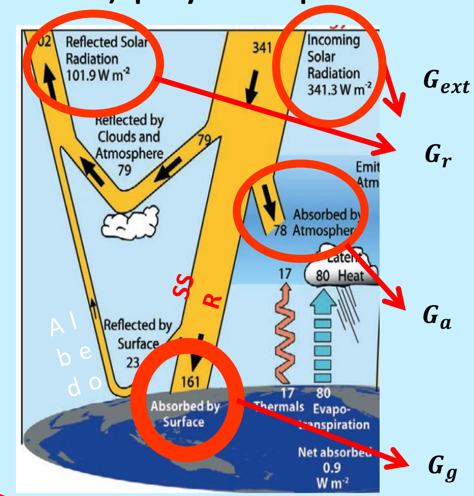
Methods to derive surface solar radiation

Statistical algorithm

based on statistical (and physical) relations

Physical algorithm

based on physical relations and observations by considering (any/most) physical processes



Basis of all methods: Treating interactions of **extraterrestrial radiation** and **the Earth-Atmosphere system**

Principle: Energy conservation

$$G_{ext} = G_r + G_a + G_n$$

Retrieval

G_{ext} Extraterrestrial radiation

G_r Reflected radiation at Top-of-Atm

G_a Atmosphere-absorbed radiation

G_n Surface-absorbed radiation (net surface)

$$G_n = (1 - \beta) * SSR$$

β Surface albedo

SSR Surface Solar Radiation (Global radiation)

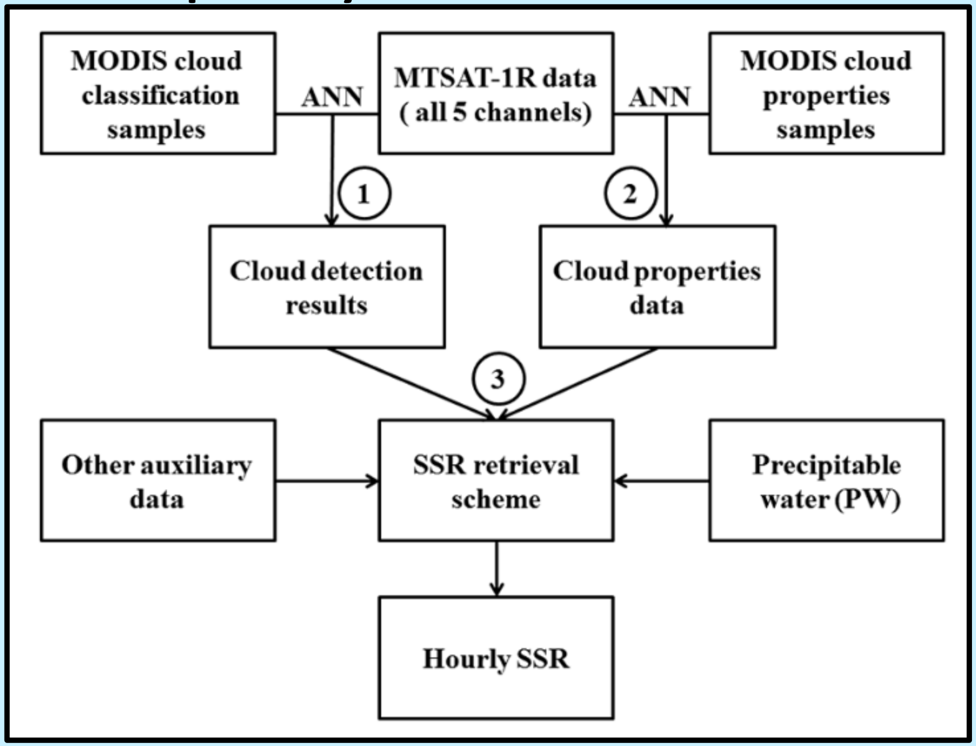
Methods to derive surface solar radiation

Basis of all methods: Treating interactions of **extraterrestrial radiation** and **the Earth-Atmosphere system**

$$G_{ext} = G_r + G_a + G_n$$

Principle: Energy conservation

Example: Physical Retrieval



Approach: Each relevant process is explicitly considered !

-> numerous **relevant properties** of the atmosphere need to be considered

-> Relatively complex and costly, many parameters necessary

Source: Tang et. al, 2015

Methods to derive surface solar radiation

	Input Variable	Source for ISCCP-FD
1	solar constant	1367 W/m^2 (with daily variation)
2	cosine solar zenith angle	3-hour mean derived from 1987 Astronomical Almanac for years 1950–2050
3	atmospheric gases (excluding ozone)	vertical profile and latitudinal gradients from climatology with 1850–2050 temporal variations
4	ozone	TOMS (Version 7) with TOVS fill
5	atmospheric aerosols	GISS climatological vertical profiles of 18 species in global 5° × 4° map, monthly means for 1950–2000 for stratosphere and troposphere
6	Atmospheric temperature profile	TOVS filled with SAGE climatology for pressures <15 mbar
7	surface air temperature	logarithmic extrapolation from temperature profile with diurnal adjustment
8	atmospheric humidity profile	TOVS filled with Oort/SAGE climatology for pressures <310 mbar; low/middle tropospheric profile adjustment
9	general cloud properties	15-type clouds from ISCCP-D1 filled from ISCCP-D2
10	cloud vertical structure (CVS)	cloud type dependent based on zonal, monthly statistical CVS model
11	cloud top temperature/pressure	ISCCP-D1 cloud top temperature filled from ISCCP-D2, linearly interpolated cloud top pressure
12	cloud layer thickness/base	20-year RAOBS climatology as function of month, latitude and cloud top pressure for land and ocean
13	cloud optical depth	ISCCP-D1 filled from ISCCP-D2
14	cloud phase	ice or liquid based on ISCCP-D1
15	cloud particle size	seasonal climatology by *Han et al.* [1994, 1999]
16	cloud particle shape	spherical liquid and nonspherical ice
17	surface albedo: VIS (0.2–0.7 μm)	land, from ISCCP-D1 with aerosol adjustment; ocean, from new GISS GCM
18	surface albedo: NIR (0.7–5.0 μm)	land, from input VIS multiplied by 5-band NIR-to-VIS ratio based on ERBE regression;
19	surface skin temperature	adjustment for cloud effects
20	surface emissivity	nonunit from GISS GCM with slight adjustment
21	land vegetation, snow, sea ice	eight vegetation types and land ice from *Matthews* [1984], snow from NOAA, sea ice from NSIDC [see *Zhang et al.*, 1995]

...raterrestrial radiation and **the Earth-**

$$G_a + G_n$$

Approach: Each relevant process is explicitly considered !

-> numerous **relevant properties** of the atmosphere need to be considered

-> Relatively complex and costly, many parameters necessary

-> Enables the retrieval of multiple (all) radiative flux components

Methods to derive surface solar radiation
Heliosat/Specmagic appraoch

Basis of all methods: Treating interactions of **extraterrestrial radiation** and **the Earth-Atmosphere system**

$$G_{ext} = G_r + G_a + G_n$$

$$G_n = (1 - \beta) * SSR$$

Principle: Energy conservation

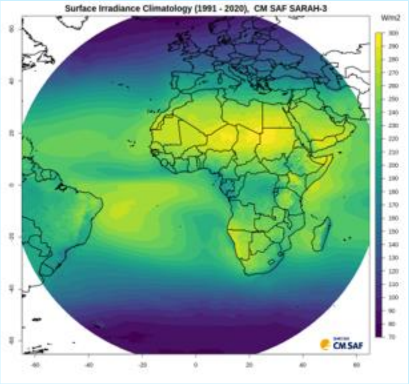
Example: „HELIOSAT/Specmagic“ used by CM SAF for generation SARAH data records

Calculation of the „**Effective Cloud Albedo (CAL)**“ (*HELIOSAT-Method*)

Clear-sky radiative transfer model caculations (*based on „libRadTran“*)

~(1-CAL)*“surface clear-sky radiation“

SSR

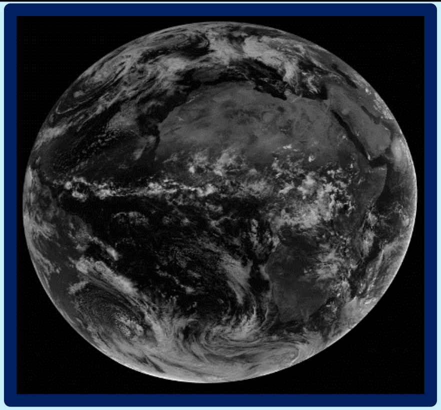


G = Global Radiation = Surface Solar Radiation = SSR

Methods to derive surface solar radiation
Heliosat/Specmagic appraoch

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

R: Meteosat VIS image



Eff. Cloud Albedo

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

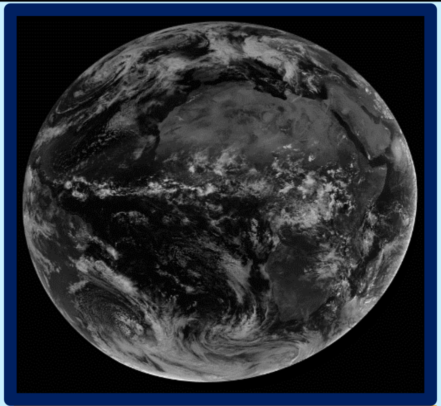
Cano et al. (1986), Beyer et al. (1996), Hammer et al. (2003), Mueller et al. (2011)

Methods to derive surface solar radiation
Heliosat/Specmagic appraoch

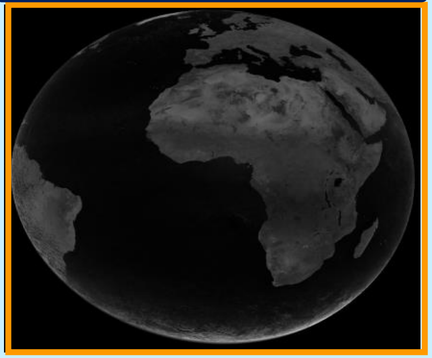
R = reflection observed by satellite; **strong signal from clouds in the visible.**

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

R: Meteosat VIS image



Rmin: „clear sky reflection“



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Methods to derive surface solar radiation *Heliosat/Specmagic* appraoch

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Rmax corrects changes in sensitivity and aging of optical instruments.

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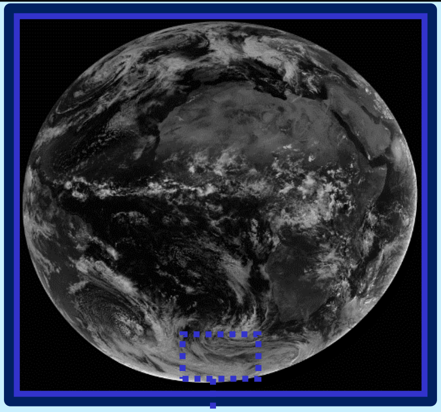
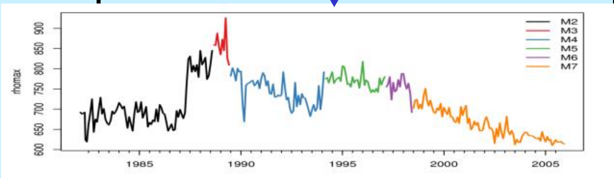


Rmin: „clear sky reflection“

Rmax: „monthly maximum reflection“



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Methods to derive surface solar radiation *Heliosat/Specmagic* appraoch

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DWD

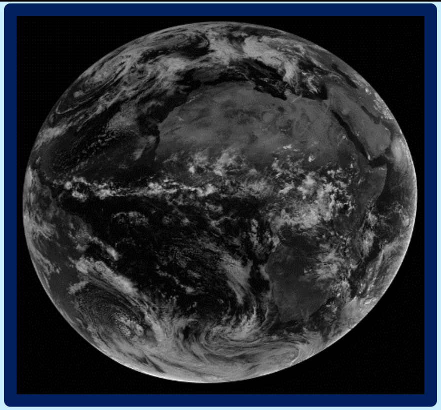
R = reflection observed by satellite; **strong signal from clouds in the visible.**

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

Rmax corrects changes in sensitivity and aging of optical instruments.

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

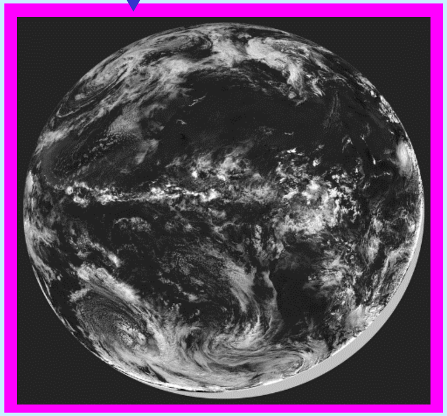
R: Meteosat VIS image



Rmin

Rmax

Observable



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)

Heliosat generates CAL

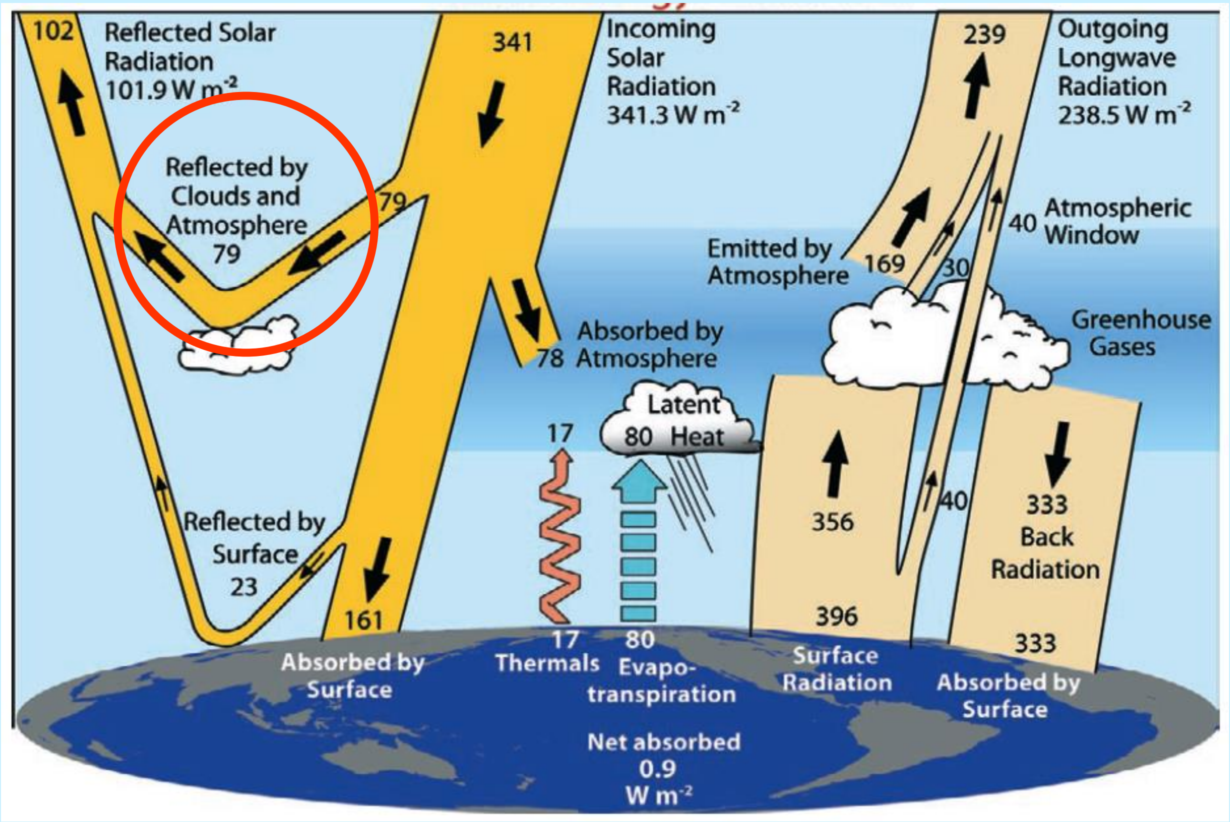
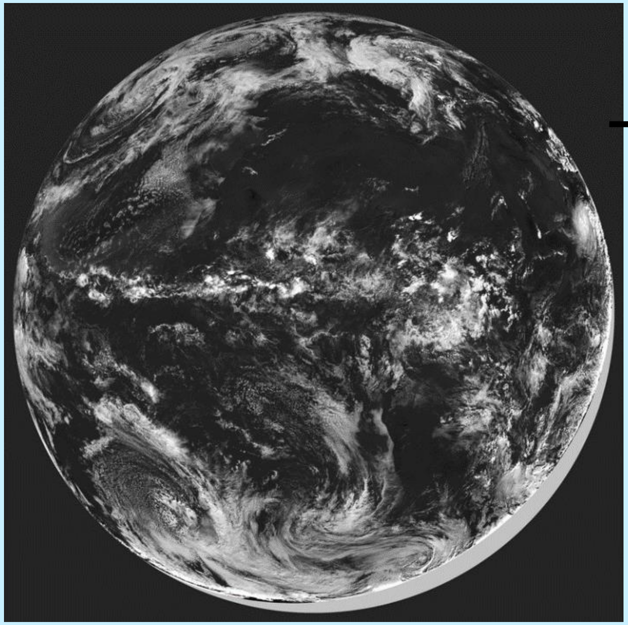


Figure from Trenberth et al. (2009)

How to retrieve SSR from CAL ?

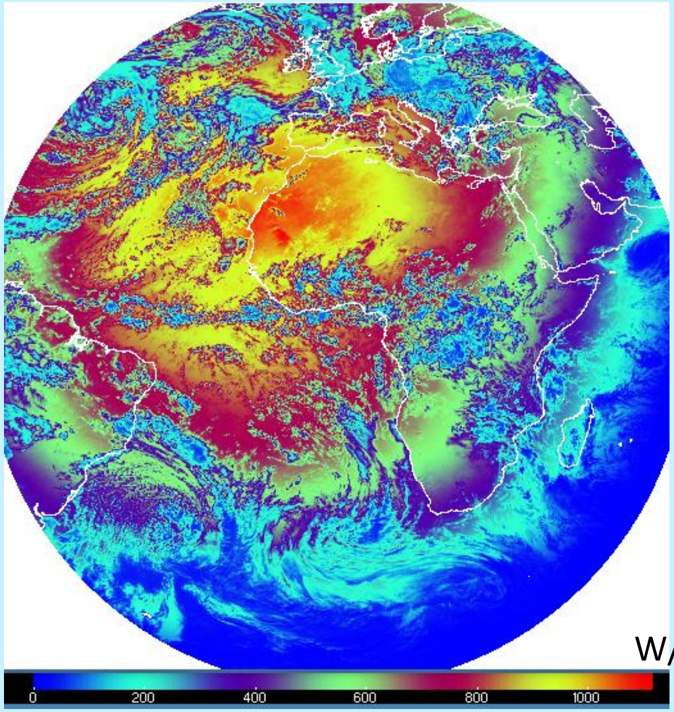
from CAL to SSR



CAL

$$CAL - 1 \sim \frac{SSR}{SSR_{clear}}$$

Radiative transfer model

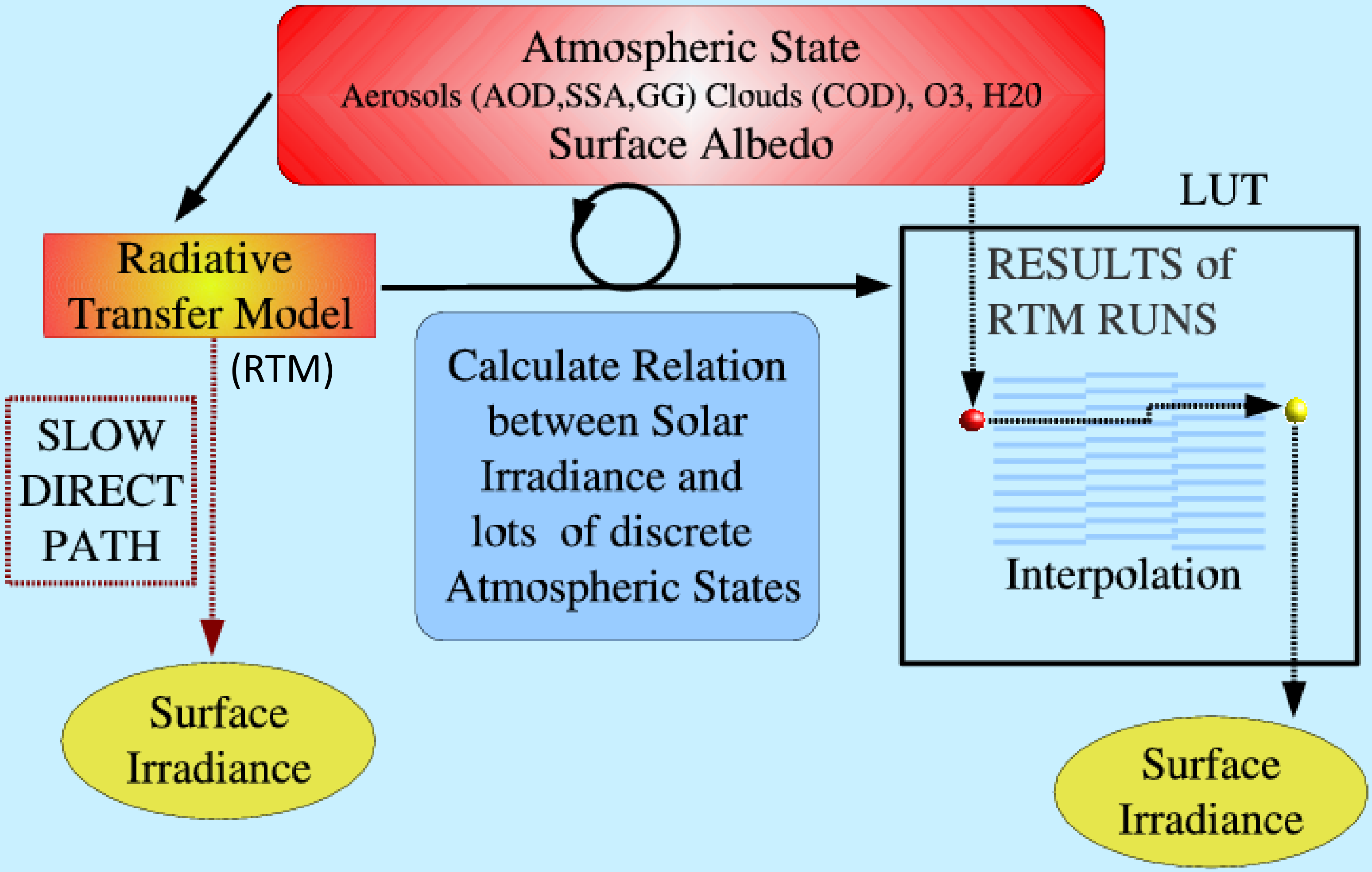


SSR(global radiation)

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

Clear-sky model – LUT approach

SSRclear is calculated with help of a **L**ook-**U**p-**T**able approach



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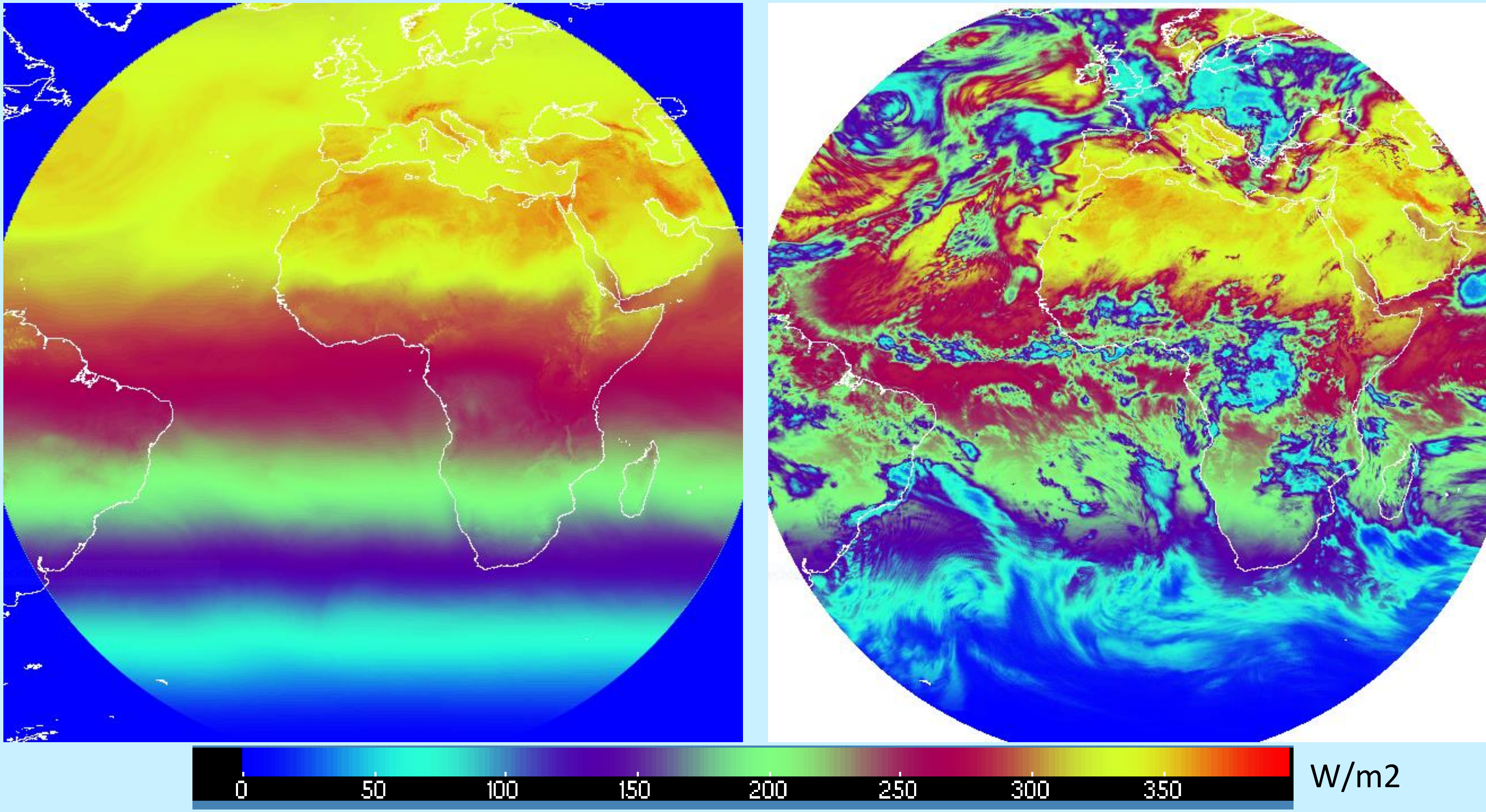
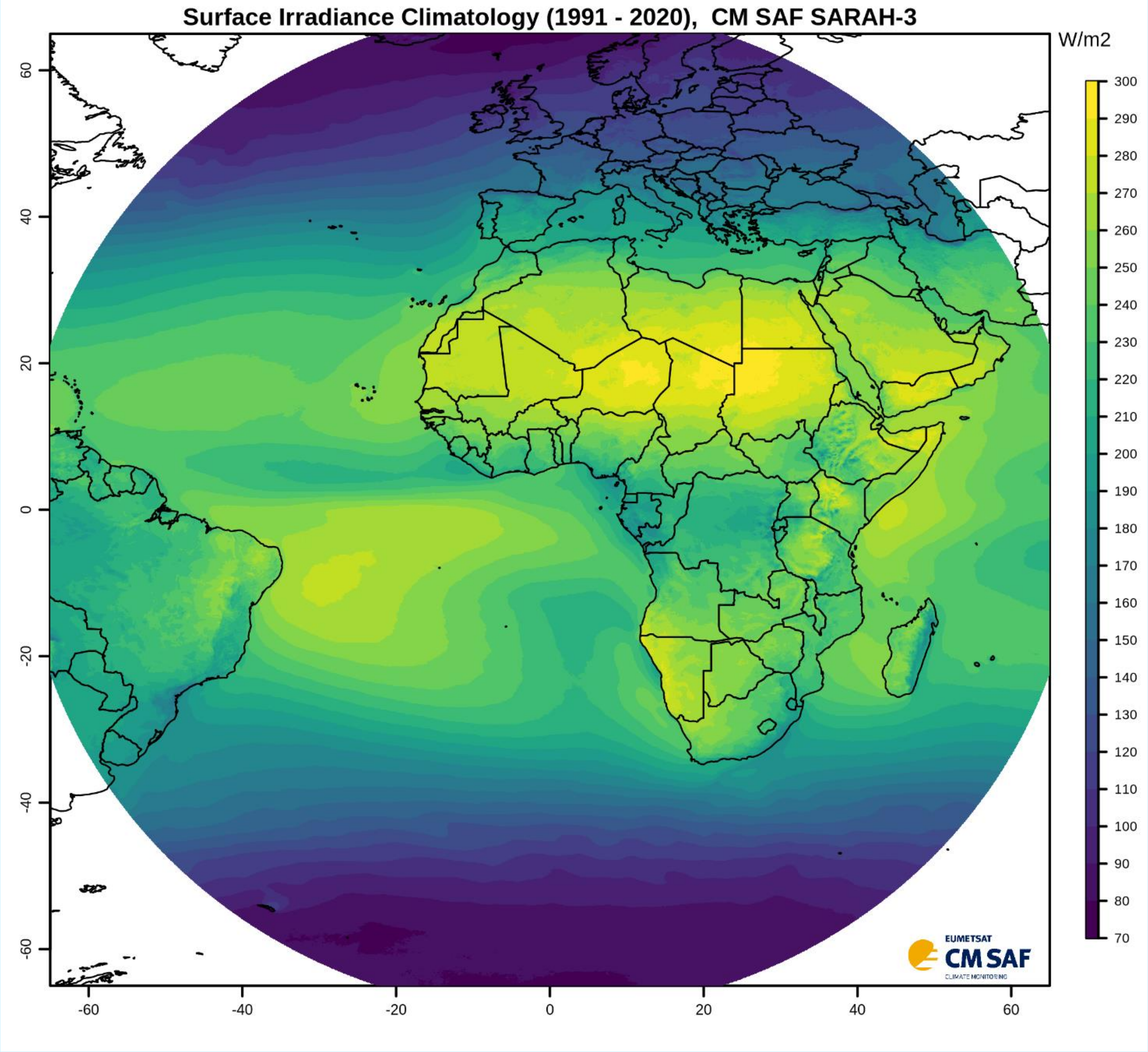
Clear-sky -> All-sky

→ Strong cloud radiative effect in the solar spectral range



Climatology of SSR

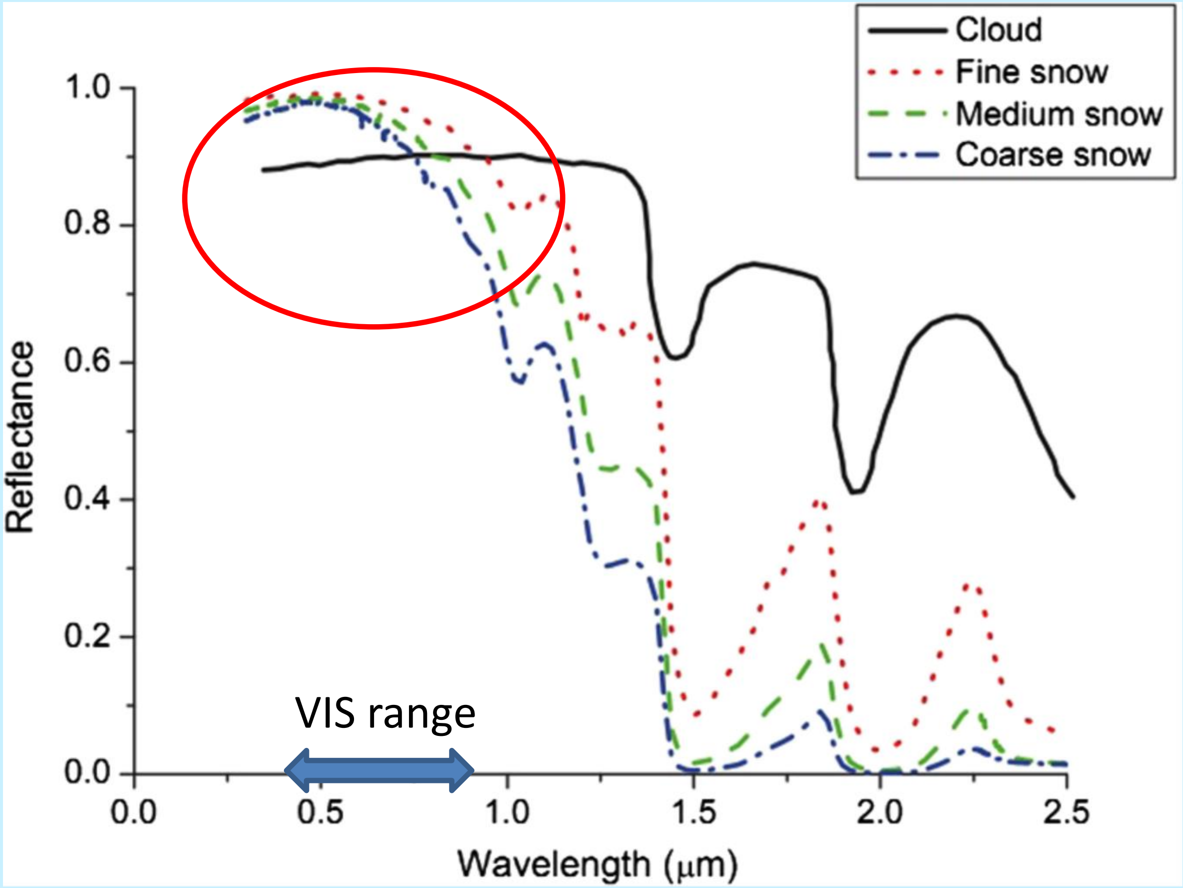


Difficulties / Challenges

- Clouds and snow can be missclassified
- Reduced quality at large sunzenith- und satellite viewing-angles
- Uncertanties in input data mitigate into retrieval schemes (e.g. aerosols) and final products
- Limited spatio-temporal resolutions

Difficulties / Challenges

- Clouds over bright surfaces (e.g. snow) may cause false cloud detection because of similar reflectances

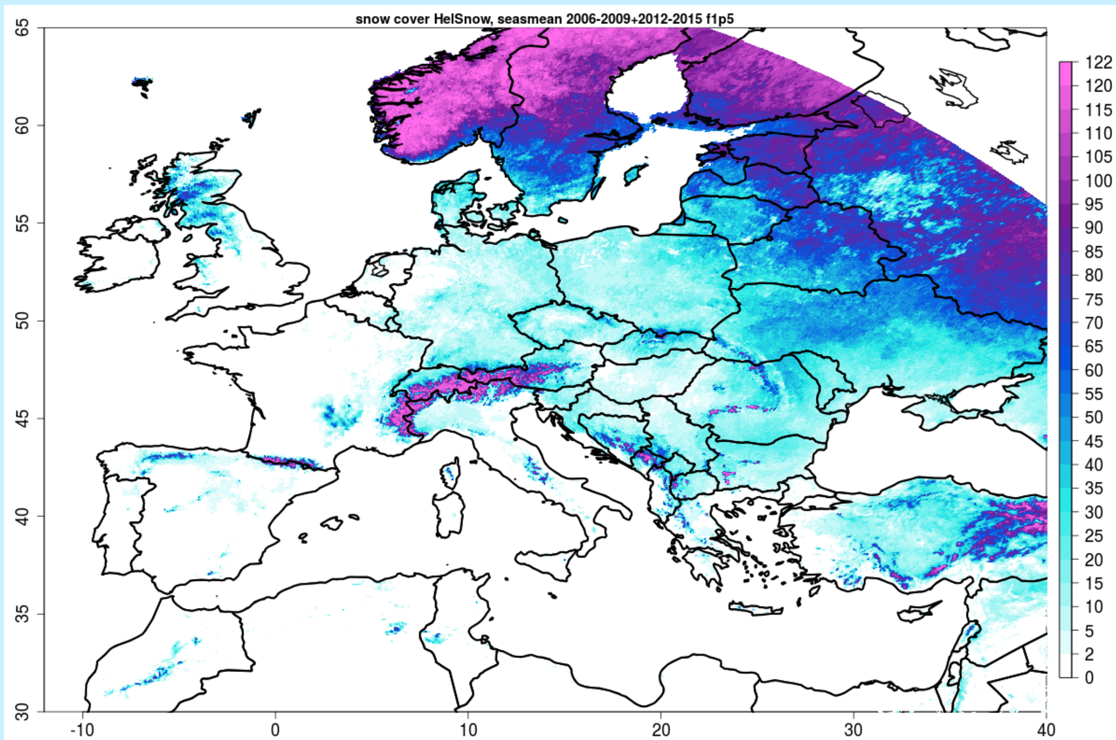


Source: Application of moderate resolution imaging spectroradiometer snow cover maps in modeling snowmelt runoff process in the central Zab basin, Iran

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

Difficulties / Challenges

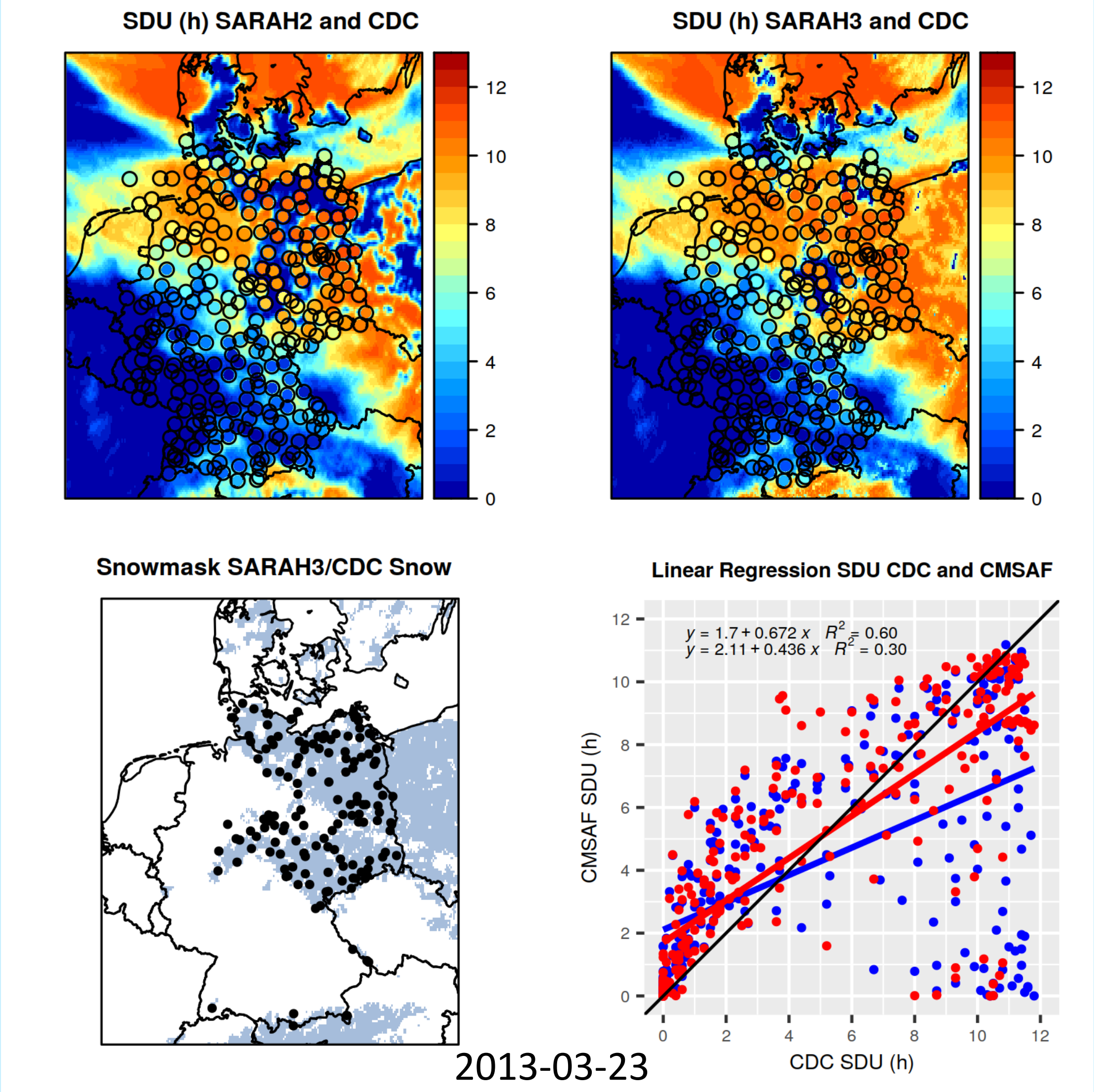
→ Internal snowmask for estimation of surface solar radiation over snow



Source:
Master theses of Vivien Priemer

Difficulties / Challenges

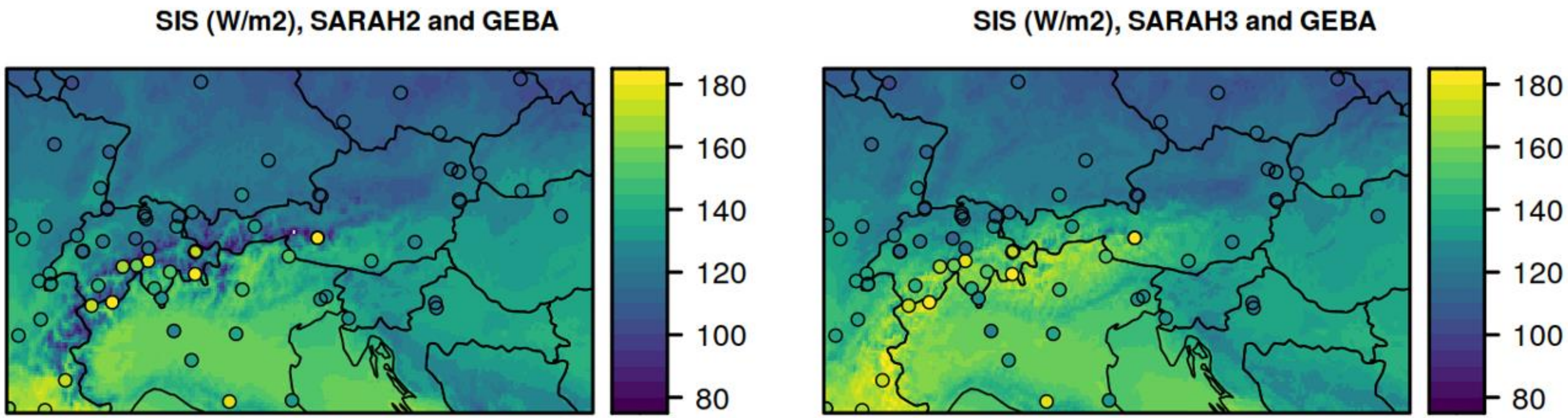
SSR from SARAH-3 -> Improvements in case of snow cover



Difficulties / Challenges

- Snow can bis missclassified as clouds

→ **New retrieval** uses snow information to reduce false interpretations
  - → higher surface solar radiation in alpine regions (SARAH-3)
  - → Better agreement with surface observations



old **March climatologies** new

Radiation in the solar und thermal range

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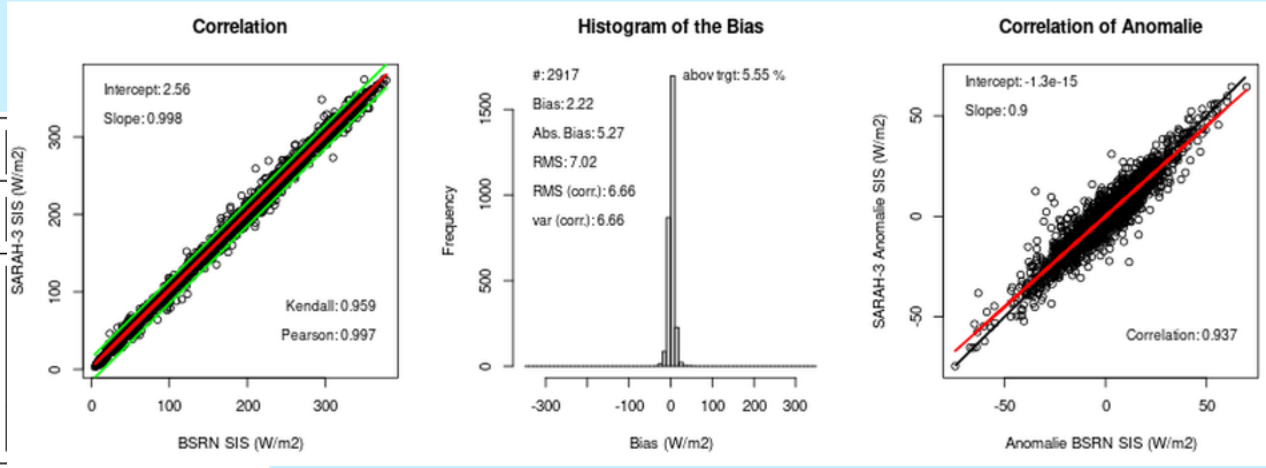
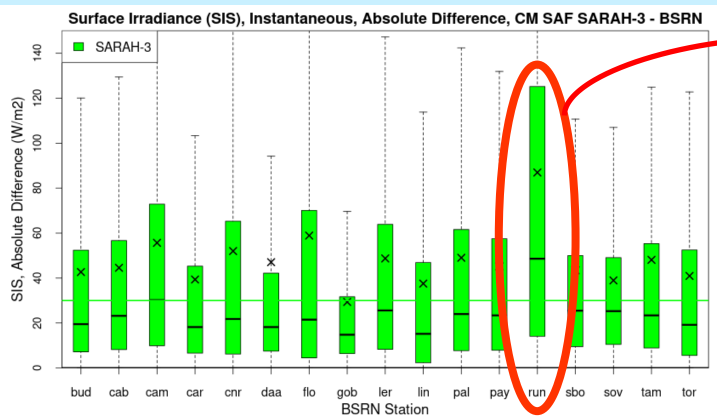
Validation

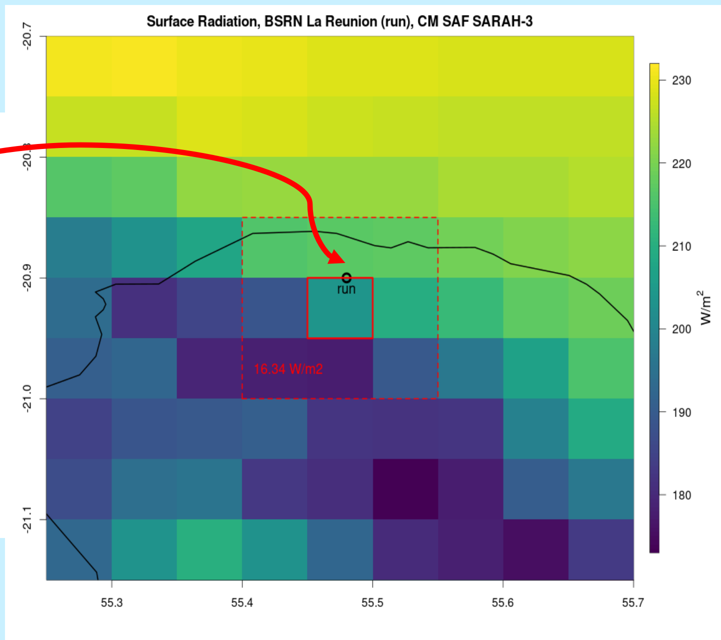
SARAH-3 SSR
monthly/daily means

Parameter	SIS	
Temp. res.	mm	dm
Bias ($W\,m^{-2}$)	2.1	2.0
MAD ($W\,m^{-2}$)	5.2	10.8
RMSE ($W\,m^{-2}$)	7.0	15.9
Anomaly corr.	0.94	0.96



SARAH-3 SSR, **30min instantaneous** data





Remember:
„point-to-area“
comparison

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Validation

DWD

Comparison of global satellite- and reanalysis data with station data:
-> Satellite data show higher accuracy as model-based reanalysis

	Full time periods					*Common period (2000-2015)*				
Data	#	bias	MAB	rmse	cor	#	bias	MAB	rmse	cor
CERES	~70k	2.35	9.16	14.0	.85	~63k	2.30	9.15	14.0	.85
CLARA-A2	~113k	1.92	10.97	15.2	.82	~63k	2.15	10.28	15.4	.86
ESA CCI	~120k	5.49	11.68	16.5	.79	~63k	4.76	10.93	15.8	.82
GEWEX SRB	~76k	3.95	13.12	18.4	.75					
ERA-5	~118k	7.34	12.60	16.1	.79	~63k	6.38	11.89	15.7	.81
MERRA-2	~124k	19.7	23.64	22.8	.69	~63k	17.3	22.02	22.1	.72

MAB= mean absolute bias [W/m2]; bias in W/m2; rmse in W/m2; cor= anomaly correlation; # = number of months

Validation

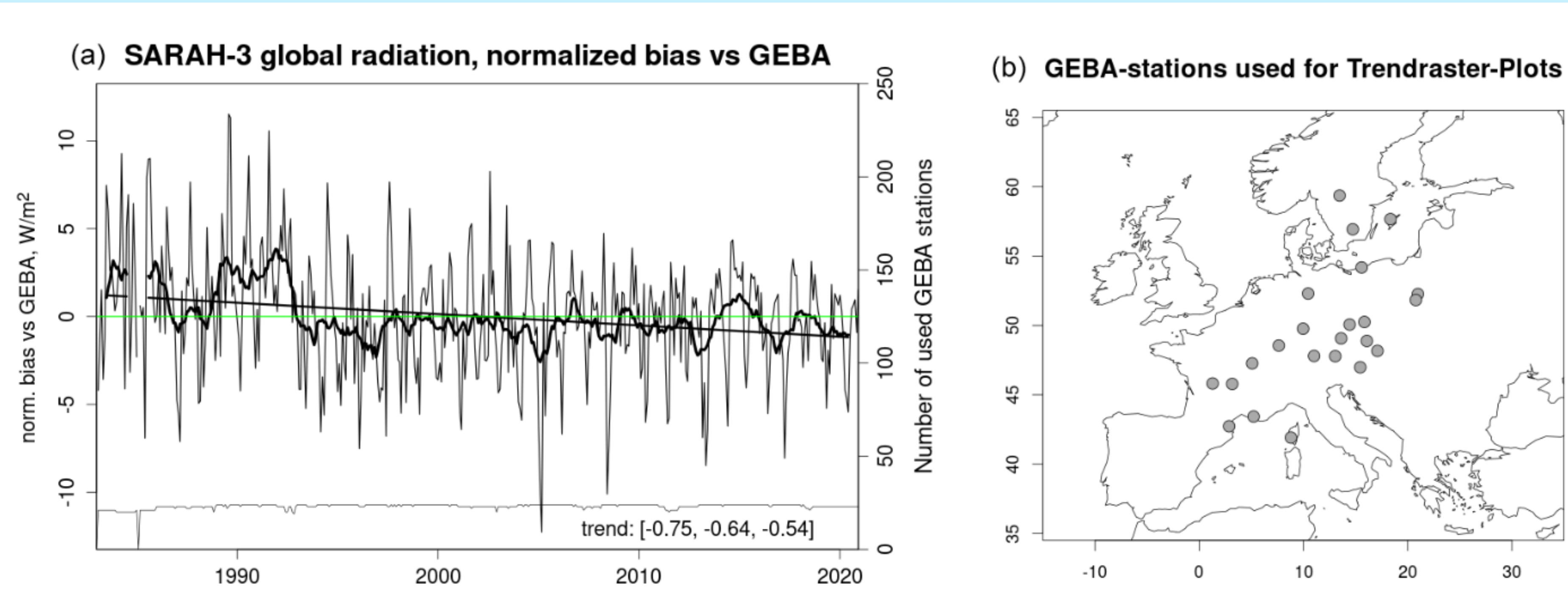
Comparison of global satellite- and reanalysis data with station data:
-> Satellite data show higher accuracy as NWP-based reanalysis products

	Full time periods					***Common period (2000-2015)***				
Data	#	bias	MAB	rmse	cor	#	bias	MAB	rmse	cor
CERES	~70k	2.35	9.16	14.0	.85	~63k	2.30	9.15	14.0	.85
CLARA-A2	~113k	1.92	10.97	15.2	.82	~63k	2.15	10.28	15.4	.86
ESA CCI	~120k	5.49	11.68	16.5	.79	~63k	4.76	10.93	15.8	.82
GEWEX SRB	~76k	3.95	13.12	18.4	.75					
ERA-5	~118k	7.34	12.60	16.1	.79	~63k	6.38	11.89	15.7	.81
MERRA-2	~124k	19.7	23.64	22.8	.69	~63k	17.3	22.02	22.1	.72

MAB= mean absolute bias [W/m2]; bias in W/m2; rmse in W/m2; cor= anomaly correlation; # = number of months

Validation with GEBA stations

-> Bias time series / stability analysis
based on a homogeneous set of GEBA stations



-> slight negative trend in the bias time series of ~-0.6 W/m^2/decade
(due to some overestimations in the early years)

Radiation in the solar und thermal range

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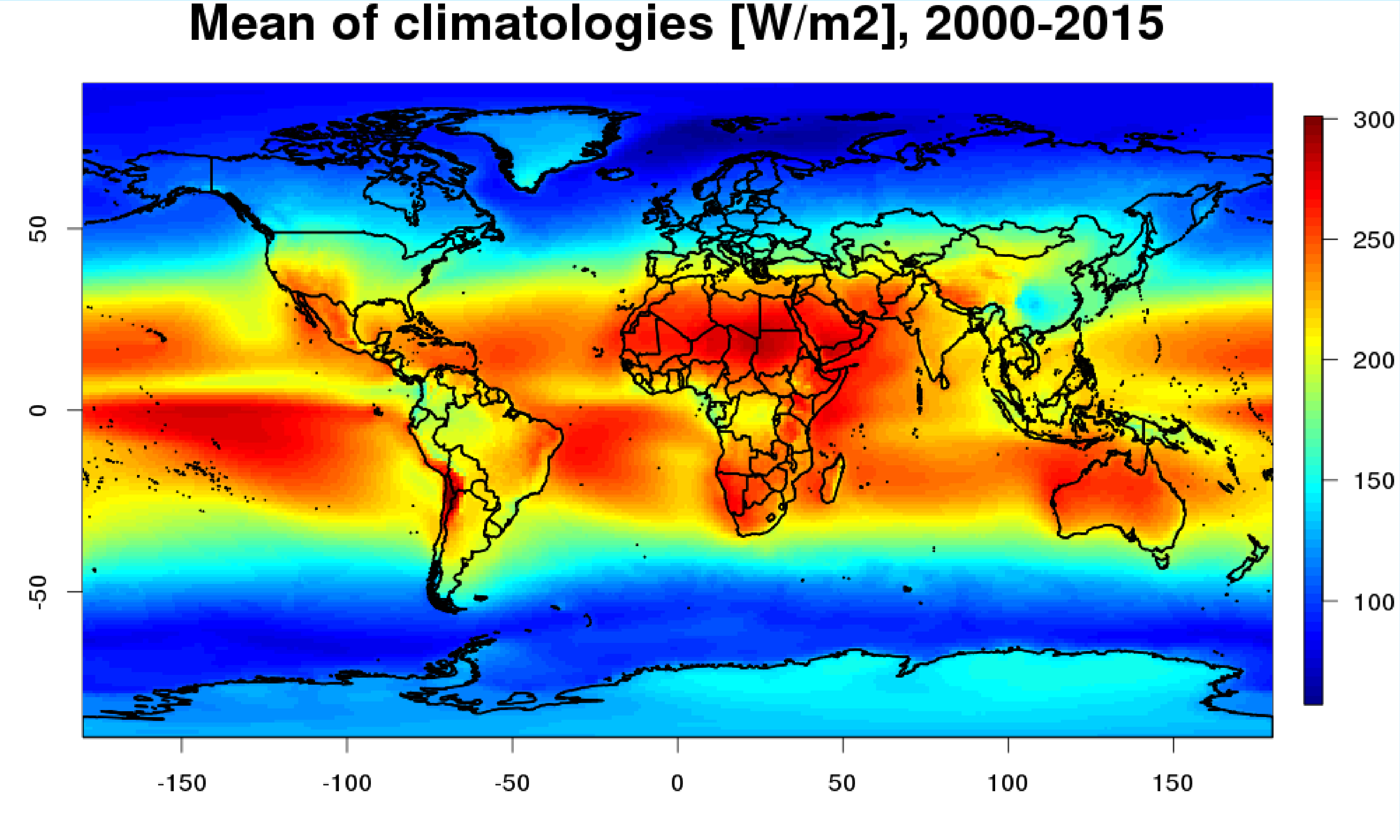
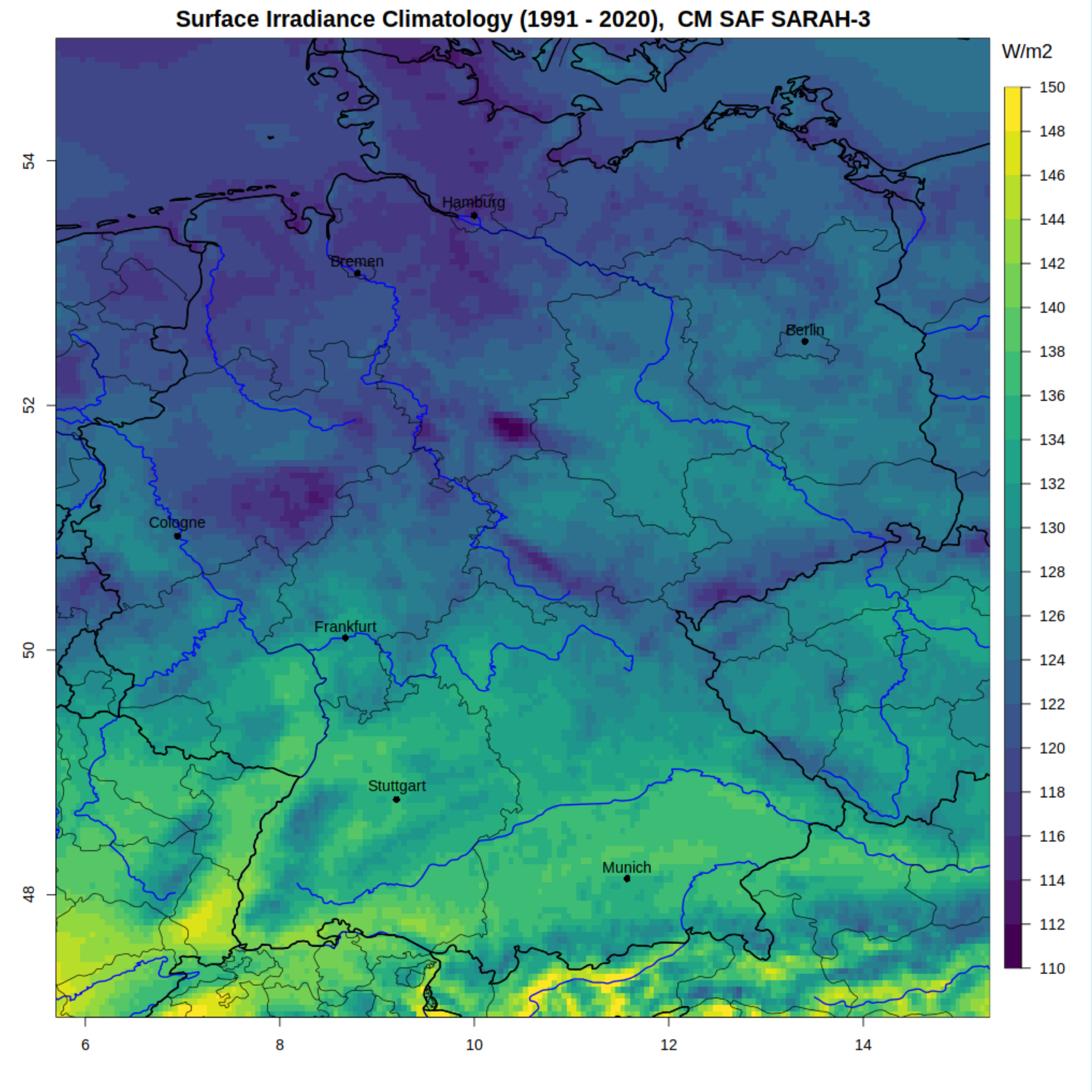
  - ➔ **Applications**
  - ➔ Climate analysis
- ➔ Surface albedo
- ➔ Longwave downward radiation at the surface
- ➔ Radiation budget at the top of atmosphere

Application Climatology

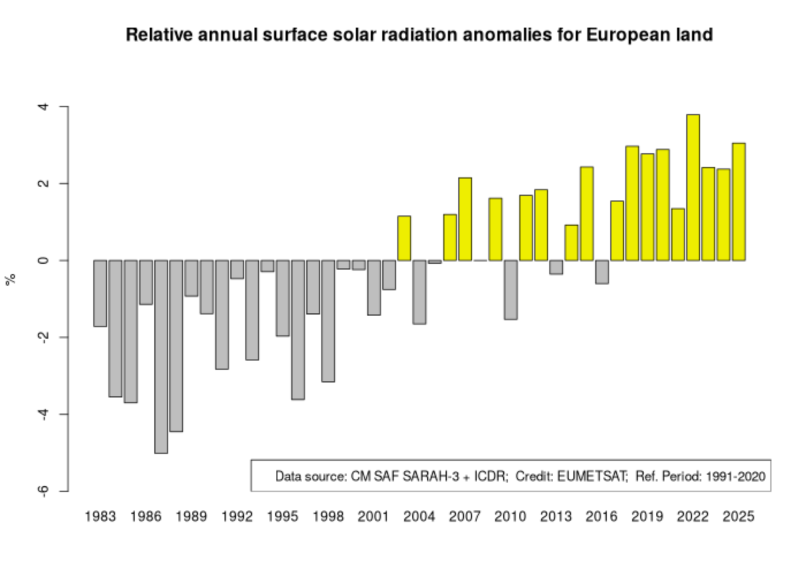
Global mean of surface solar radiation: 188 W/m2

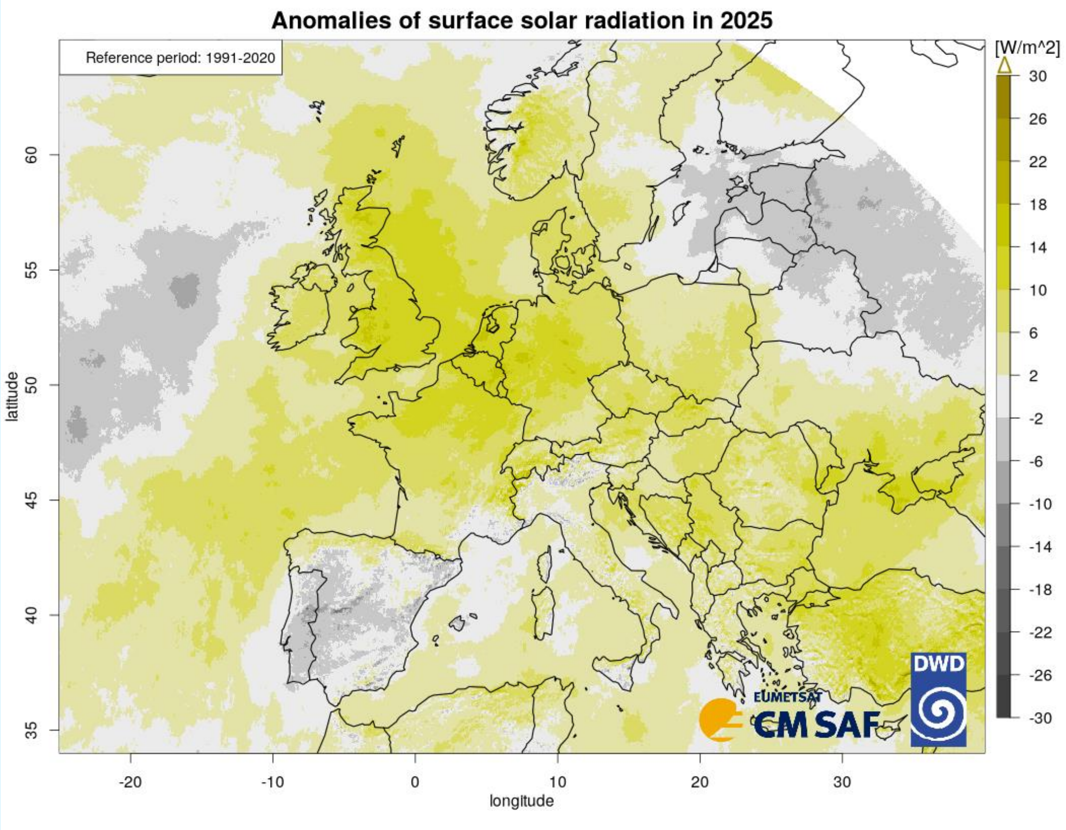


Application Climatology

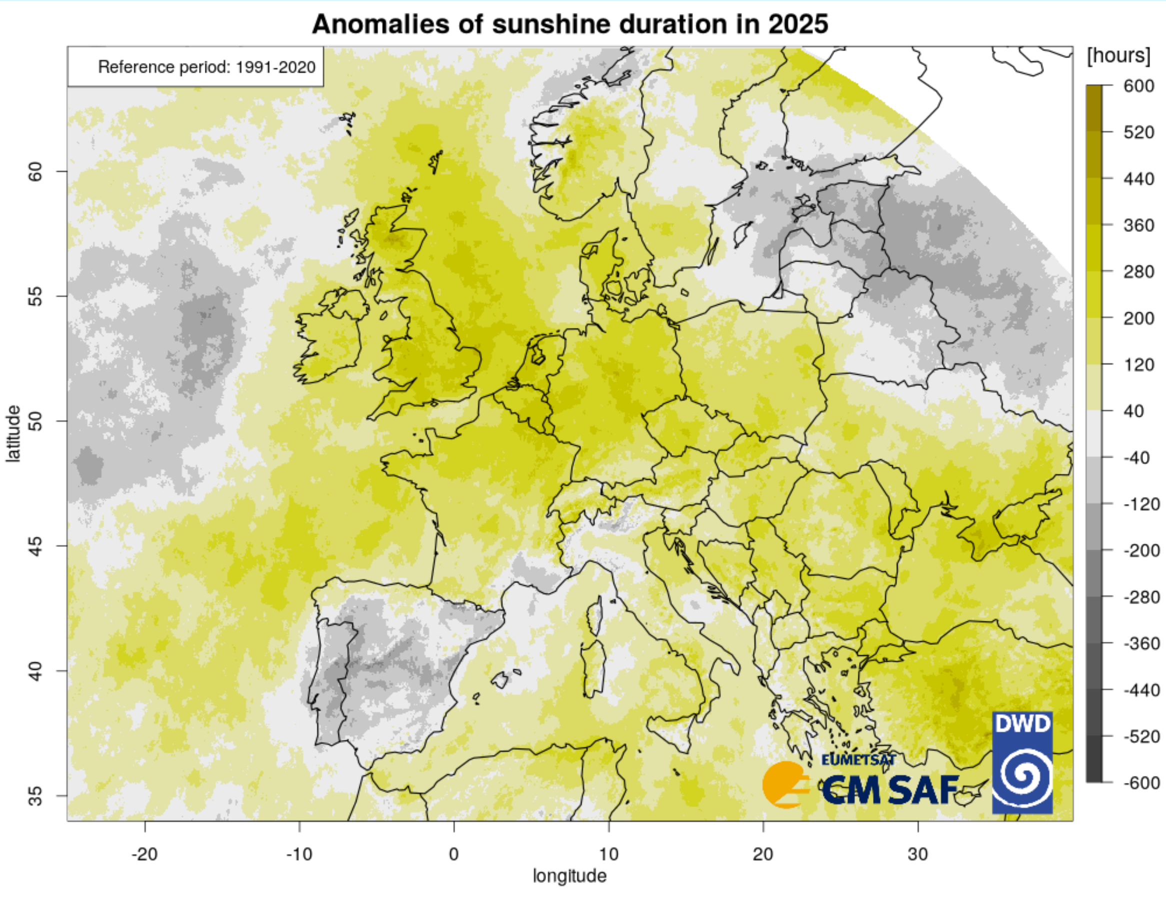


SSR Anomaly 2025



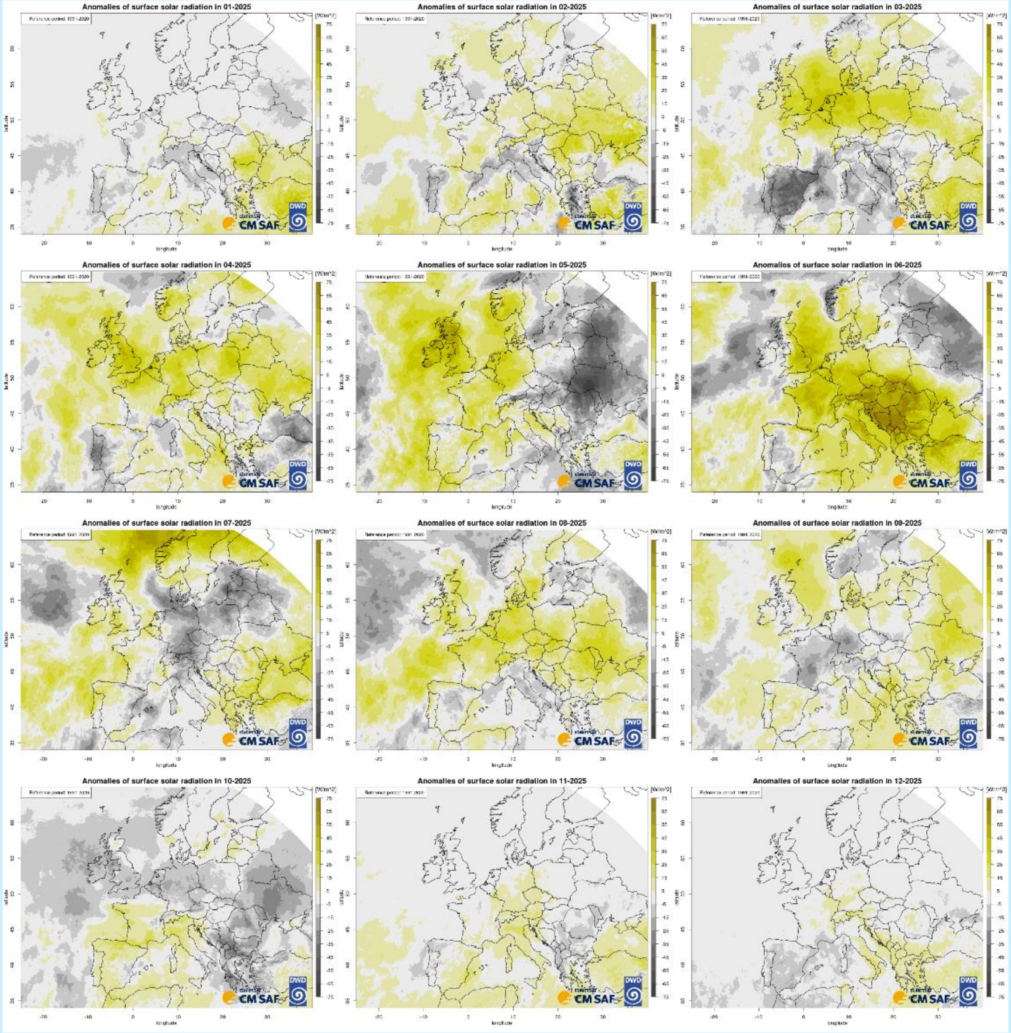


Sunshine Duration* Anomaly

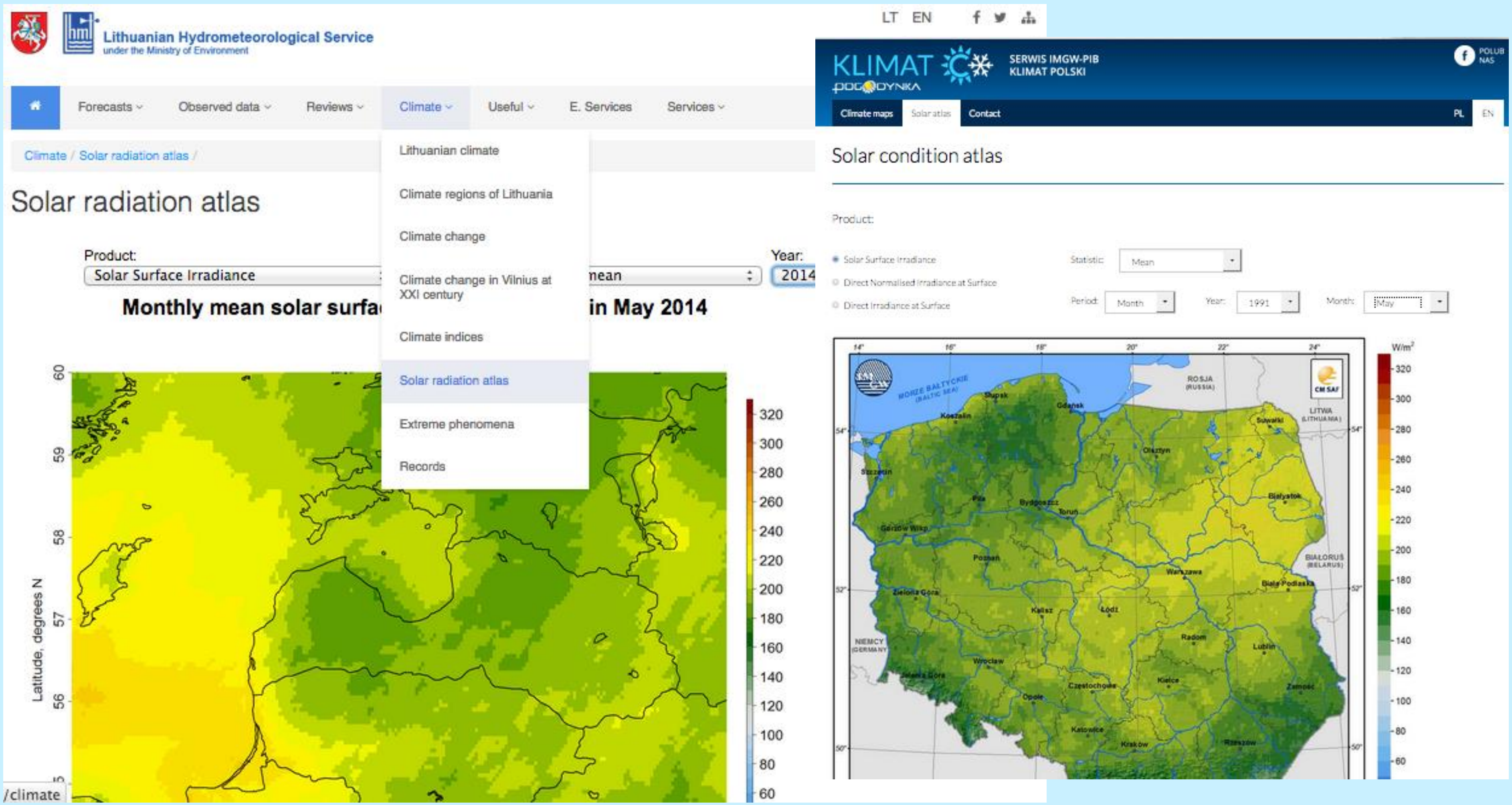


* The sunshine duration is calculated from the Direct Surface Radiation, both also part of the SARAH-3 data record

Monthly SSR Anomalies 2025

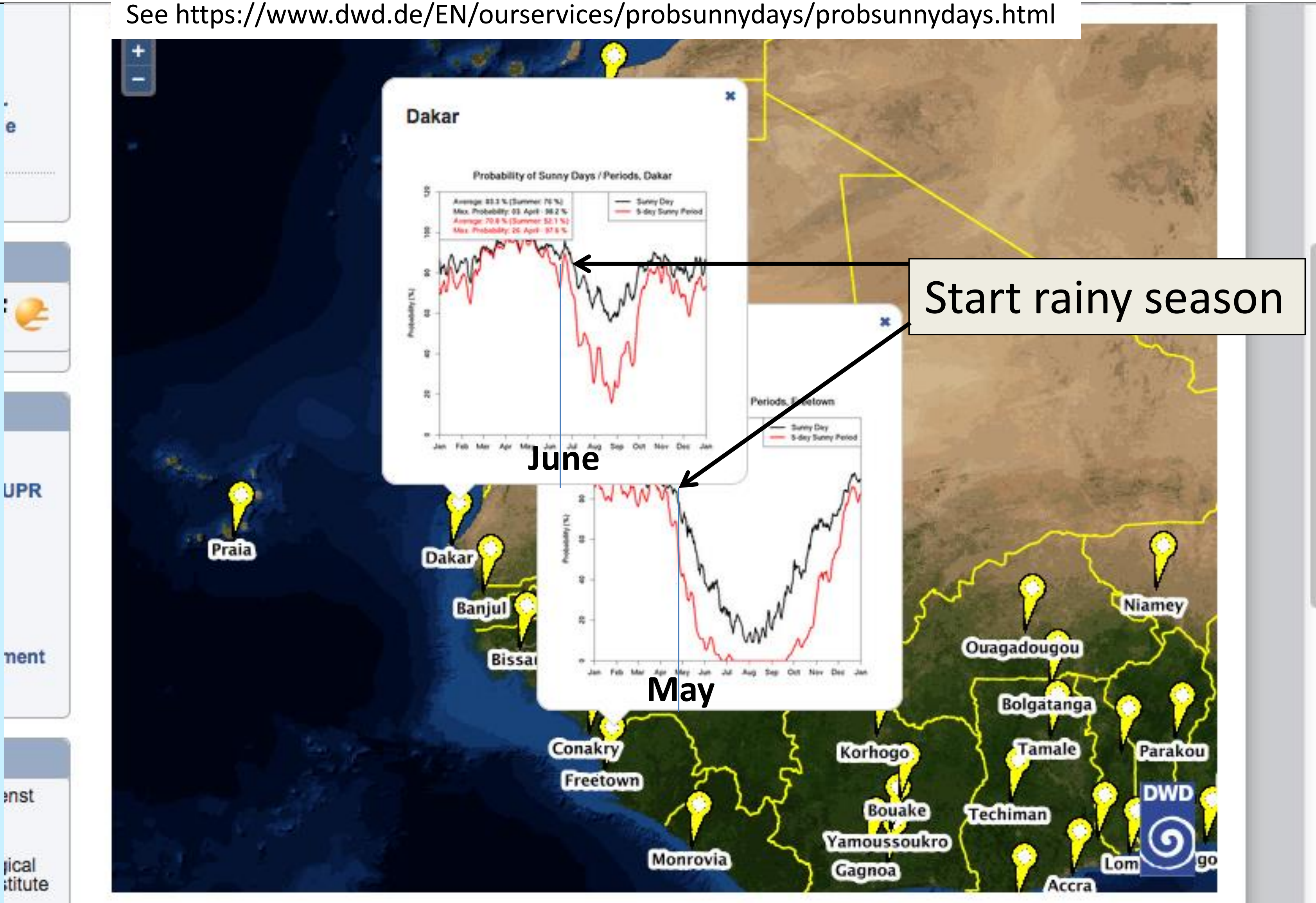


Solar Radiation Atlas for Baltic States and Poland



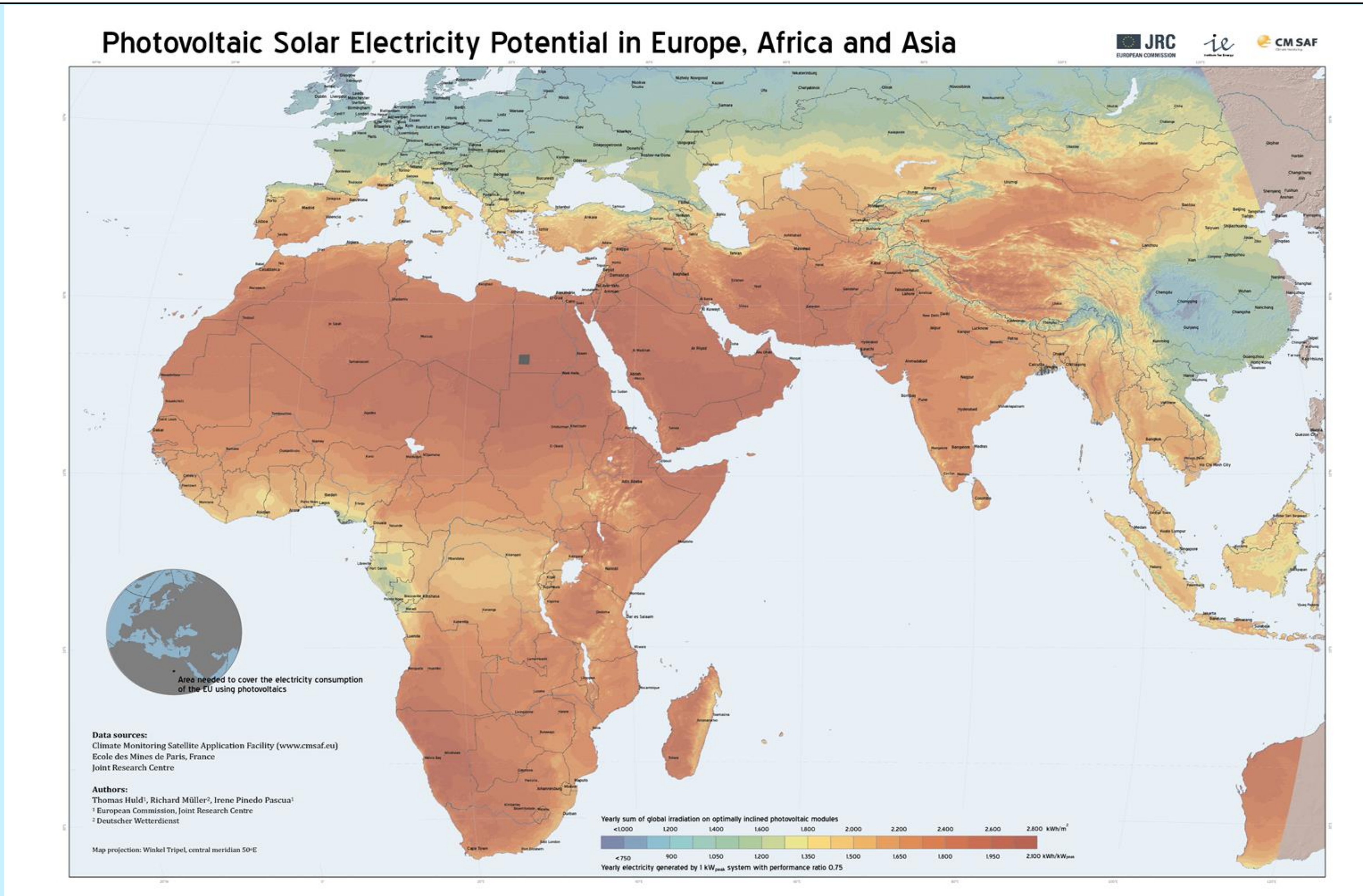
Application: Sunny Days

See https://www.dwd.de/EN/ourservices/probsunnydays/probsunnydays.html



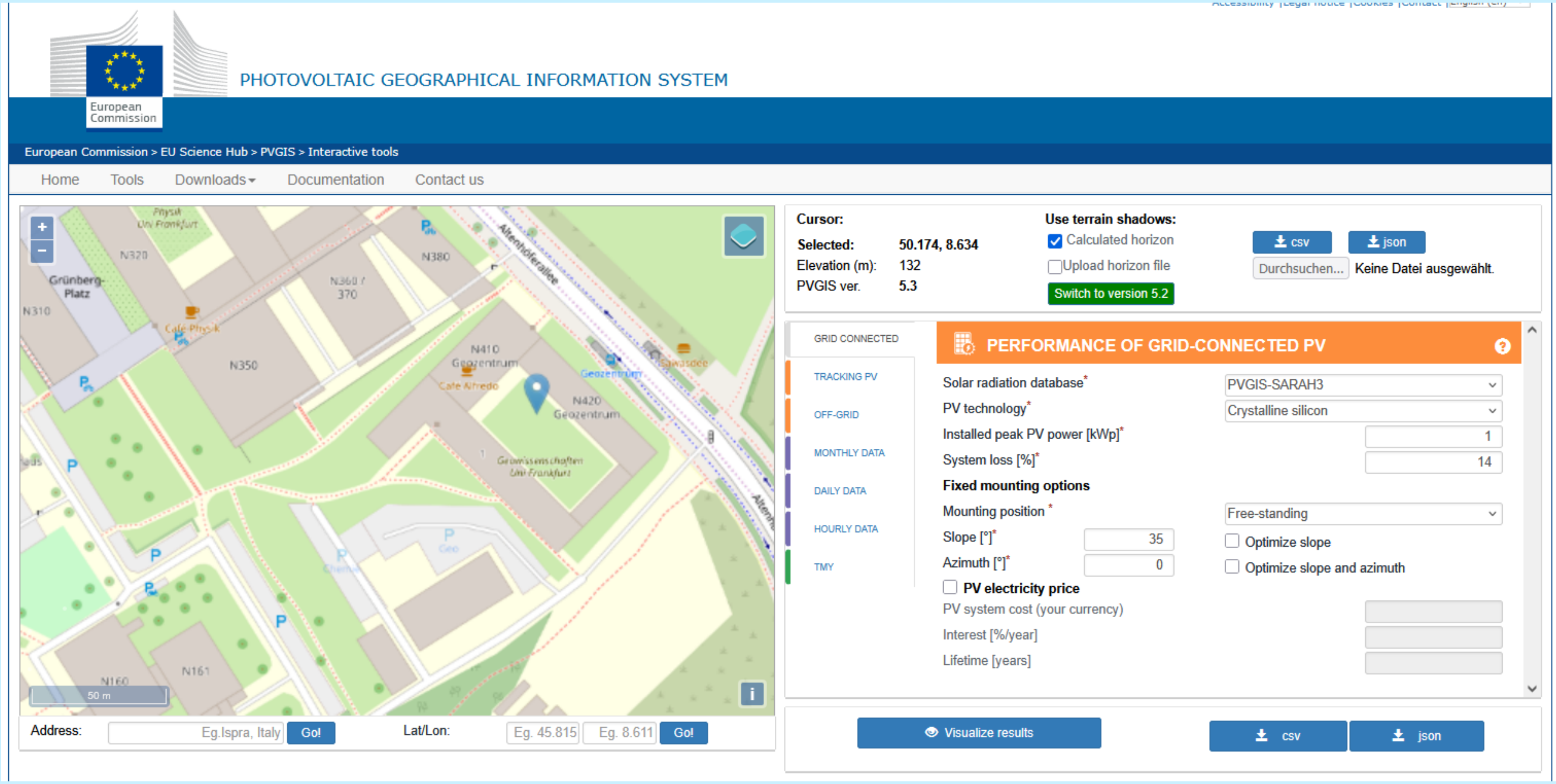
In this analysis, a day is defined as a sunny day if the daily surface solar radiation exceeds 80% of the clear-sky surface solar radiation; a 5-day sunny period is defined as five consecutive sunny days. With these definitions and based on more than 3

Solar energy potential



Generated by Thomas Huld, Joint Research Center, EU.

PVGIS: Free PV energy yield web tool



PVGIS: Free PV energy yield web tool

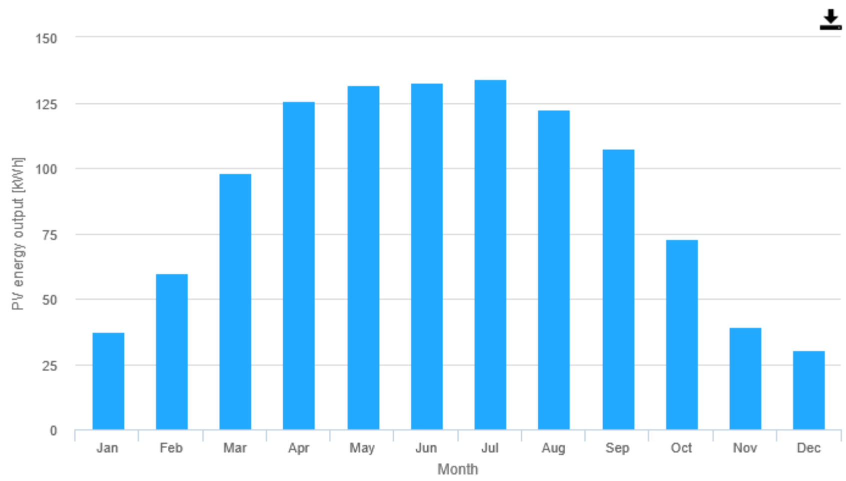
PERFORMANCE OF GRID-CONNECTED PV: RESULTS

PV output | Radiation | Info | PDF

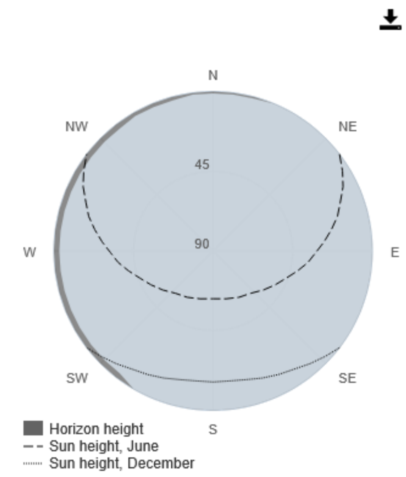
Summary

Provided inputs:	
Location [Lat/Lon]:	50.174,8.634
Horizon:	Calculated
Database used:	PVGIS-SARAH3
PV technology:	Crystalline silicon
PV installed [kWp]:	1
System loss [%]:	14
Simulation outputs:	
Slope angle [°]:	35
Azimuth angle [°]:	0
Yearly PV energy production [kWh]:	1091.66
Yearly in-plane irradiation [kWh/m^2]:	1375.06
Year-to-year variability [kWh]:	55.29
Changes in output due to:	
Angle of incidence [%]:	-3.01
Spectral effects [%]:	1.68
Temperature and low irradiance [%]:	-6.4
Total loss [%]:	-20.61

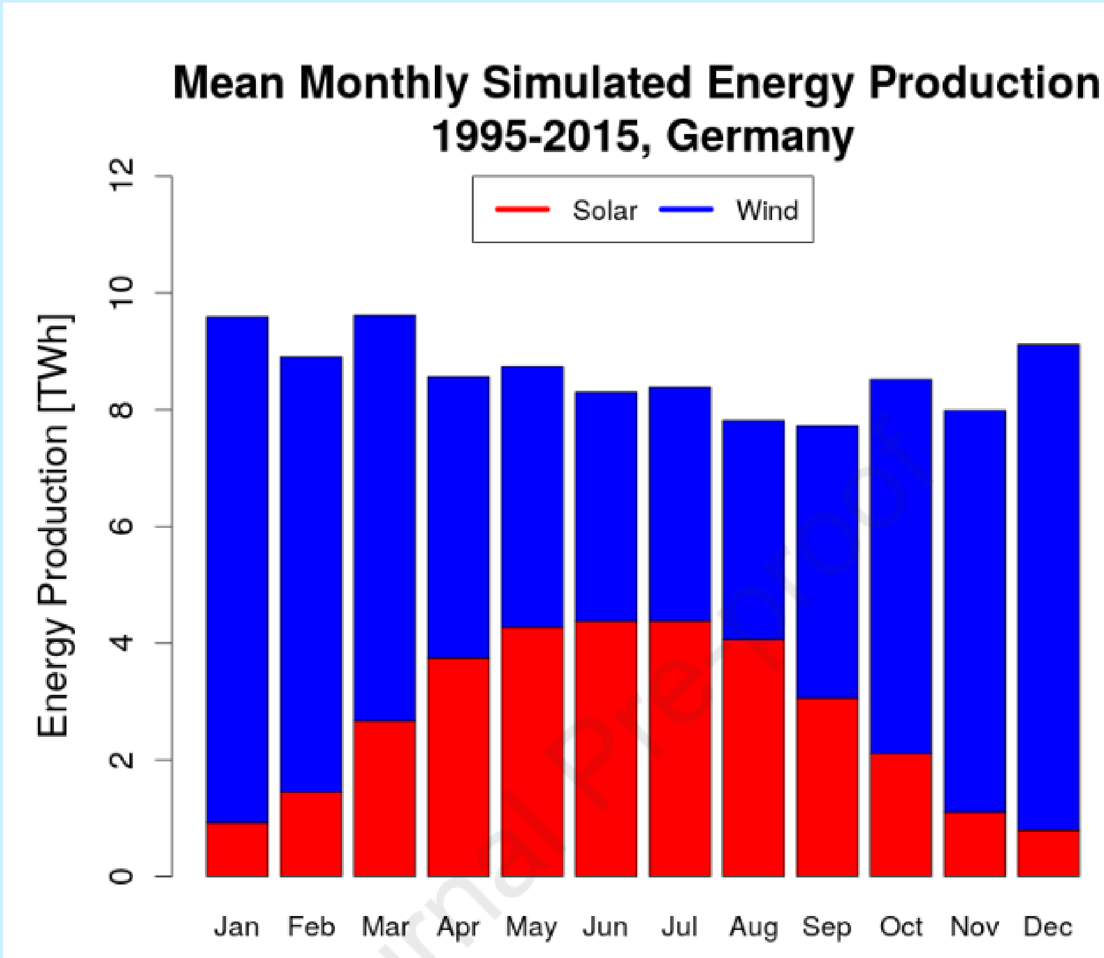
Monthly energy output from fix-angle PV system



Outline of horizon

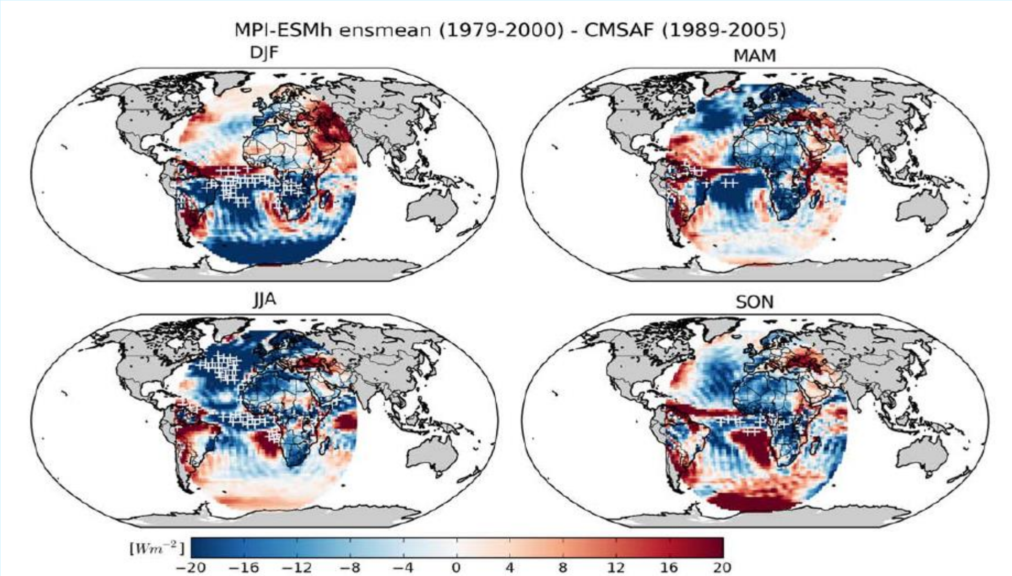


Interplay of wind and solar energy



See Drücke, J. et al., 2020: „Climatological analysis of solar and wind energy in Germany using the Grosswetterlagen classification", Renewable Energy.

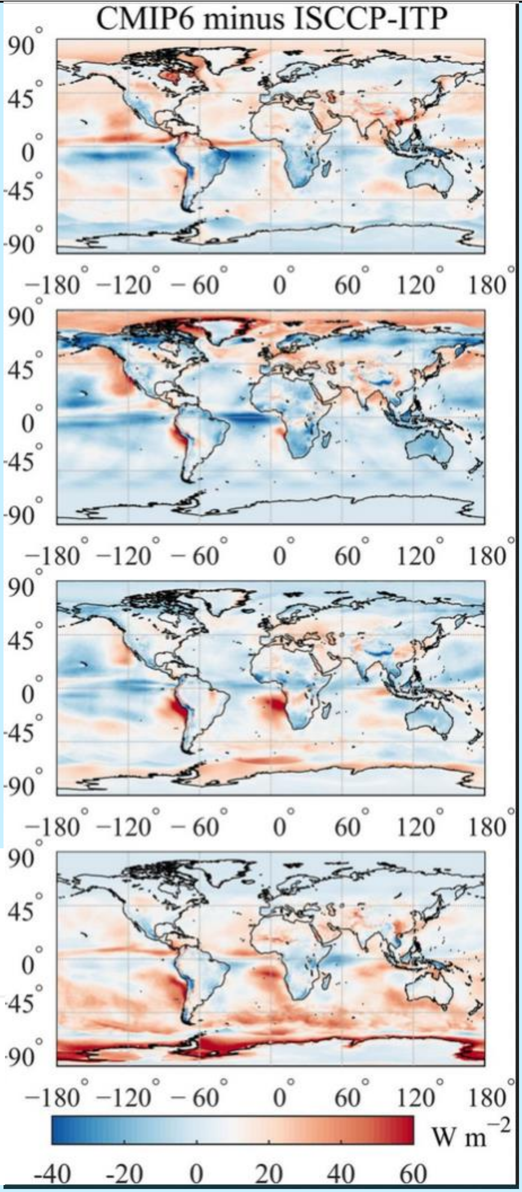
Validation of climate models



Combined evaluation of MPI-ESM land surface water and energy fluxes

Stefan Hagemann,[1] Alexander Loew,[1] and A. Andersson[2]

JOURNAL OF ADVANCES IN MODELING EARTH SYSTEMS, VOL. 5, 1–28, doi:10.1029/2012MS000173, 2013



MAM

JJA

SON

DJF

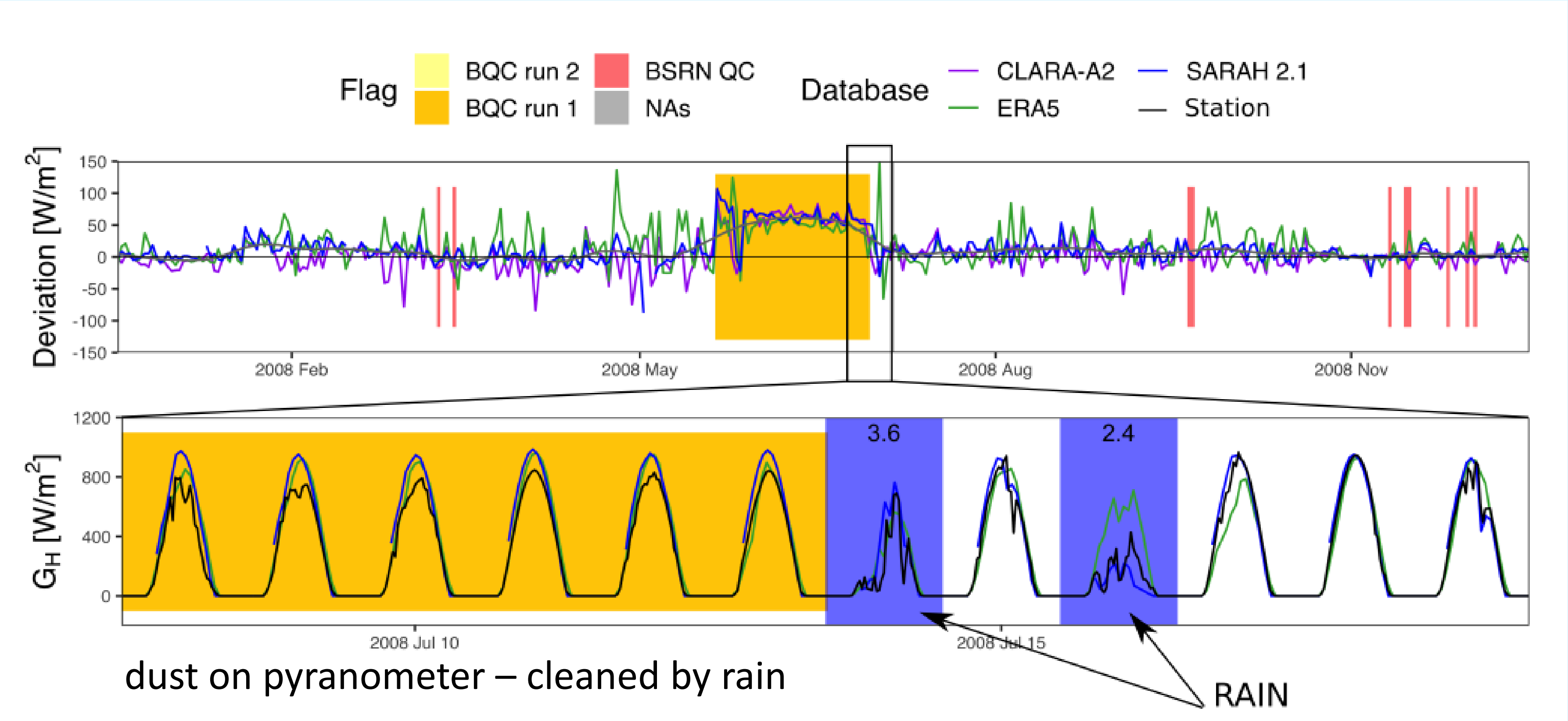
ELSEVIER
Atmospheric Research
Volume 292, 1 September 2023, 106896

Global evaluation of simulated surface shortwave radiation in CMIP6 models

Junmei He [a] [b], Liang Hong [a], Changkun Shao [c], Wenjun Tang [b]

Quality control of station data

➔ Monitoring differences of stations- und satellite- / reanalysis surface radiation data



See
http://www.bqcmethod.com/

Urraca et al. 2017, 2020

Radiation in the solar und thermal range

Outline

- Motivation: satellite data as valuable data source
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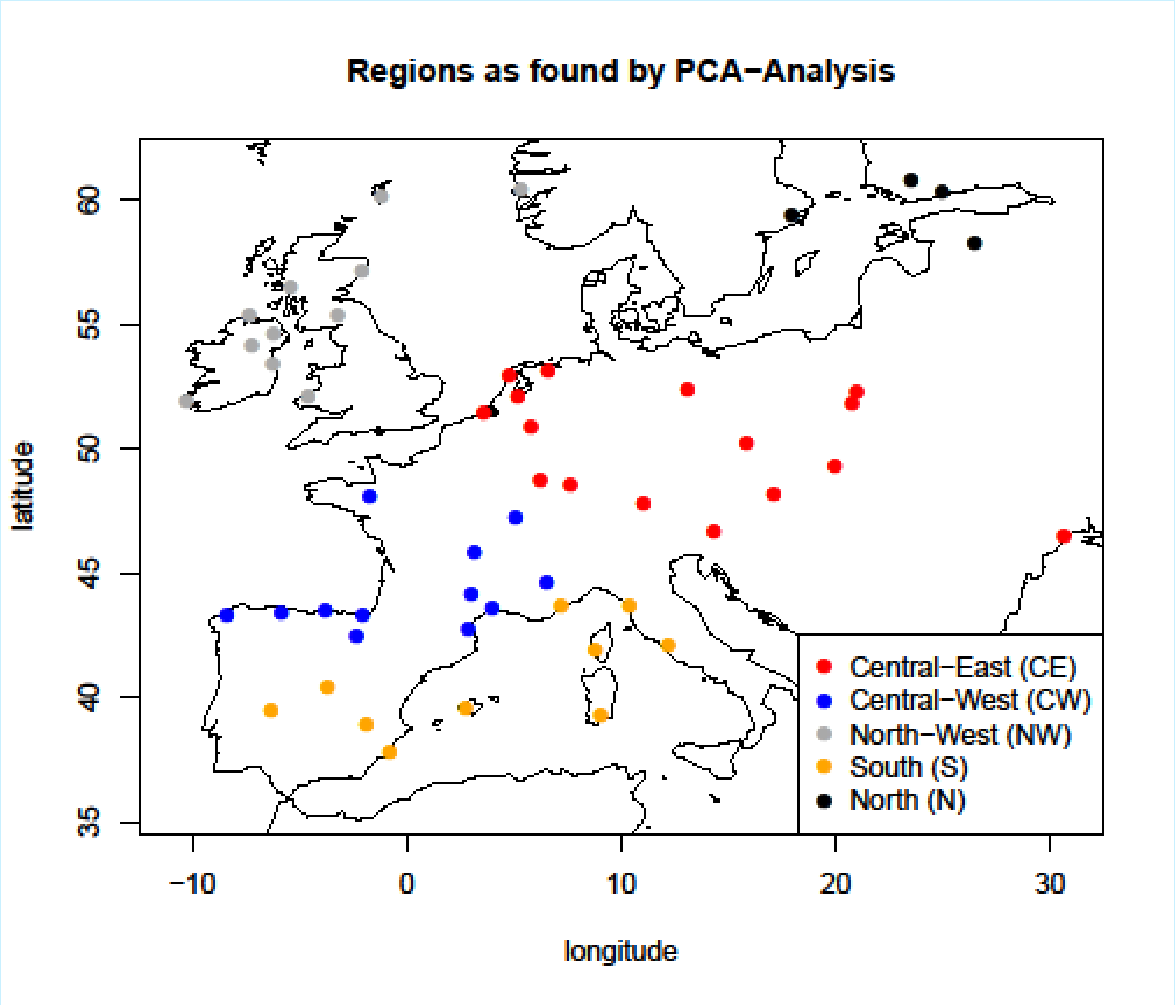
- Surface albedo
- Longwave downward radiation at the surface
- Radiation budget at the top of atmosphere

Trend and variability analysis

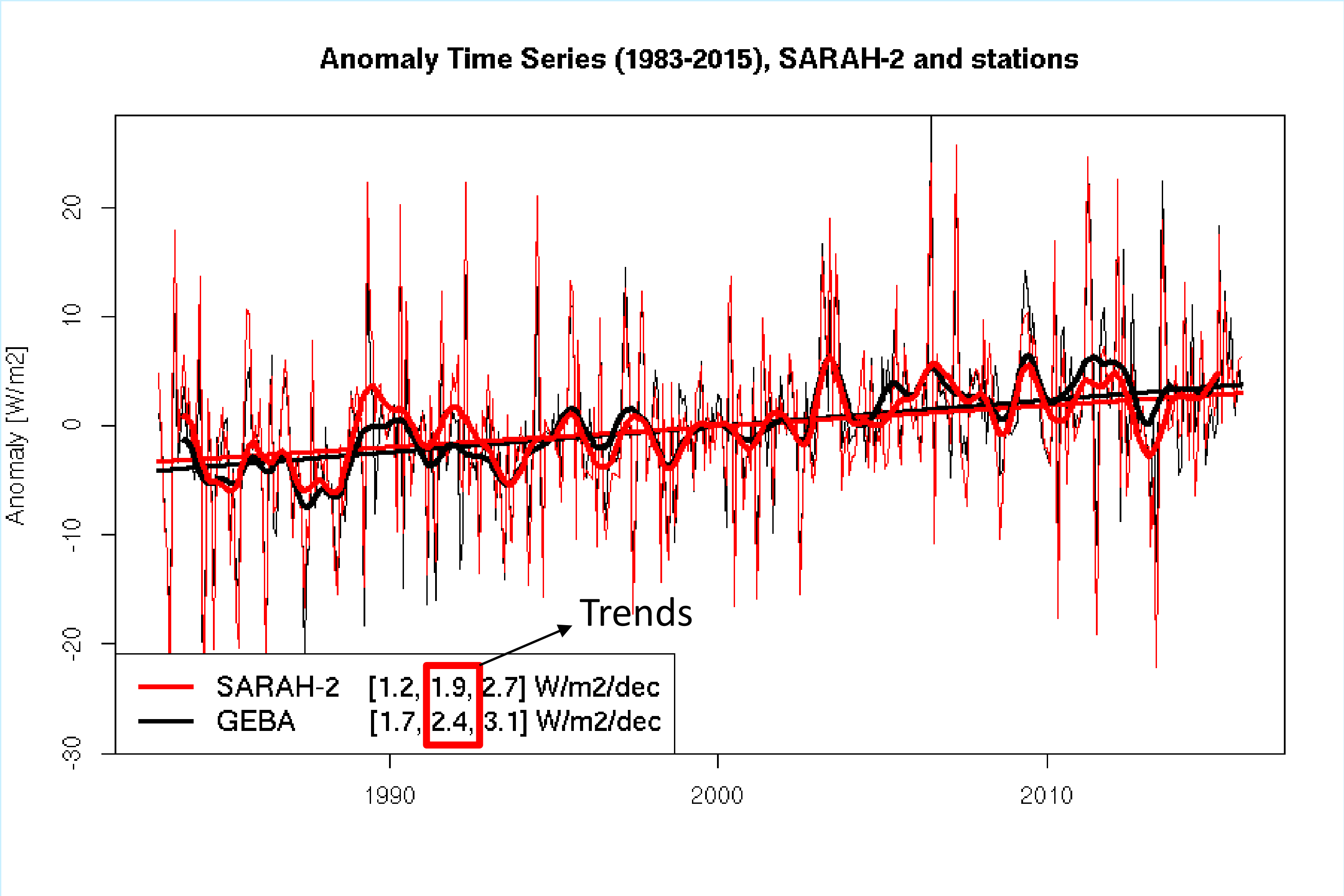
GEBA used as reference for validation/ trend- analysis



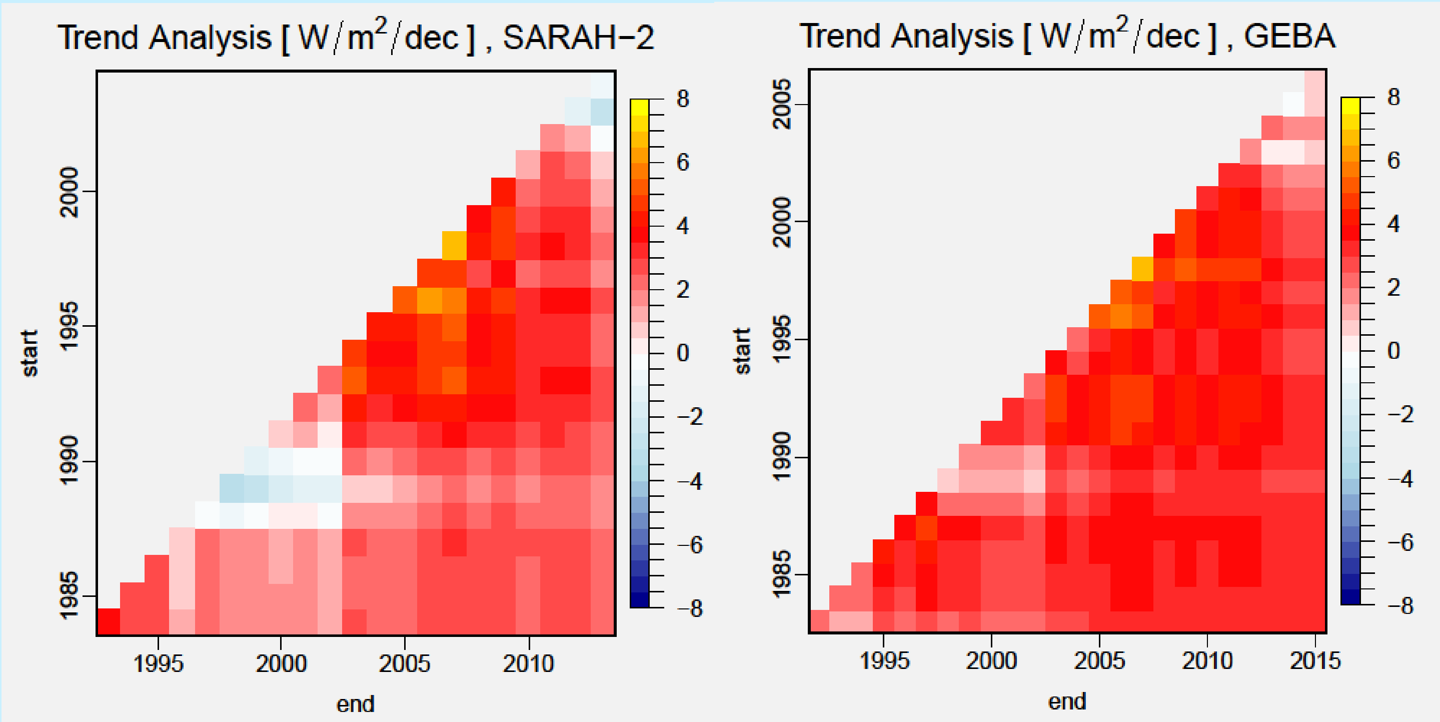
Trend and variability analysis

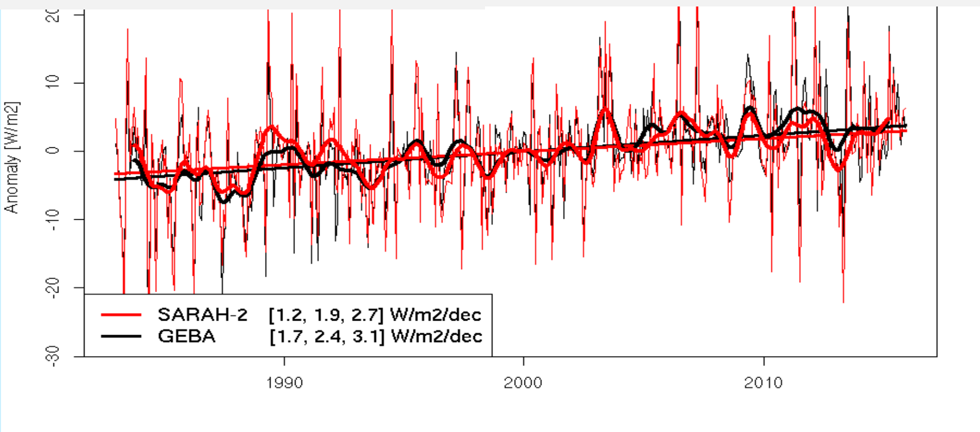
Anomaly time series of SARAH-2 und station data agree well

Positive trend of global radiation in Europe during 1983-2015

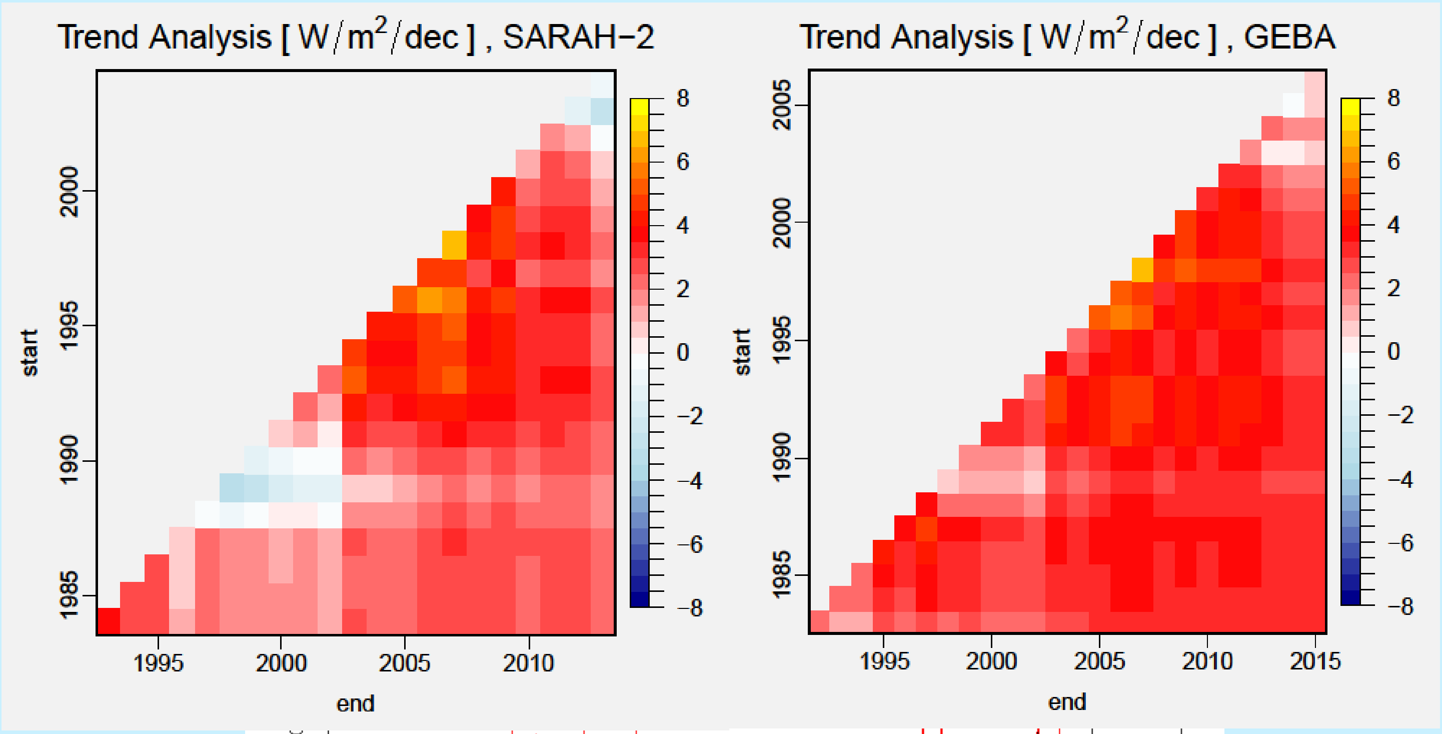


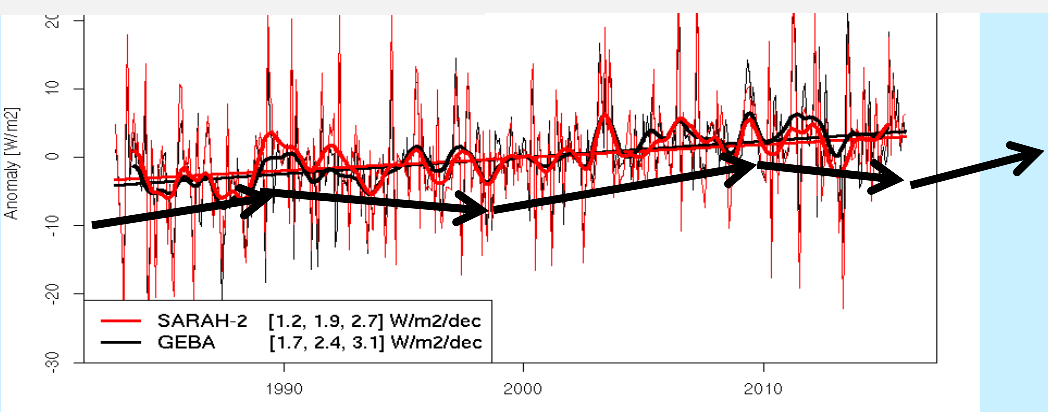
Trendraster-Analysis





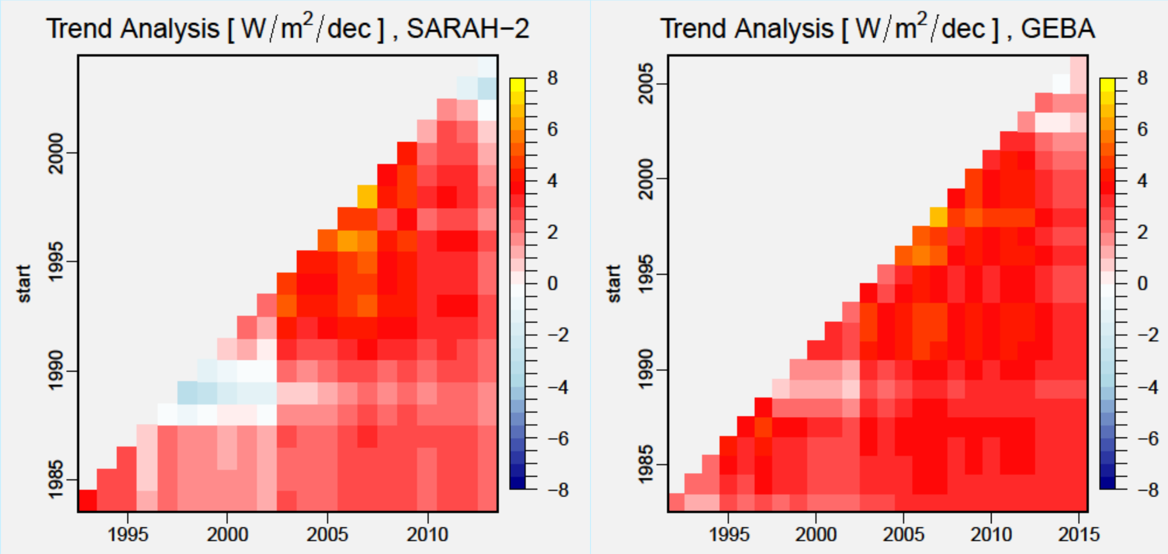
Trendraster-Analysis

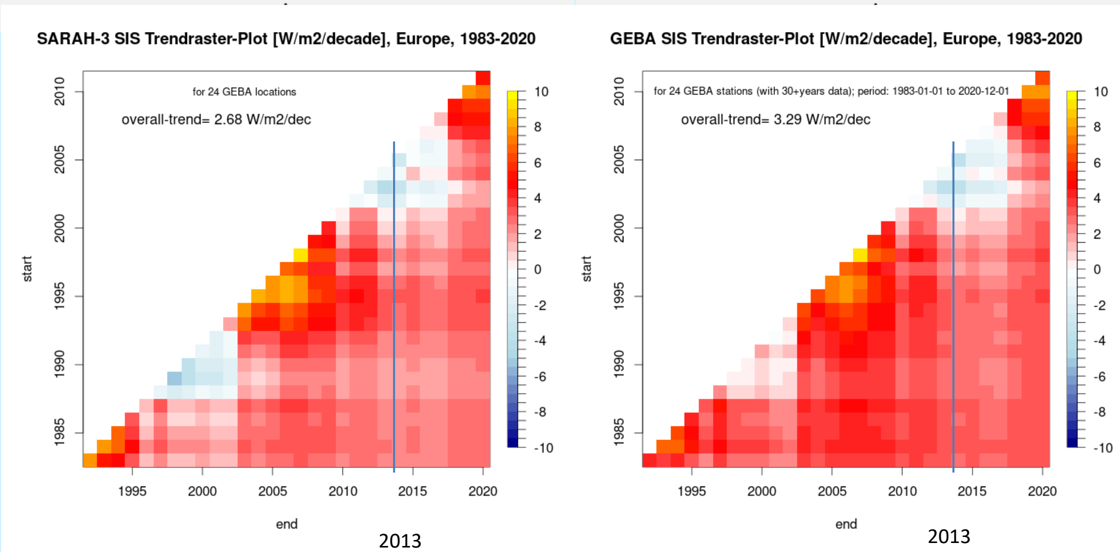




Trend and variability analysis

Trendraster-Analysis

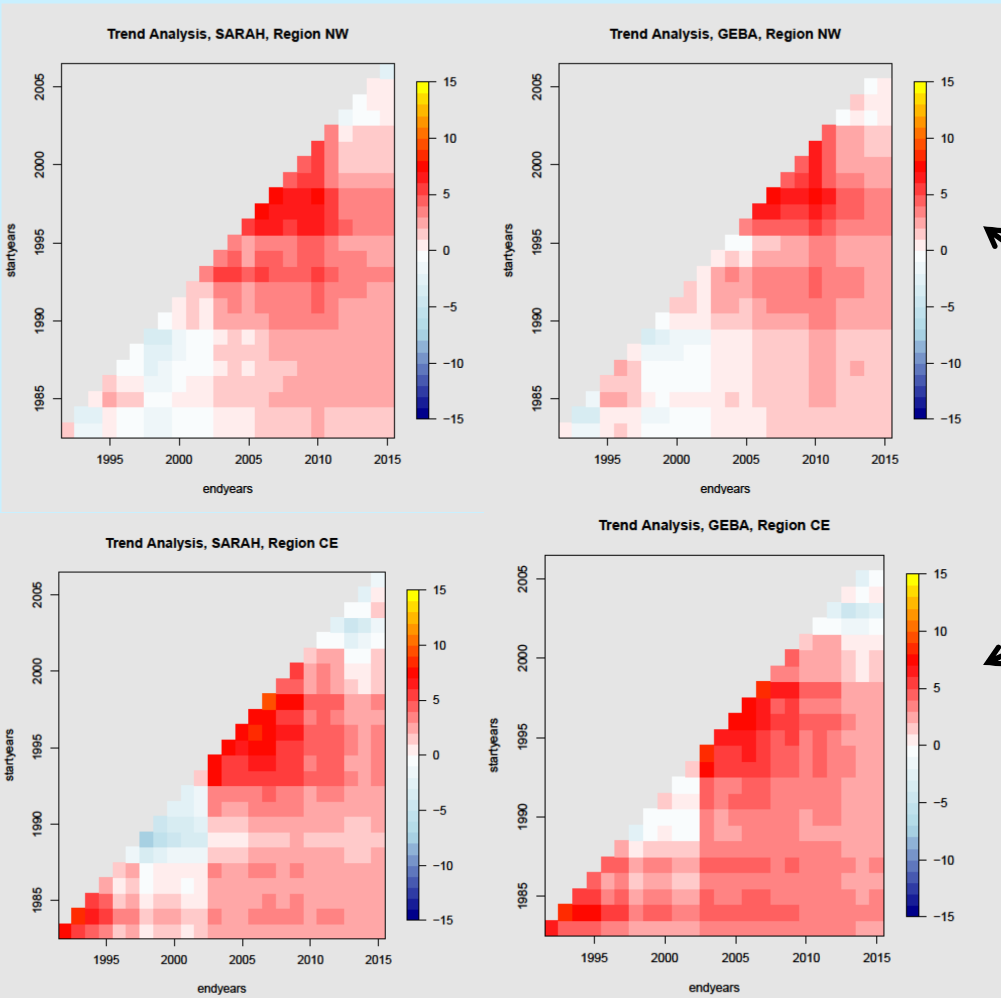


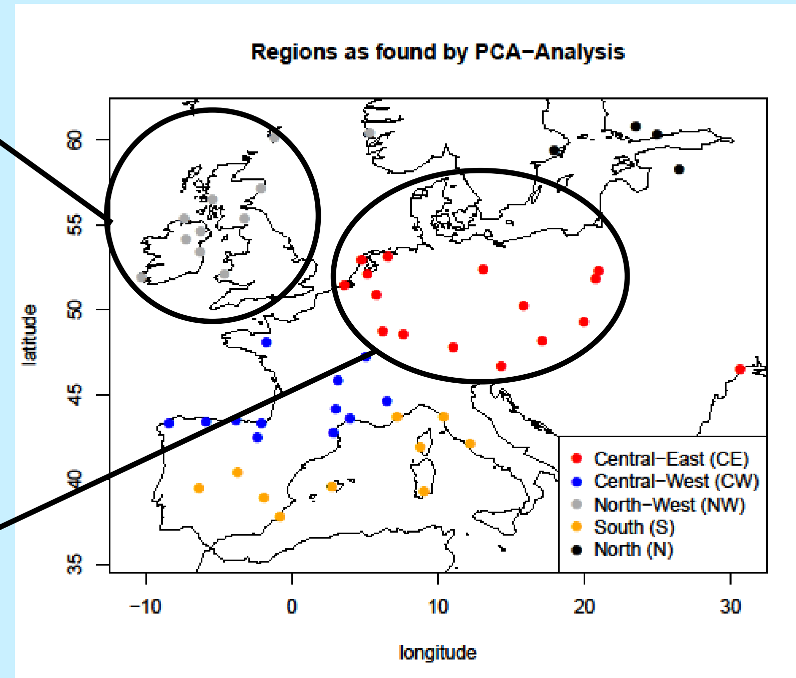


Extended time period

Trendraster-Analysis shows **regional differences**

Satellite | Stations

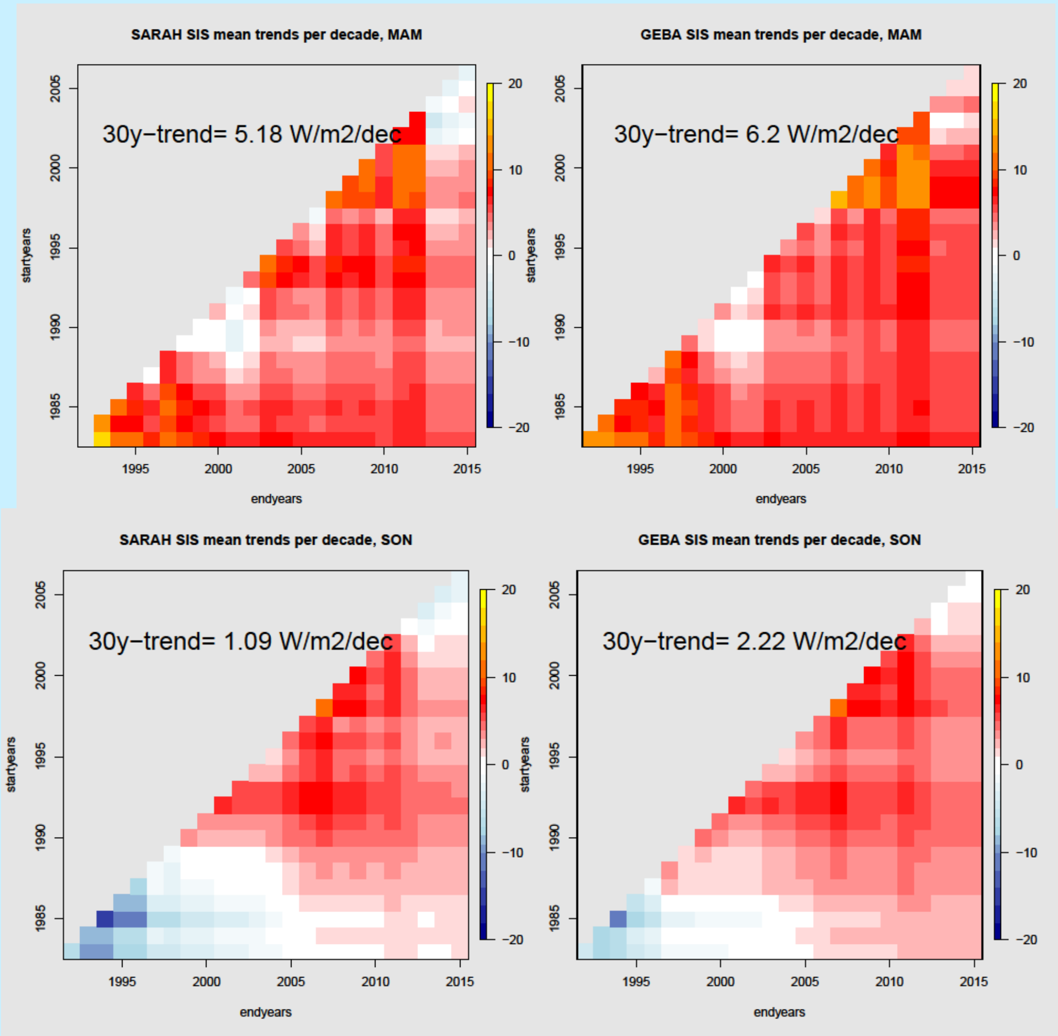




Trend and variability analysis

Trendraster-Analysis shows **seasonal differences**

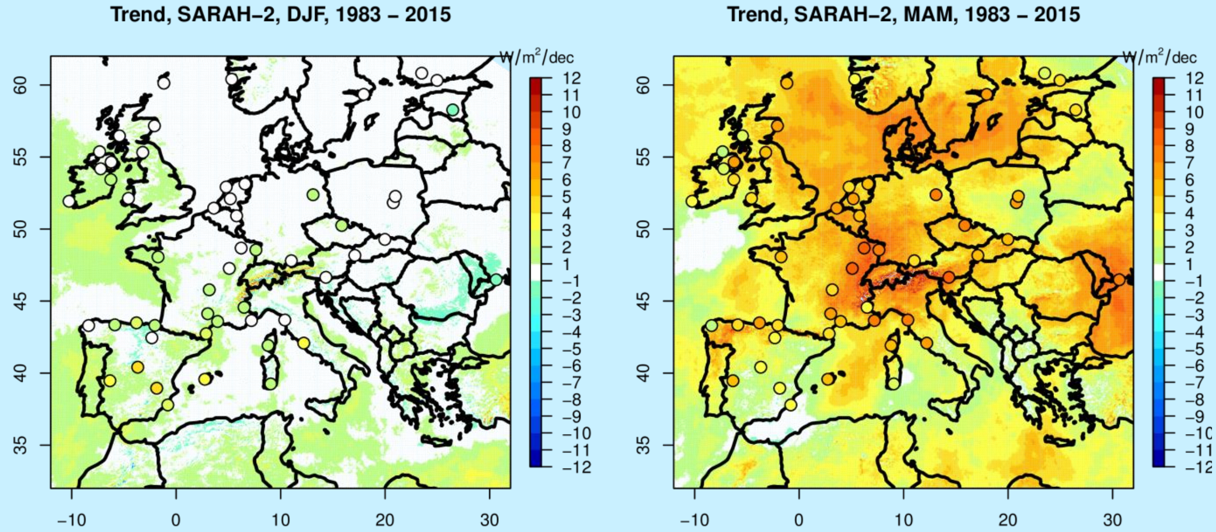
Satellite | Stations



Spring

Autumn

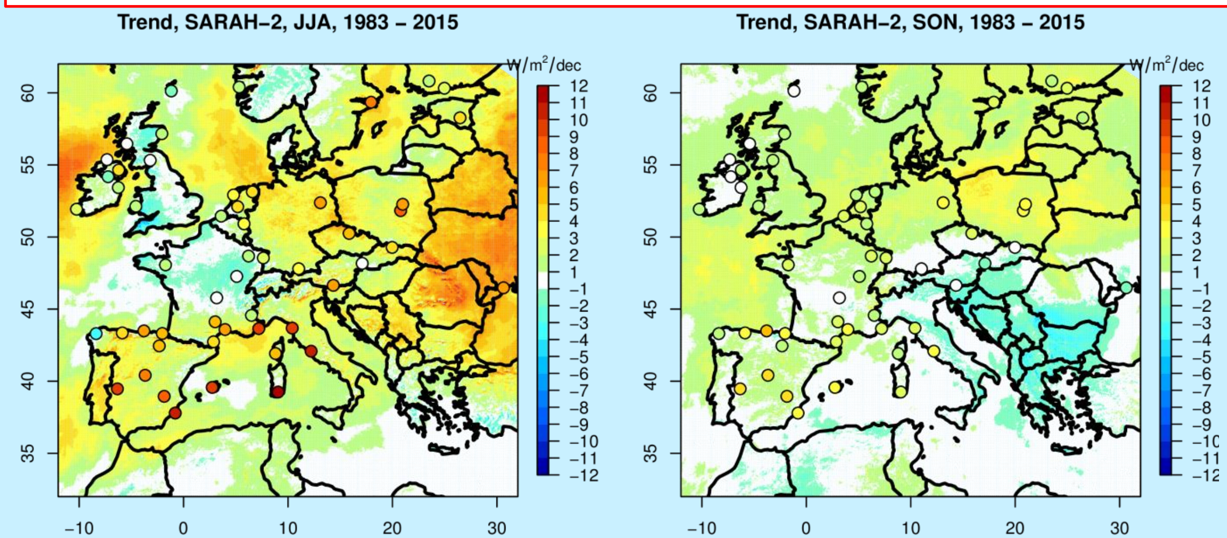
Trend and variability analysis



Strongest trend in spring

Why ?

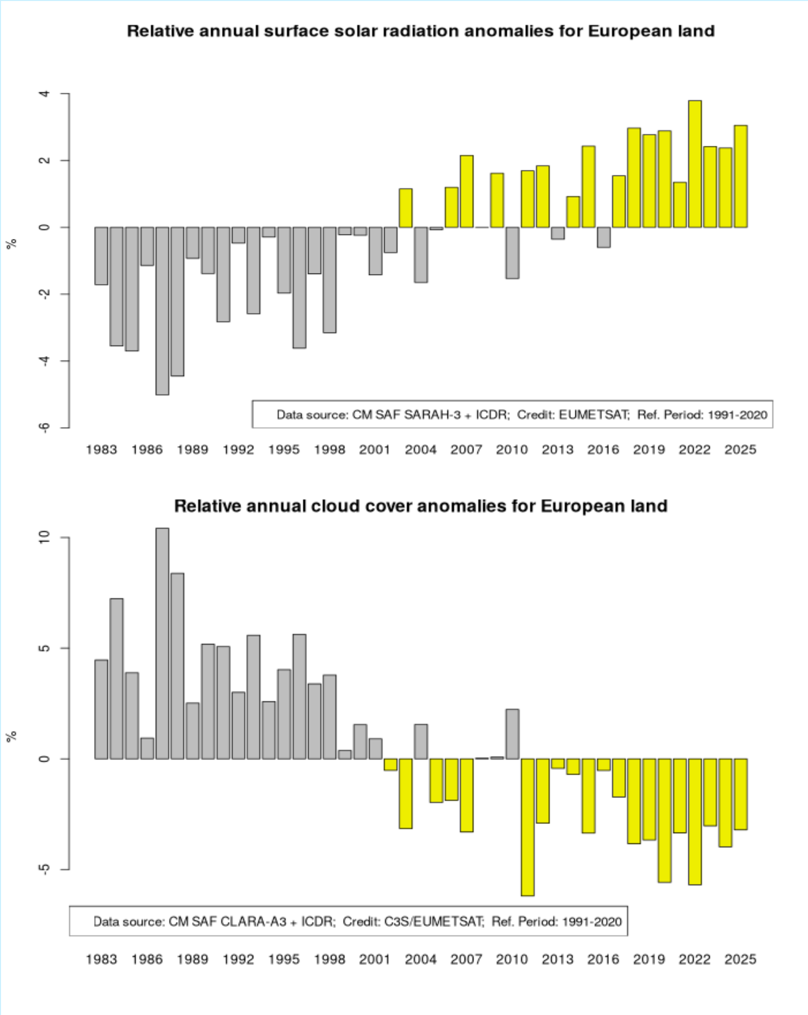
Indications that typical large-scale circulation patterns in spring are changing



See Pfeifroth et al., 2018, Journal of Geophysical Research

Trend and variability analysis

Analysis of surface solar radiation and cloud fractional cover in Europe



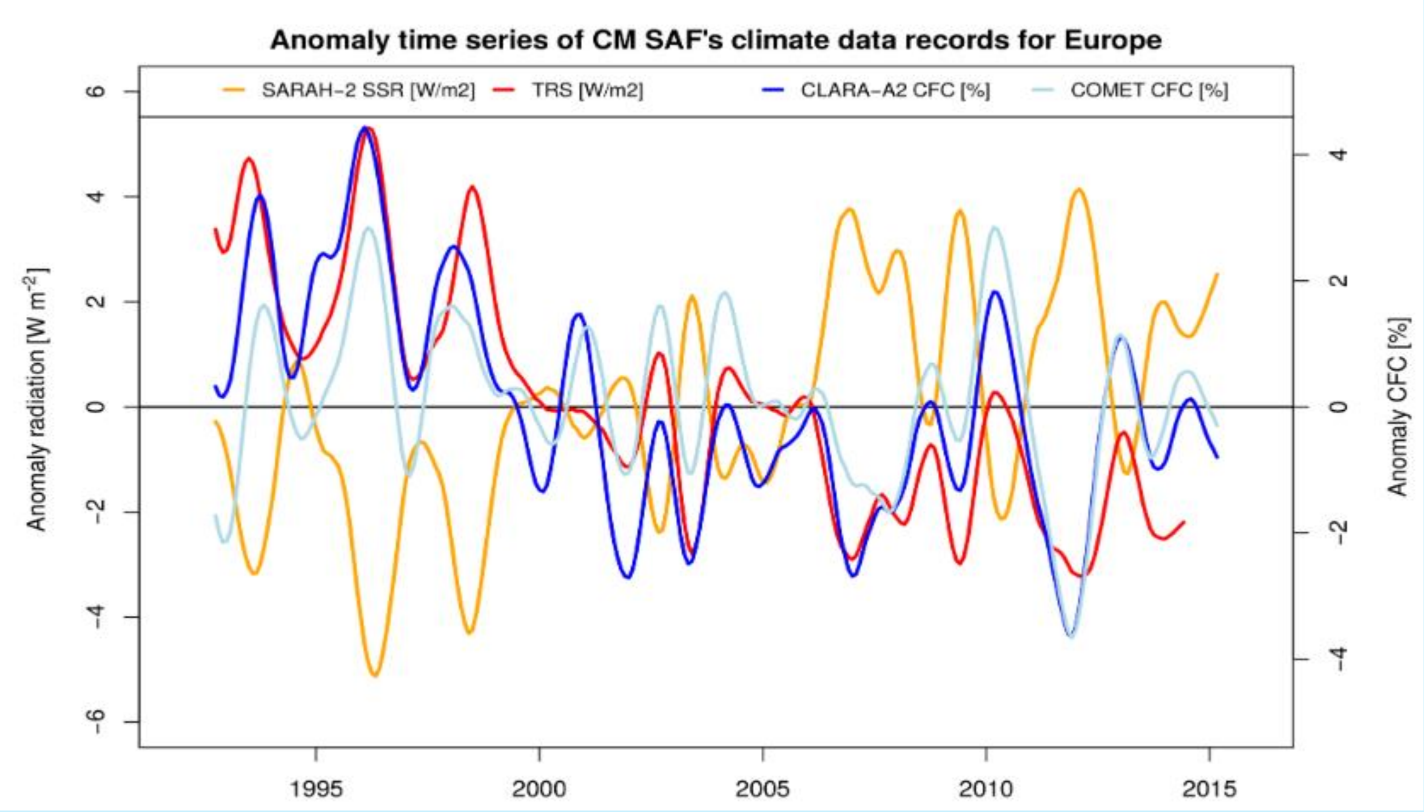
-> ***Positive*** *trend in surface solar radiation*

-> ***Negative*** *trend in cloud cover*

Trend and variability analysis

Intercomparison of **global radiation, cloud cover and top-of-atmosphere reflected solar radiation**

-> consistency of anomalies and trends in different independent satellite-based data records



See Pfeifroth et al., 2018, Advances in Science and Research

Summary solar radiation

- ➔ Physical und statistical methods to derive surface solar radiation, by combining satellite observations and radiative transfer calculation
- ➔ Satellite observations enable the generation of (global) data records with high spatial and temporal resolution, and a length of more than 40 years
- ➔ Various application areas (e.g. solar energy, climate analysis)
- ➔ high quality enables global and regional climate analysis of satellite-based climate data records
- ➔ Trend analysis: positive trend in global radiation in Europe However homogeneity testing and validation with reference data (if available) important
- ➔ Many satellite-based data records freely available

Radiation in the solar und thermal range

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  - ➔ Applications
  - ➔ Climate analysis
- ➔ **Surface albedo**
- ➔ Longwave downward radiation at the surface
- ➔ Radiation budget at the top of atmosphere

Surface Albedo

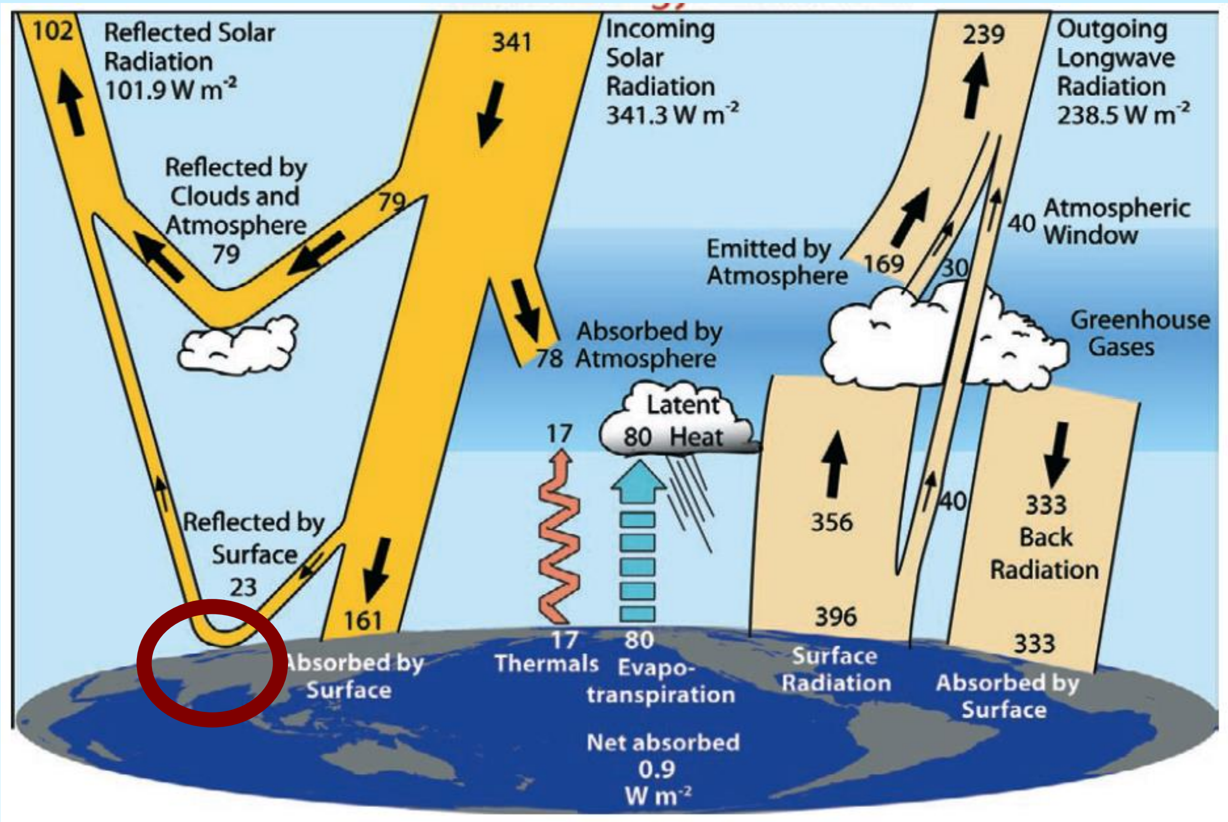


Figure from Trenberth et al. (2009)

Surface albedo

$$\alpha(\theta_s, \phi_s) = \int_0^{2\pi} \int_0^{\pi/2} \rho(\theta_s, \phi_s; \theta_v, \phi_v) \cos(\theta_v) \sin(\theta_v) d\theta_v d\phi_v$$

α albedo

ρ reflectance

θ_s, ϕ_s incident angles

θ_v, ϕ_v viewing angles

(spectral dependencies disregarded here)

Surface albedo

$$\alpha(\theta_s,\phi_s) = \int_0^{2\pi}\int_0^{\pi/2} \rho(\theta_s,\phi_s;\theta_v,\phi_v)\cos(\theta_v)\sin(\theta_v)d\theta_v d\phi_v$$

Not corrected for atmospheric influences

→ α = “black-sky” albedo

α albedo

ρ reflectance

θ_s, ϕ_s incident angles

θ_v, ϕ_v viewing angles

(spectral dependencies disregarded here)

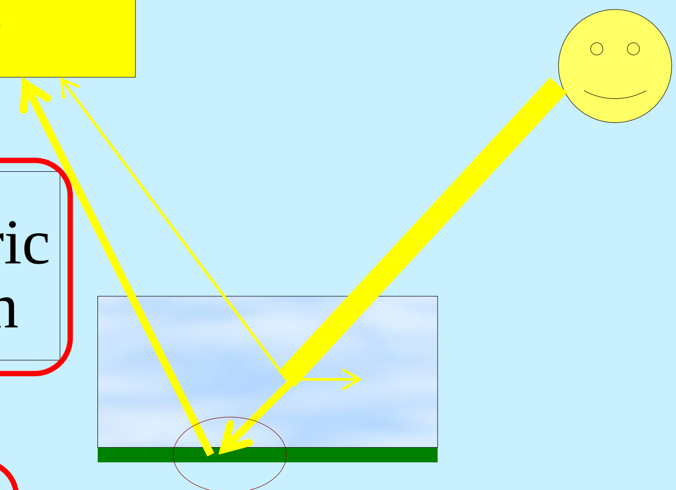
EUMETSAT CM SAF CLIMATE MONITORING

Retrieval principle surface albedo

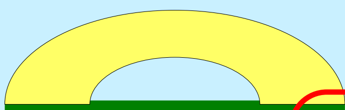
DWD

Cloud mask → Cloud free ?

Satellite Radiances

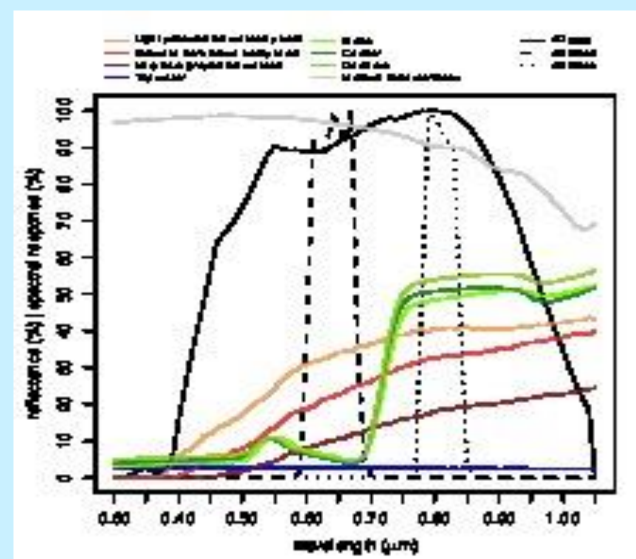


1st step — Correction of atmospheric reflection and absorption



2nd step — Correction of anisotropy (BRDF)

3rd step — Narrow to broadband conversion



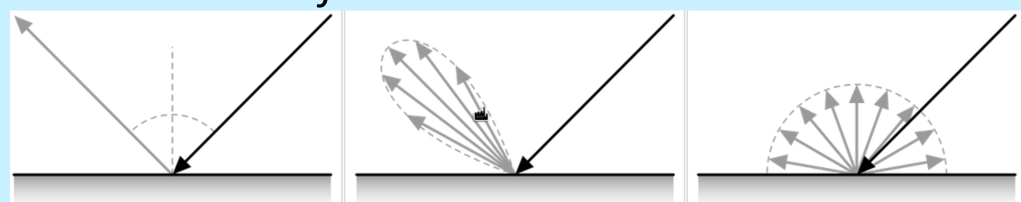
Retrieval principle surface albedo

Correction of atmospheric reflection and absorption

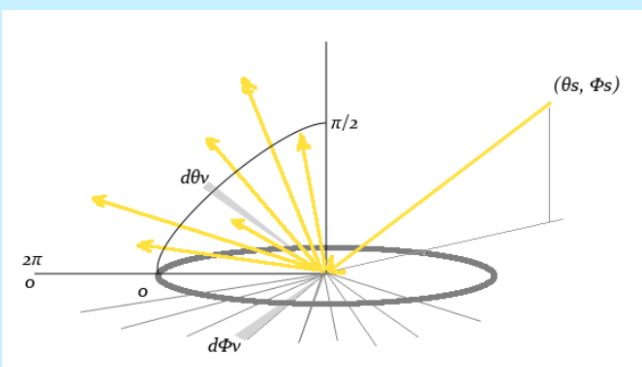
→ mainly with help of water vapor, aerosol optical depth and ozone

Correction of anisotropy (BRDF)

BRDF= Bidirectional Reflectance Distribution Function



Source: wikipedia.org

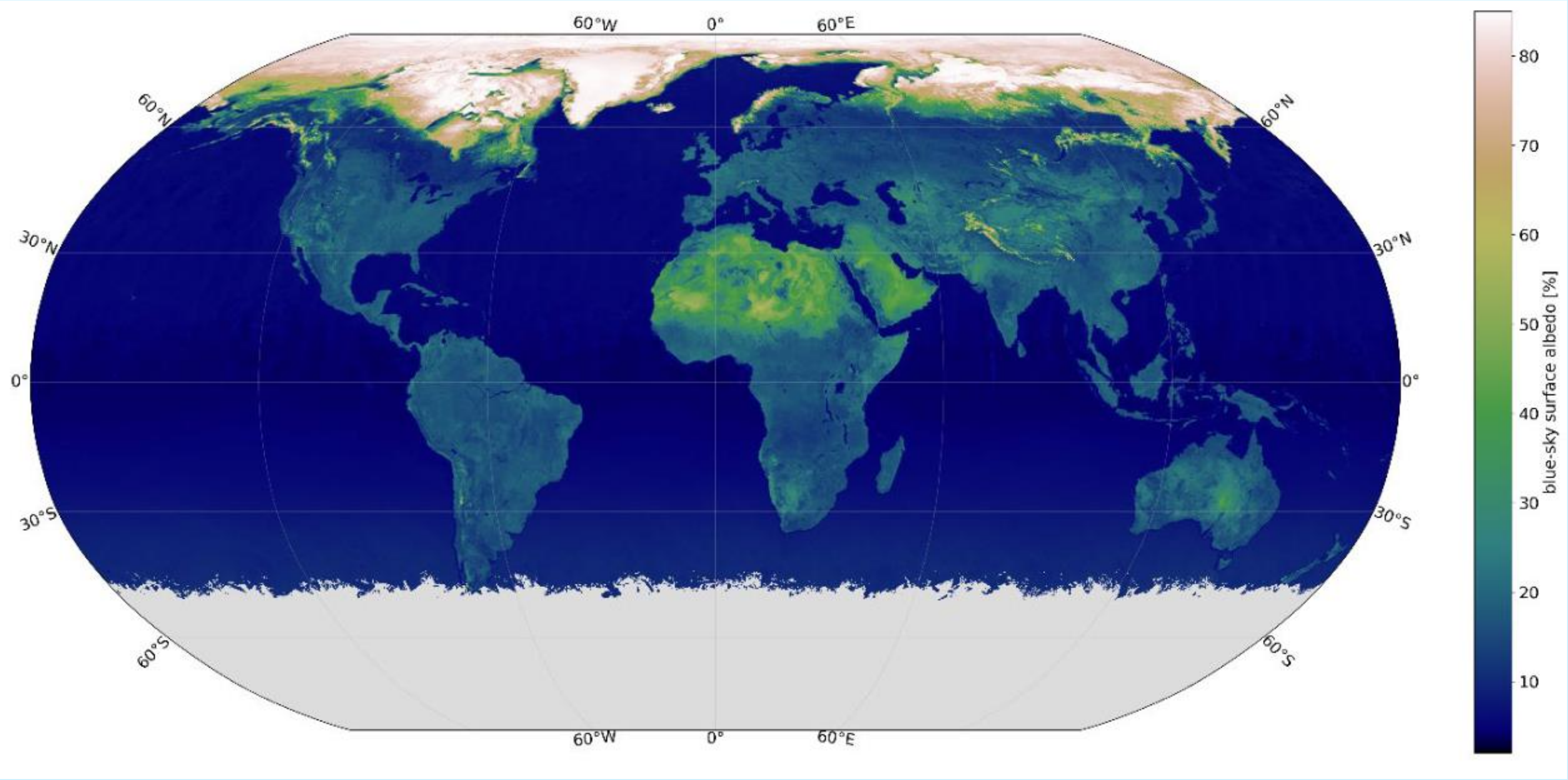


Source: www.cmsaf.eu, CLARA-A2 SAL ATBD

→ depends on surface type (land-use) and on ocean roughness (wind)

Example surface albedo

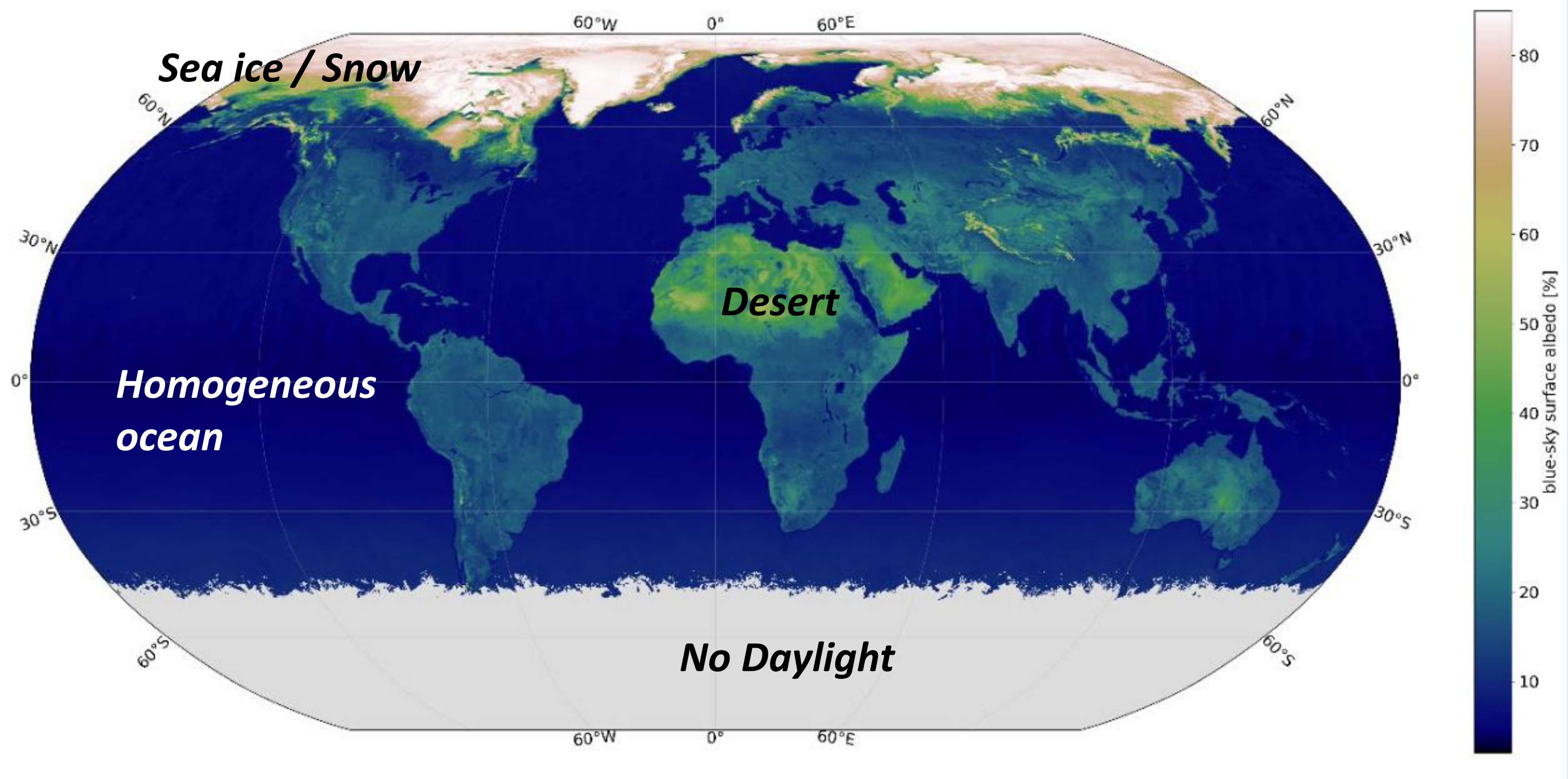
May 2009



Source: www.cmsaf.eu, CLARA-A3 Blue Sky Albedo

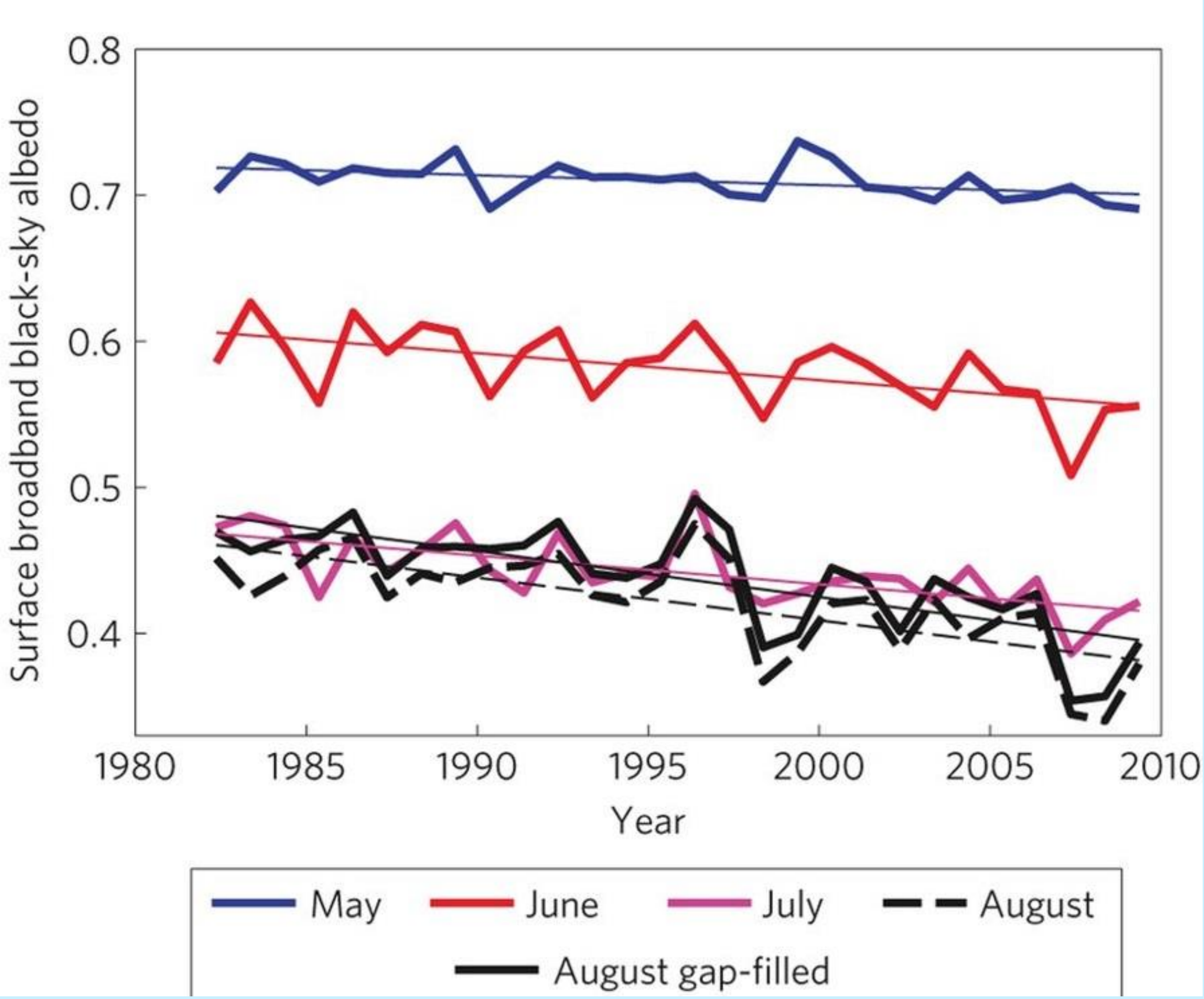
Example surface albedo

May 2009



Source: www.cmsaf.eu, CLARA-A3 Blue Sky Albedo

Example Arctic Sea Ice



Source: Riihelä et al., 2013

Radiation in the solar und thermal range

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- Radiation budget at the top of atmosphere

Longwave radiation

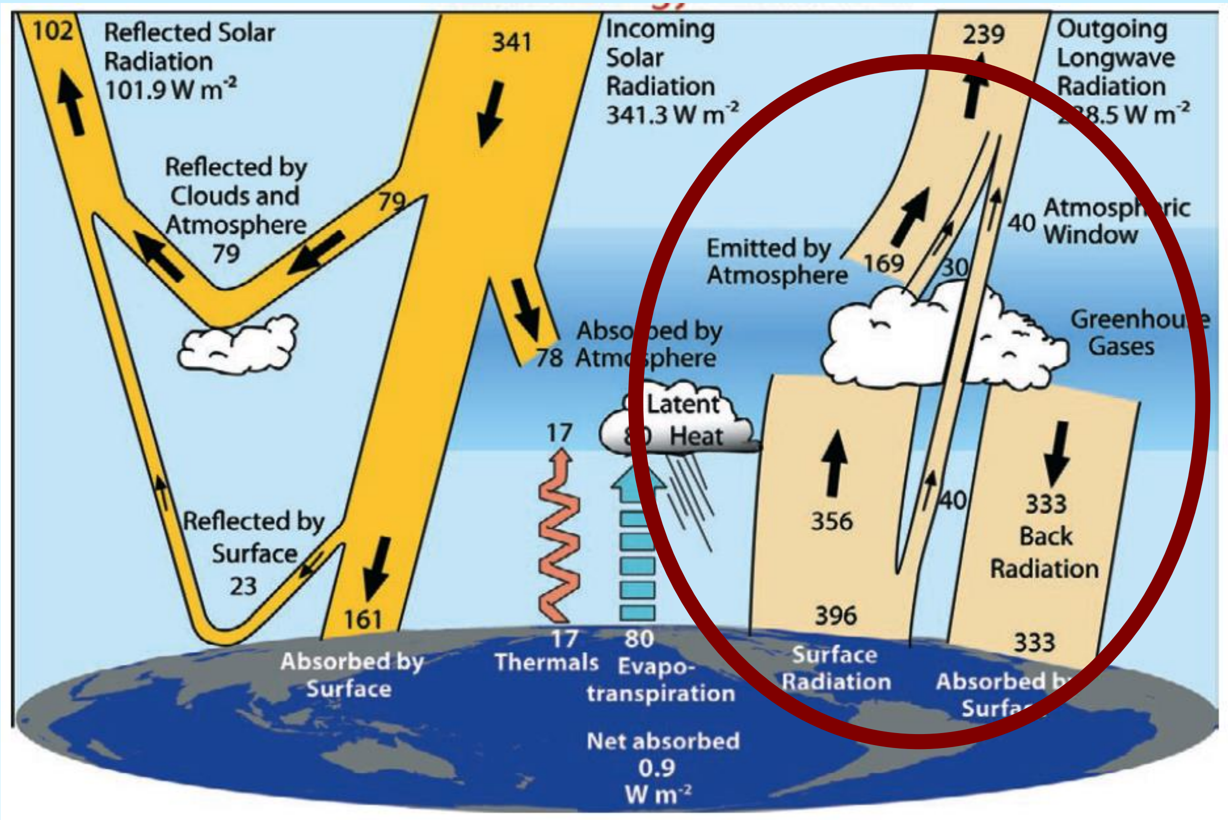

Figure from Trenberth et al. (2009)

Thermal Surface Radiation is not directly linked with the satellite observations.

Satellite retrievals have lower accuracies in the longwave surface radiation !

Longwave radiation

- Surface thermal fluxes are mainly **controlled by temperatures** of the surface and of the lower atmosphere

- LW-downward radiation is dependent on tropospheric temperatures and cloud properties (e.g. cloud thickness), as clouds absorb and re-emit thermal radiation
  → Problem: Cloud thickness can only roughly be estimated from meteorological satellites

Example of LW radiation retrieval from Gupta et al. 1992

$$LW_{down} = LW_{clear} + F2 + AC$$

F2=„cloud forcing factor“
AC=fractional cloud cover

$$LW_{net} = LW_{down} - \sigma T^4$$

T=Surface temperature

LW_{clear} is calculated based on water vapor and on the emitting temperature of the lower troposphere

$$F2 = \frac{T_{cbase}^4}{b_0 + b_1 + WV_c + b_2 + WV_c^2 + b_3 + WV_c^3}$$

„b“s are regression coefficients
WV_c is the water vapor below cloud base
(in Gupta 1992, cloud base is given by a „climatology“)

Longwave radiation

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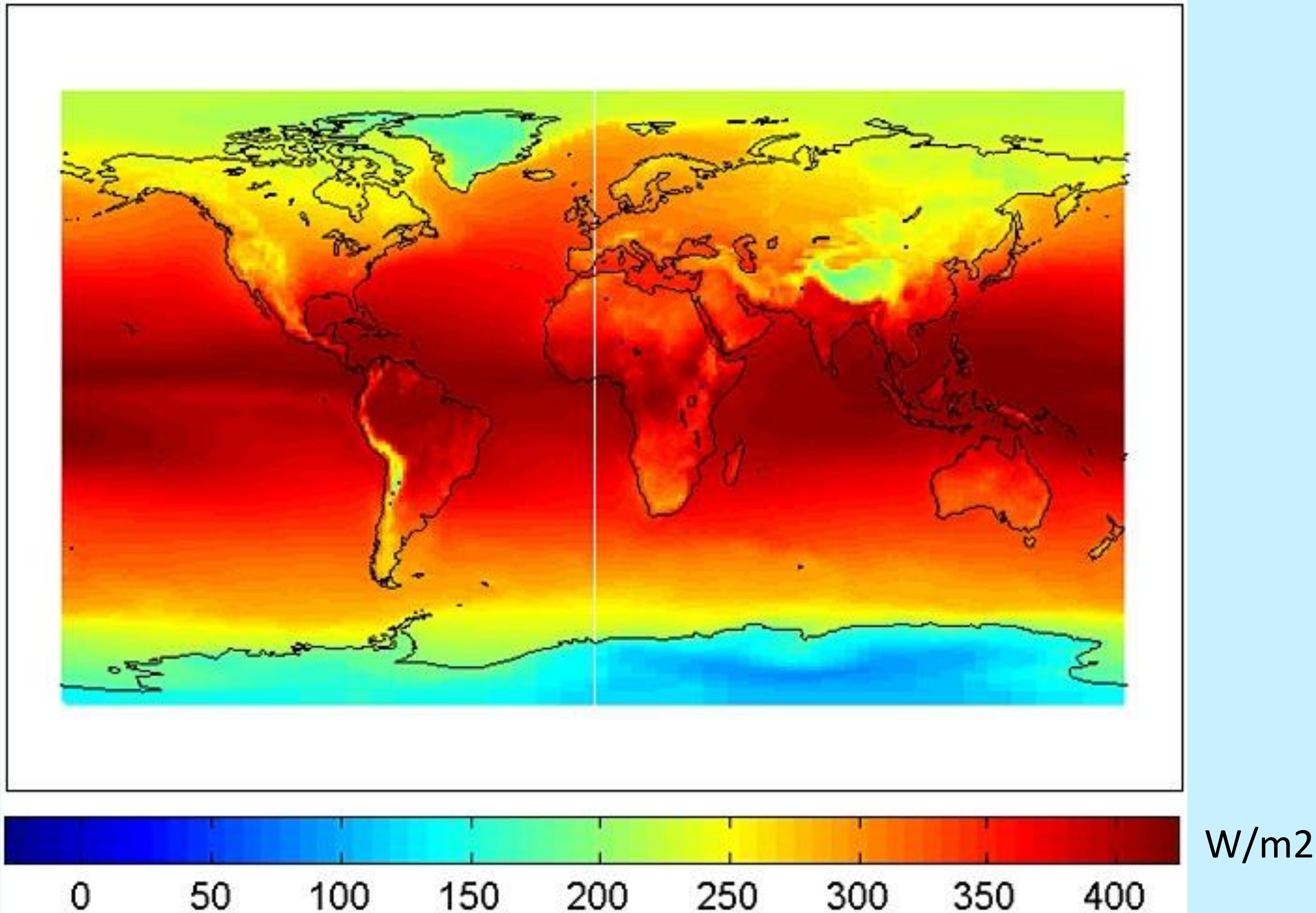
„b“s are regression coefficients
WV_c is the water vapor below cloud base
(in Gupta 1992, cloud base is given by a „climatology“)

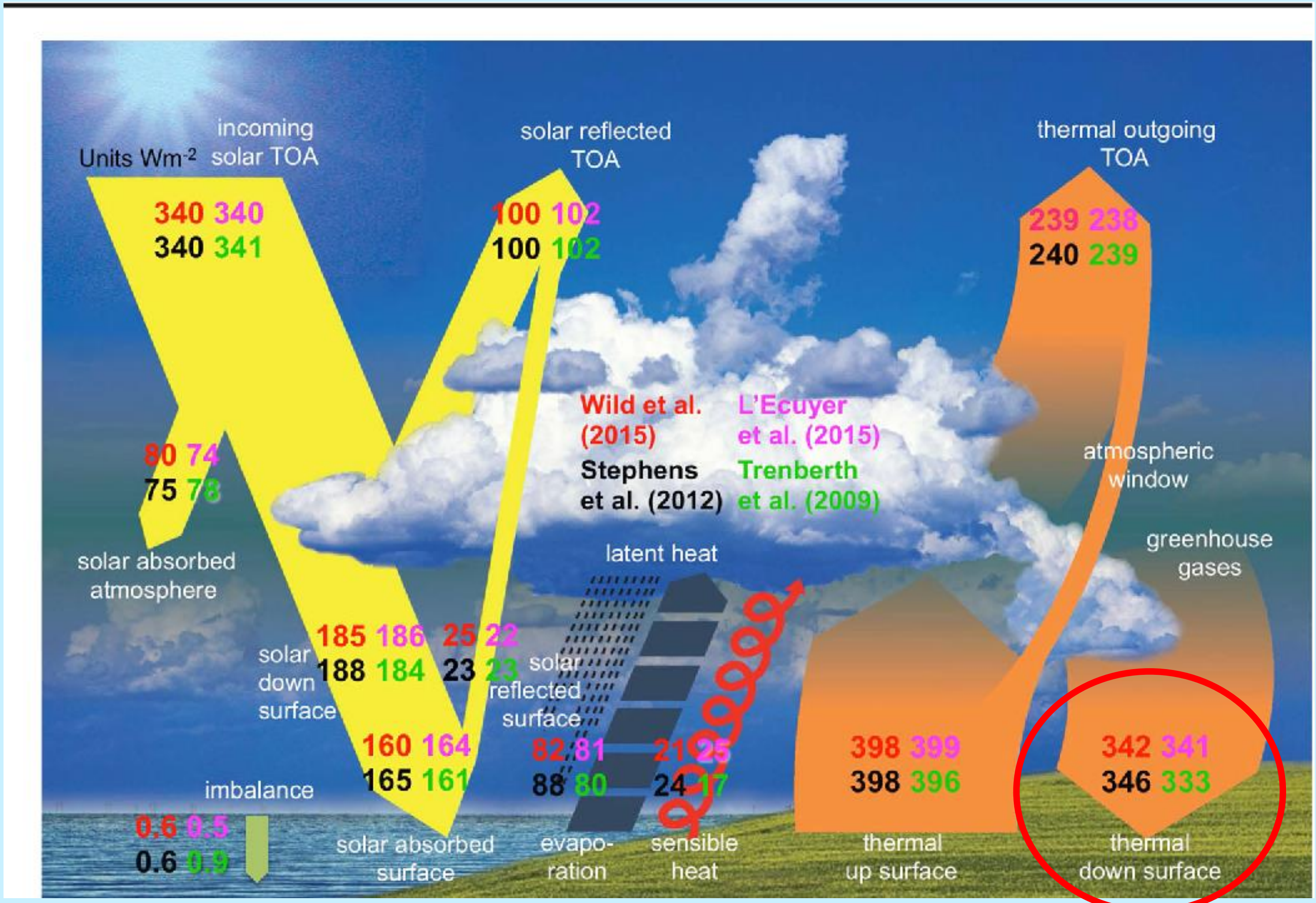
→ Parametrizations, assumptions and external data necessary

Example: Longwave downward radiation



Source: Wang, K., and R. E. Dickinson (2013)

Example: Longwave backward radiation



Source: Wild et al, 2017

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Top-of-atmosphere budget

Top-of-atmosphere radiation can only be observed with help of **satellite data**

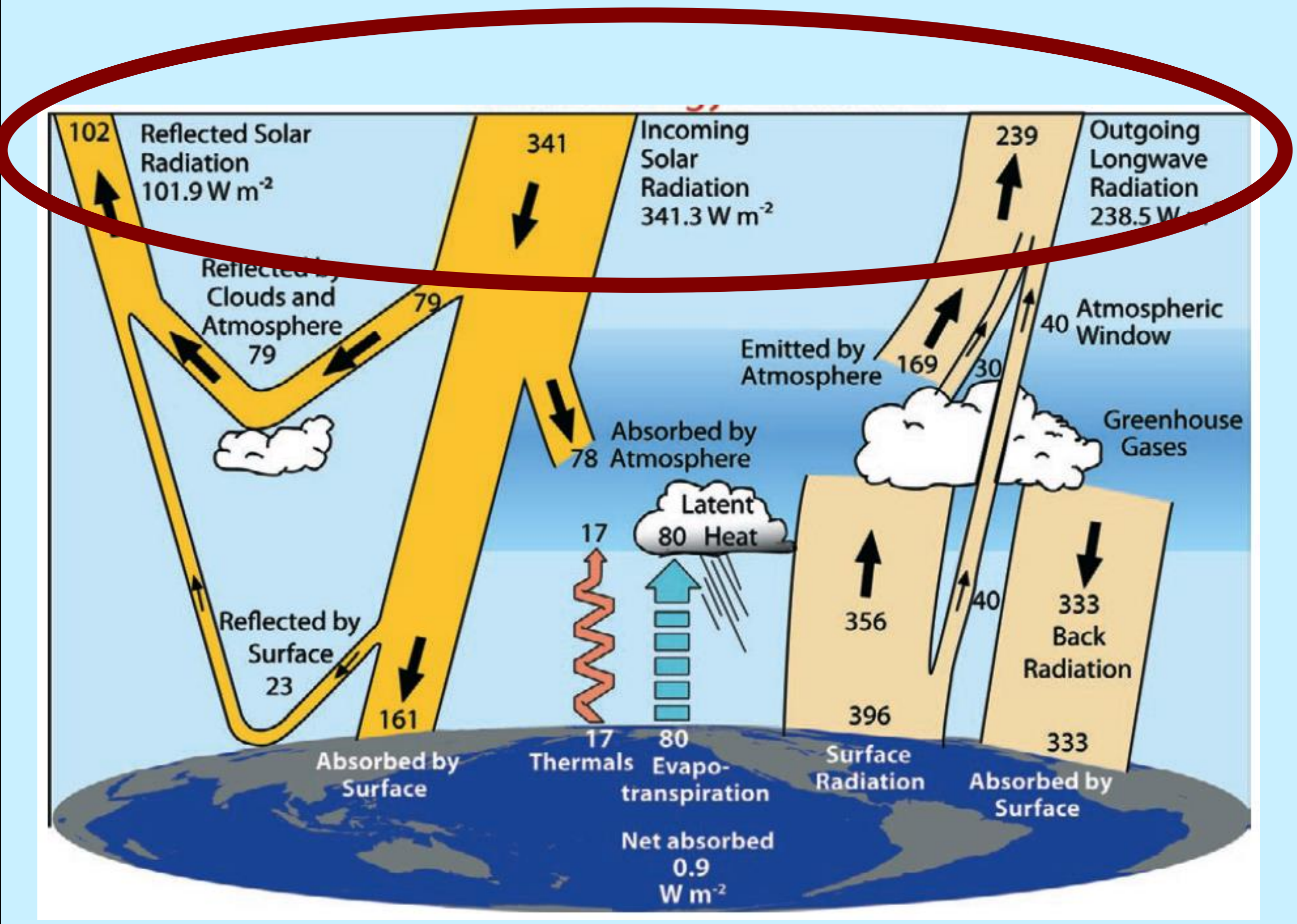
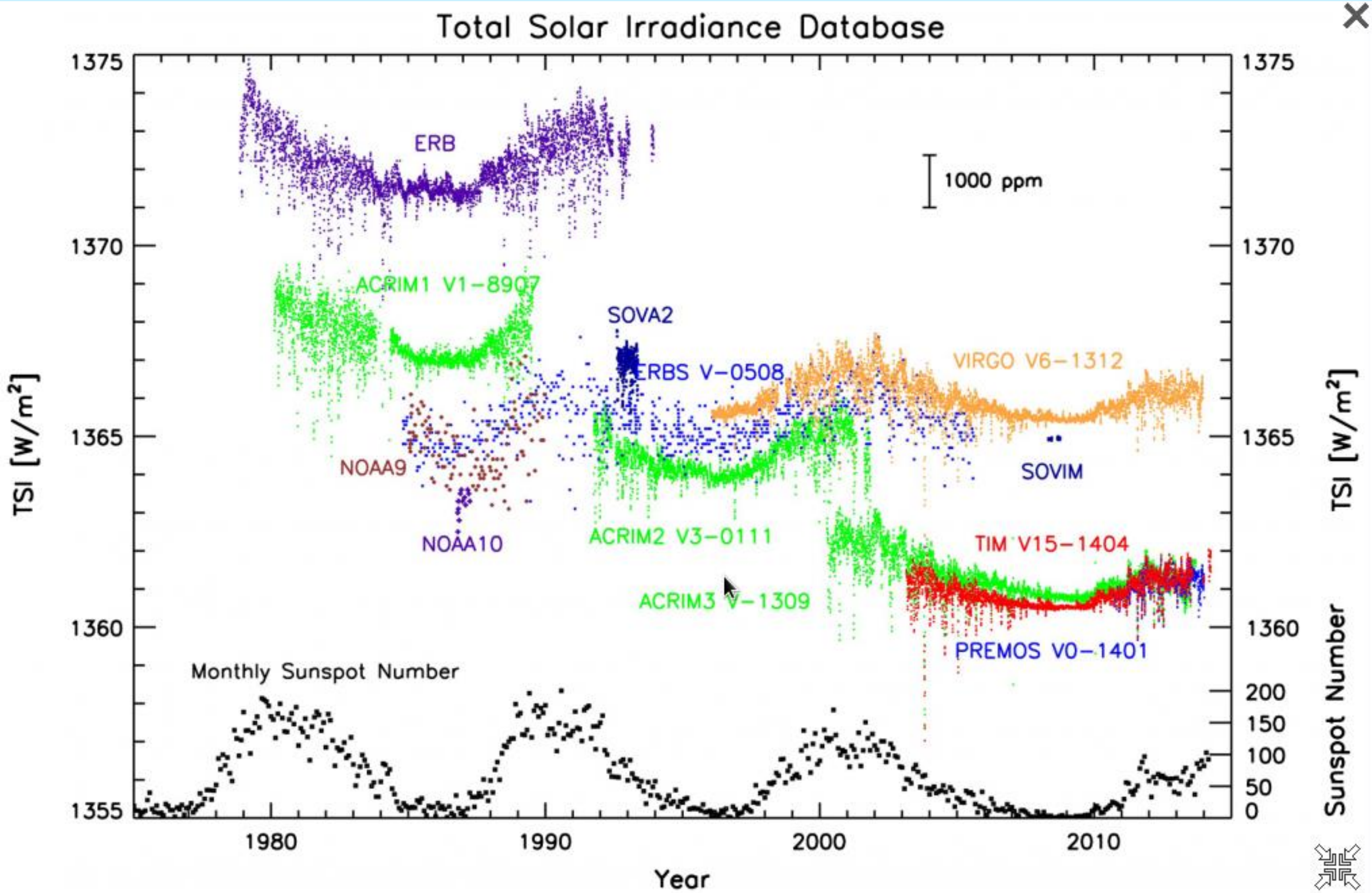


Figure from Trenberth et al. (2009)

Measuring of the „Solar constant“

Measuring of the „Solar constant“



Summary timeseries of satellite-era TSI datasets. From Kopp (2014): http://dx.doi.org/10.1051/swsc/2014012

TOA flux comonents

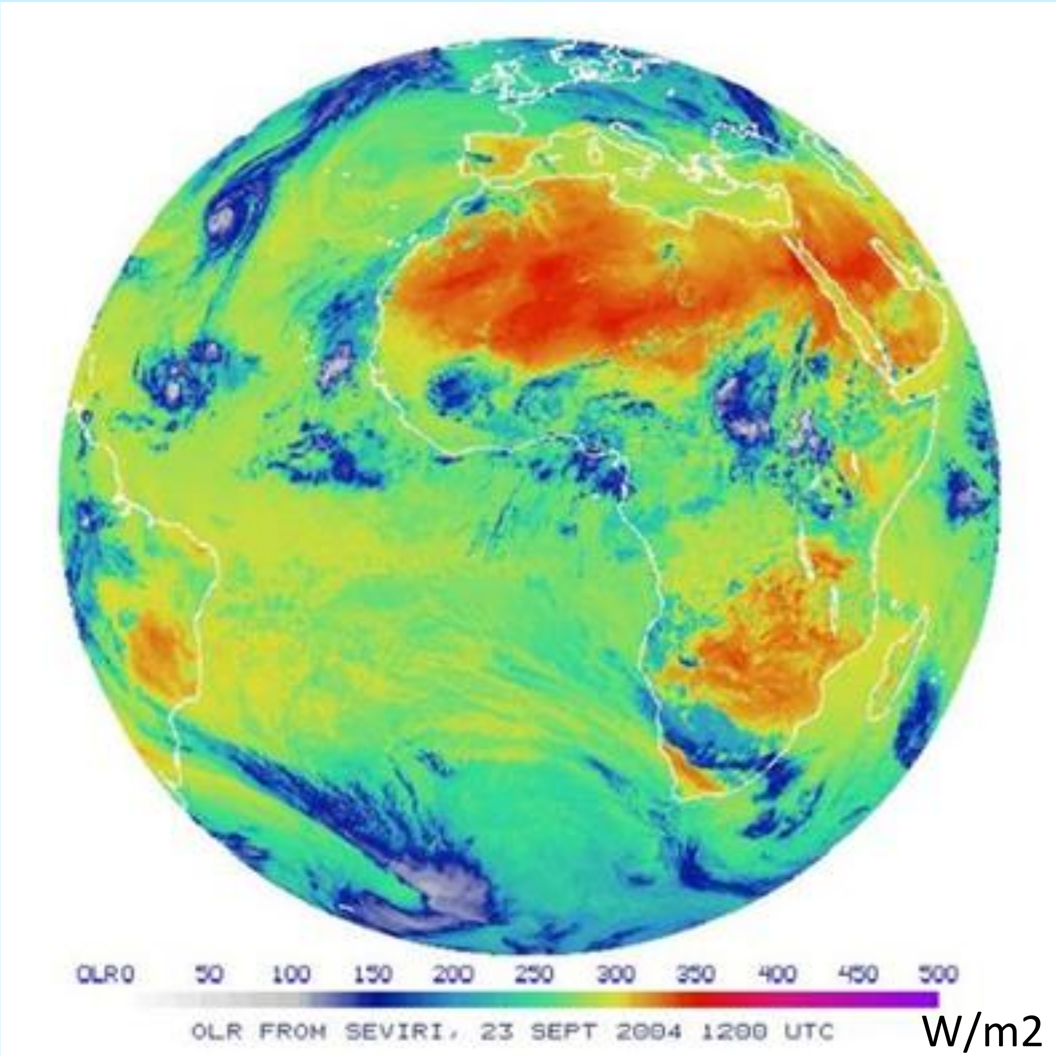
Overview of TOA flux components based on different datasets

TABLE 1. Global mean clear- and all-sky SW, LW, and net TOA radiative fluxes, solar irradiance, and CRE for satellite-based data products (units in W m^{-2}).

		CERES				
Product name	ERBE S-4	ES-4 Ed2_rev1	SRBAVG-nonGEO Ed2D_rev1	SRBAVG-GEO Ed2D_rev1	GEWEX SRB Version 2.86	ISCCP FD
Time period	02/85 – 01/89			03/00 – 02/2005		
Solar irradiance	341.3	341.3	341.3	341.3	341.8	341.5
LW (All sky)	235.2	239.0	237.7	237.1	240.4	235.8
SW (All Sky)	101.2	98.3	96.6	97.7	101.7	105.2
Net (All Sky)	4.9	4.0	7.0	6.5	−0.3	0.5
LW (Clear Sky)	264.9	266.6	266.4	264.1	268.1	262.3
SW (Clear Sky)	53.6	49.3	51.2	51.1	54.5	54.2
Net (Clear Sky)	22.8	25.4	23.7	26.2	19.2	25.0
LW CRE	29.7	27.6	28.7	27.0	27.7	26.5
SW CRE	−47.6	−49.0	−45.4	−46.6	−47.2	−51.0
NET CRE	−17.9	−21.4	−16.7	−19.7	−19.5	−24.5

Source: Loeb et al., 2009

TOA Outgoing Longwave



Example:
2004-09-23, 12 UTC

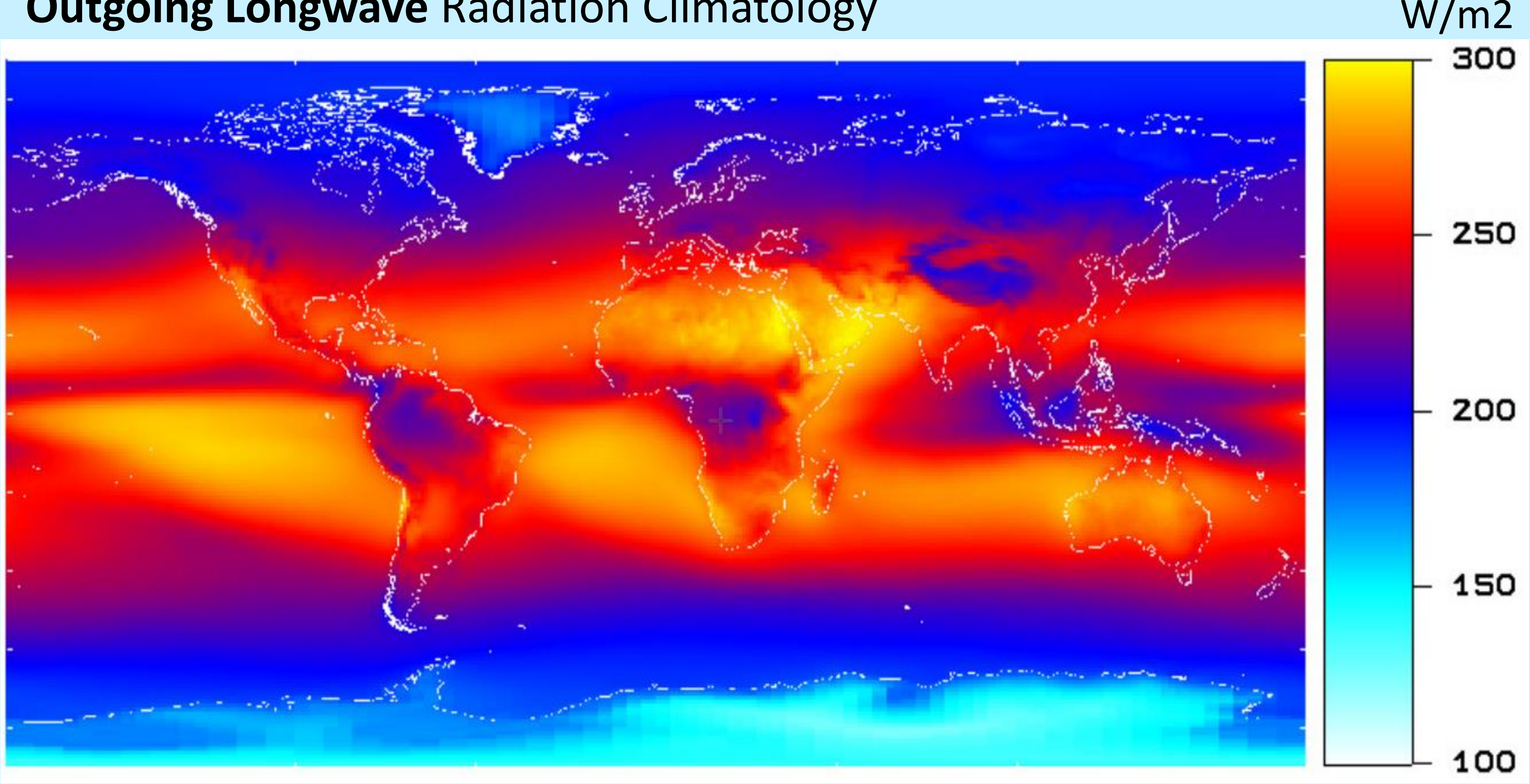
“Planck”:
E = sigma * T**4

Hot desert leads to large values of longwave radiation.

Cold (high) clouds e.g. as apparent in the ITCZ lead to very low outgoing longwave radiation.

TOA Outgoing Longwave

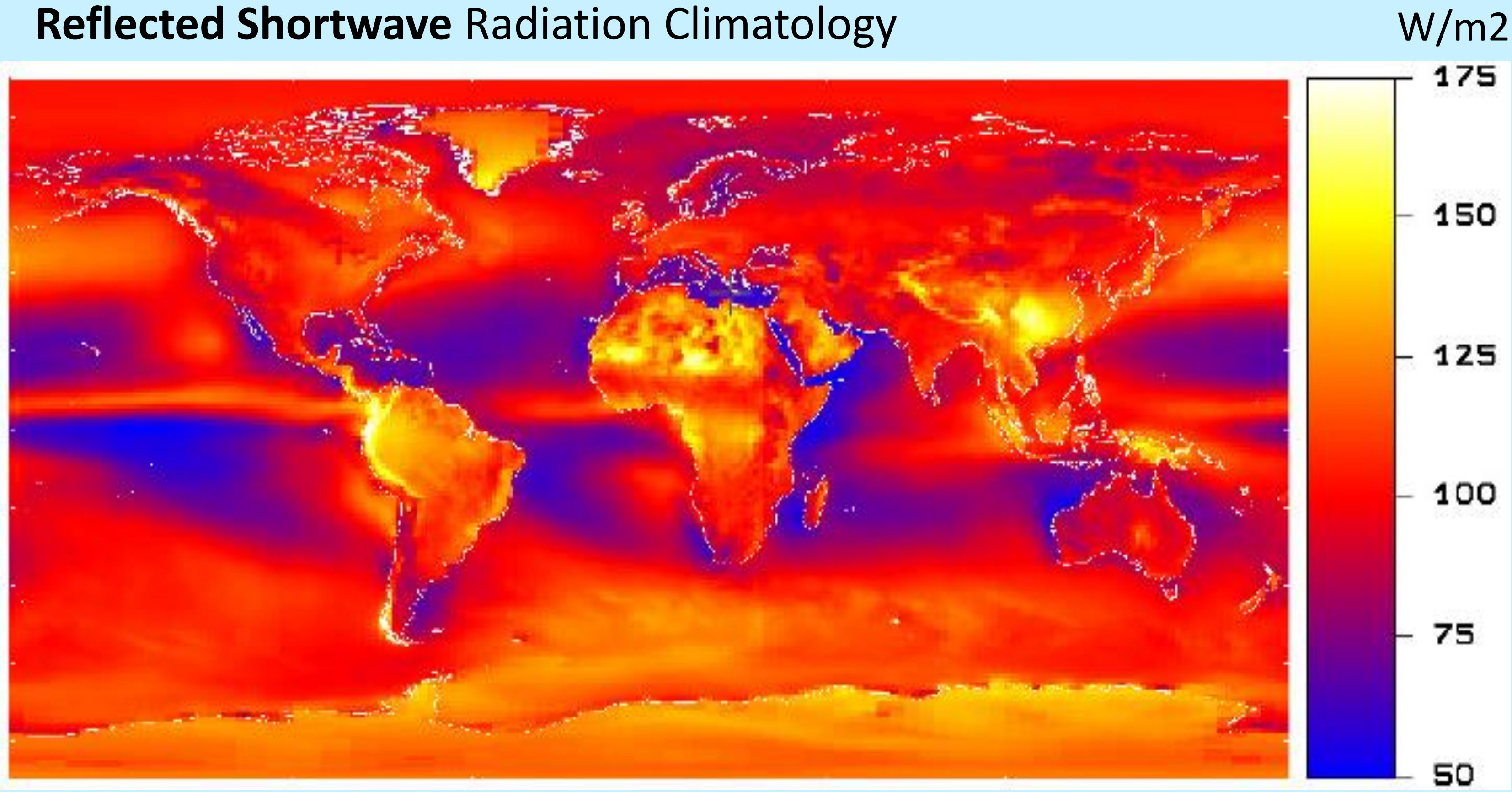
Outgoing Longwave Radiation Climatology



Source: Dewitte and Clerbaux, Remote Sensing, 2017, based on CERES EBAF data

TOA Reflected Shortwave

Reflected Shortwave Radiation Climatology

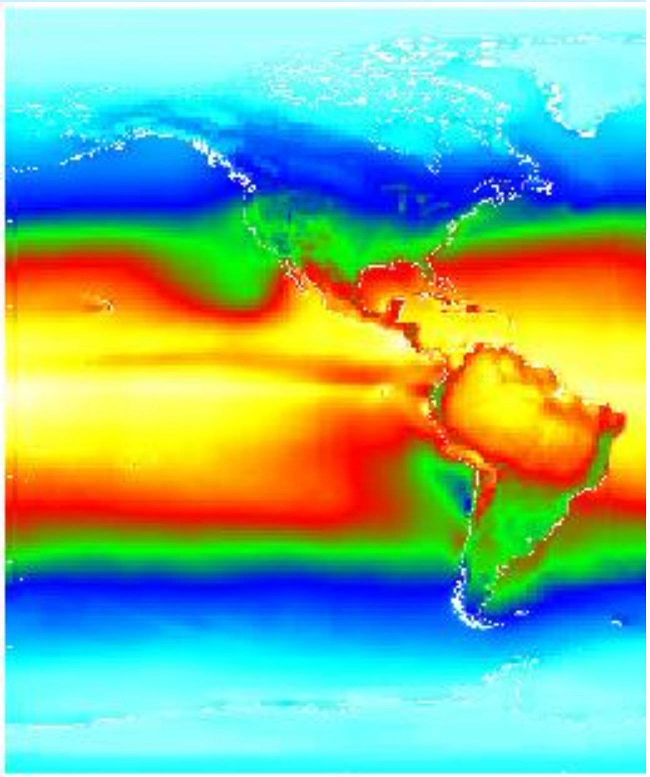


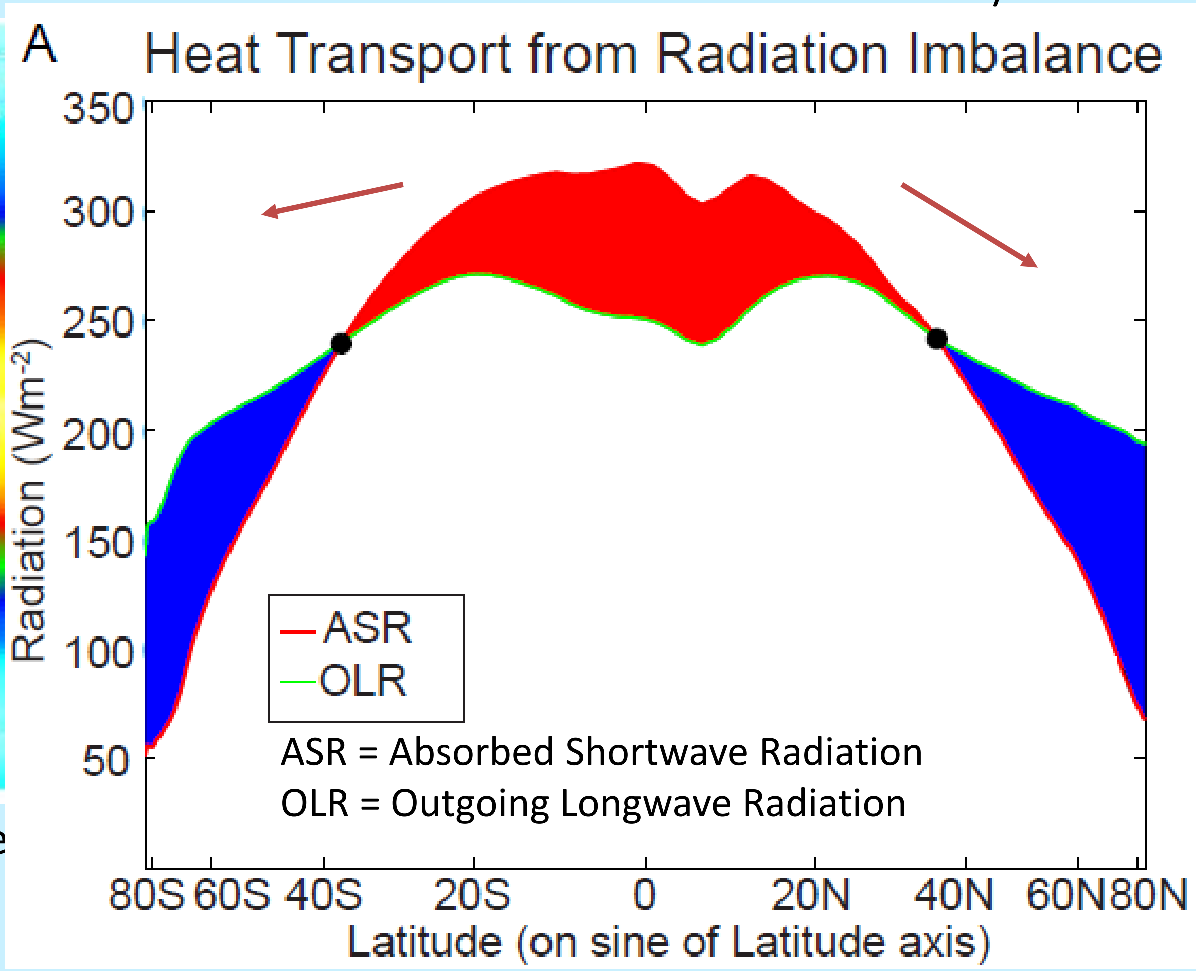
Source: Dewitte and Clerbaux, Remote Sensing, 2017, based on CERES EBAF data

TOA net flux

TOA Net Radiative Flux Climatology

W/m2





Quelle: Dewitte and Clerbaux, Re

Radiation in the solar und thermal range

Outline

- Motivation: satellite data as valuable data source
- Surface Solar Radiation (SSR)
  - Methods to derive SSR
  - Validation and comparisons
  - Applications
  - Climate analysis
- Surface albedo
- Longwave downward radiation at the surface
- Radiation budget at the top of atmosphere

Proposal for **Seminar Work** on **Radiation**

Comparison of CM SAF Climate Data Records (SARAH-3, CLARA-A3, HANNA) and gridded datasets based on stations and reanalysis (ERA-5, E-OBS) with surface reference observations (e.g. GEBA)

This seminar work investigates how the CM SAF satellite-based solar radiation datasets perform against other established gridded products. Comparisons are conducted on a monthly basis and, where applicable, on a daily temporal resolution.
The validation of the gridded products with surface reference observations (e.g. from GEBA) can provide an objective measure of data quality.

Processing steps

- Data collecting and describing (data sources, properties)
- Data preparations (monthly/daily averages/anomalies; common grid/domain/time period; data extraction at station locations; …)
- Data comparisons, calculation of quality measures (bias, differences, correlations, trends …)
- Data visualisations (condense information to maps/graphics/tables, …)
- Description and interpretation of results
- Summarize processing steps and results in the seminar report

Recommended tools

R, python, cdo,

Links:

- EOBS https://doi.org/10.24381/cds.151d3ec6
- ERA-5 https://doi.org/10.24381/cds.adbb2d47
- GEBA https://geba.ethz.ch/
- SARAH-3 https://doi.org/10.5676/EUM_SAF_CM/SARAH/V003
- CLARA-A3 https://doi.org/10.5676/EUM_SAF_CM/CLARA_AVHRR/V003
- HANNA https://www.cmsaf.eu/EN/Products/Demonstrator_Data_Records/Hanna/Hanna_node.html