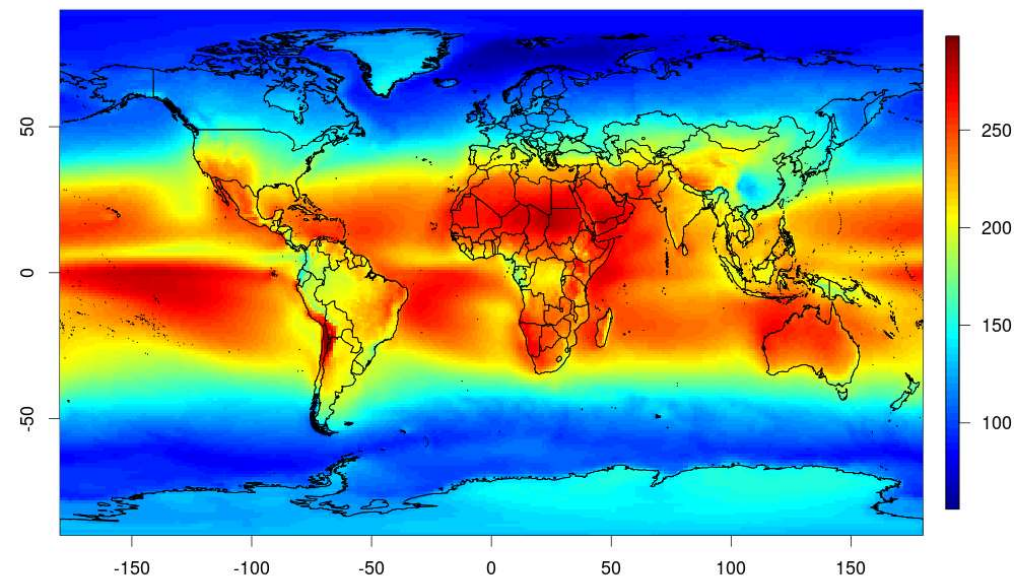# Global validation of satellite-based and reanalysis surface solar radiation data sets

Jörg Trentmann, Uwe Pfeifroth, Roswitha Cremer, Martin Stengel

Mean of climatologies [W/m2], 2000-2017

Motivation of this study

➔ Consistent evaluation of available global climate data records of surface irradiance

➔ Identify regions of consistency and of inconsistency between the different data records

➔ Focus on the absolute accuracy and decadal trends

Data: 3 reference data sets, 6 gridded data sets

➔ Reference Data

   ➔ BSRN, GEBA / WRDC, Buoy networks: TAO / TRITON, PIRATA, RAMA

➔ Satellite Data

   ➔ CERES EBAF ed 4.0 (1°x1°; 2000-2018)

   ➔ CM SAF CLARA-A2.1 (0.25°x0.25°; 1982-2017)

   ➔ ESA Cloud_cci AVHRR-PMv3 (0.5°x0.5°; 1982-2018)

   ➔ GEWEX SRB v3 (1°x1°; 1983-2007)

➔ Reanalysis Data

   ➔ ECMWF ERA-5 (0.25°x0.25°; 1983-2018)

   ➔ NASA MERRA-2 (0.5°x0.625°; 1980-2018)

Methods

➔ Evaluate monthly mean surface irradiance for a total of about 400 reference stations on land and ocean

➔ Estimate various statistical quantities, e.g., bias, abs. bias, anomaly correlation, trends, …

➔ Provide information for the full period (for each gridded data set) and for a common time period (2000 to 2017) to allow comparison between data sets

➔ Calculate the 'ensemble' climatology and trend including spread between the gridded data sets

Results: Global values

Data	Full time periods				Common period (2000-2017)				
	#	bias	MAB	rmse	cor	#	bias	MAB	rmse	cor
CERES	~69k	2.33	9.14	14.0	.85	~63k	2.30	**9.15**	**14.0**	.85
CLARA	~119k	1.76	10.85	15.2	.82	~63k	**2.15**	10.28	15.4	**.86**
ESA CCI	~119k	5.46	11.66	16.5	.79	~63k	4.76	10.93	15.8	.82
GEWEX	~75k	3.81	13.13	18.4	.75					
ERA-5	~117k	7.29	12.55	16.1	.79	~63k	6.38	11.89	15.7	.81
MERRA-2	~123k	19.6	23.61	22.8	.70	~63k	17.3	22.02	22.2	.72

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

➔ Satellite data compare better to reference data than reanalysis data records

➔ CERES and CLARA-A2.1 data records have comparable quality

➔ Quality of MERRA-2 data set significantly reduced compared to other data sets

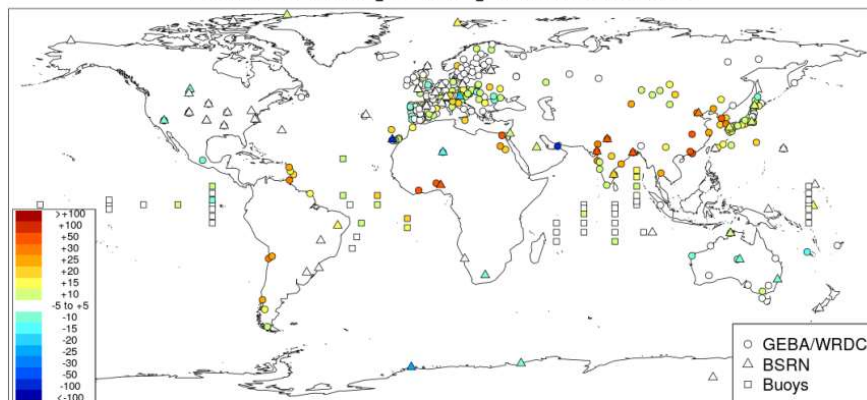# Regional Results: bias, common period, satellite data sets

CERES_EBAF_Ed4 bias [W*m-2] vs. all stations
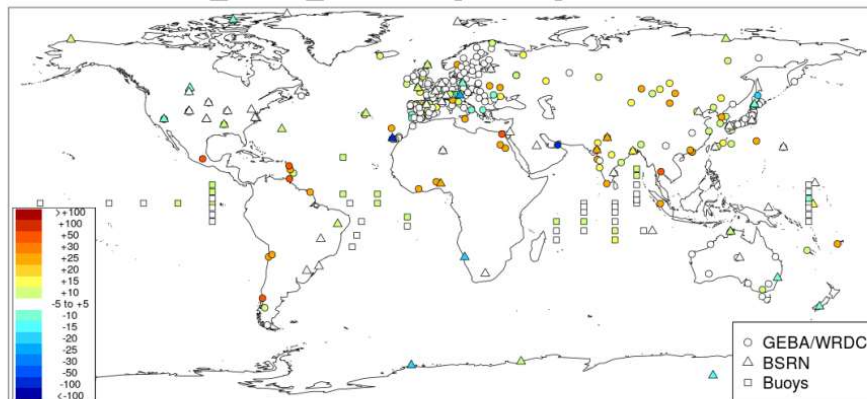
CLARA-A2 bias [W*m-2] vs. all stations
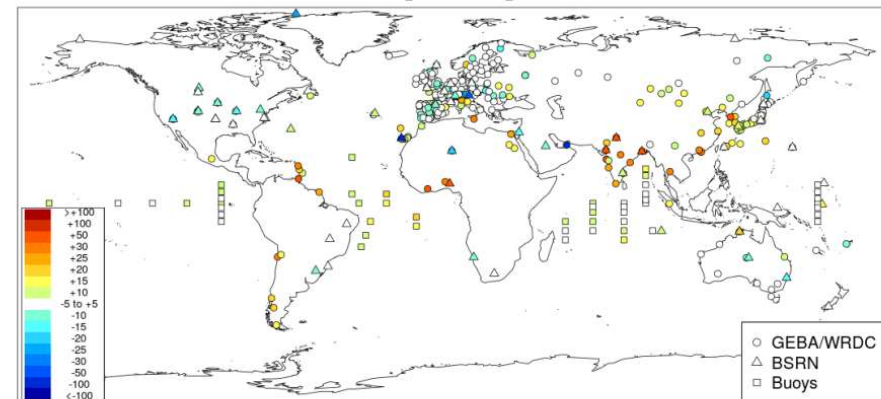
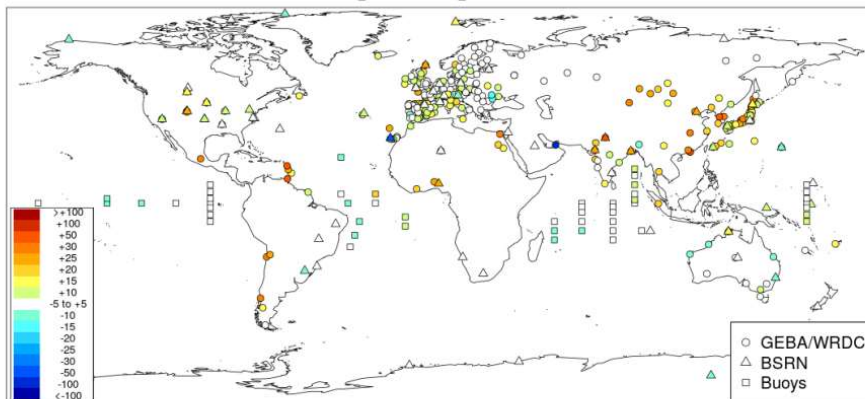ESACCI bias [W*m-2] vs. all stations

➔ Comparable spatial distribution*

➔ Low bias in Europe, North America*
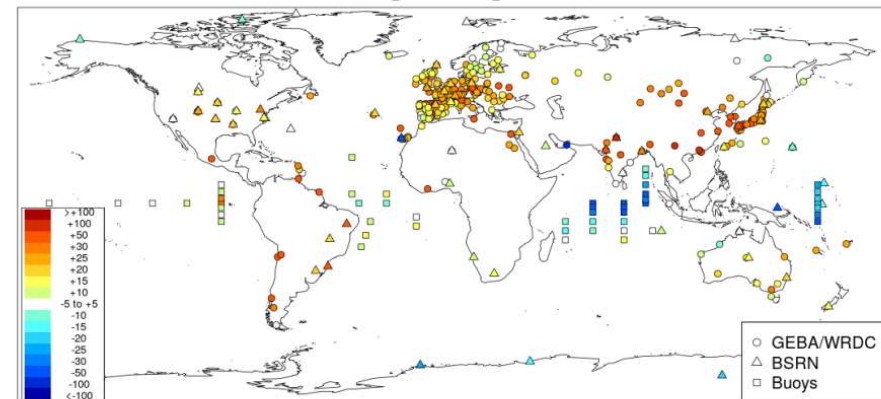
➔ Overestimation of surface irradiance in China / India*

*Please zoom-in for the details

Regional Results: bias, common period, reanalysis data sets

ERA5 bias [W*m-2] vs. all stations

MERRA2 bias [W*m-2] vs. all stations

➔ ERA-5

   ➔ moderate bias in Europe, North America[*]

   ➔ overestimation of surface irradiance in China / India[*]

➔ MERRA

   ➔ Significant overestimation in Europe, North America, China India, Japan[*]

   ➔ Underestimation in the Indian and Western Pacfic Oceans[*]

[*]Please zoom-in for the details

EUMETSAT
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CLIMATE MONITORING

Deutscher Wetterdienst
Wetter und Klima aus einer Hand
DWD

Surface Radiation Ensemble Climatology I

➜ Estimate the surface radiation ensemble climatology (2000 to 2017) as the average of the mean surface irradiance from the three satellite data records and ERA-5 (i.e., neglecting MERRA due to degraded accuracy)
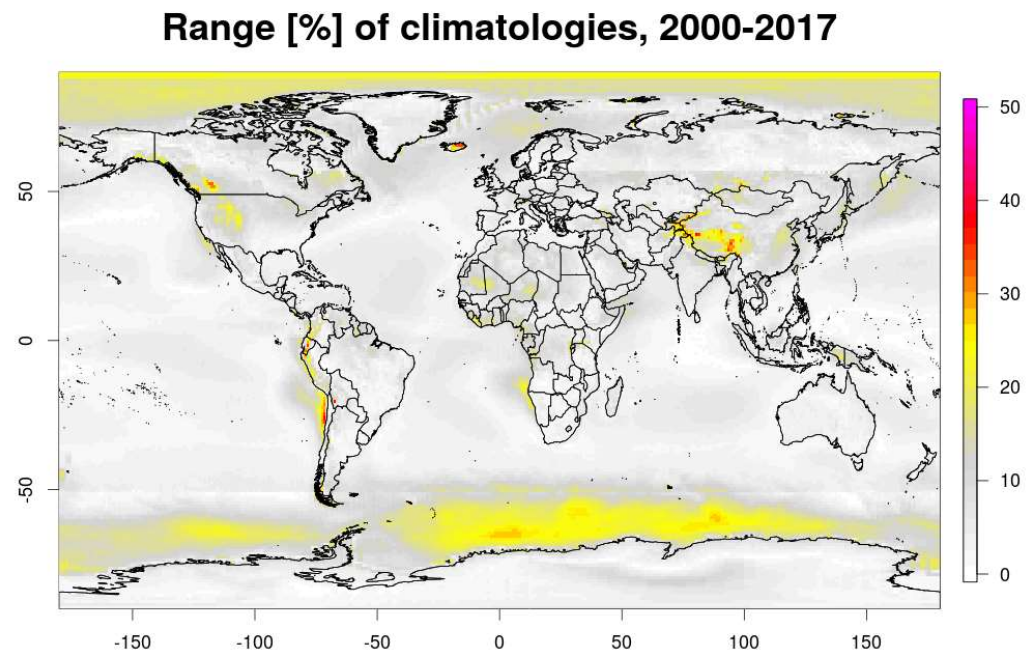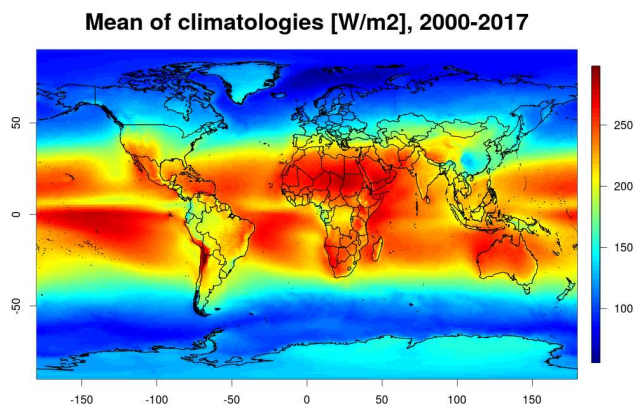
Mean of climatologies [W/m2], 2000-2017
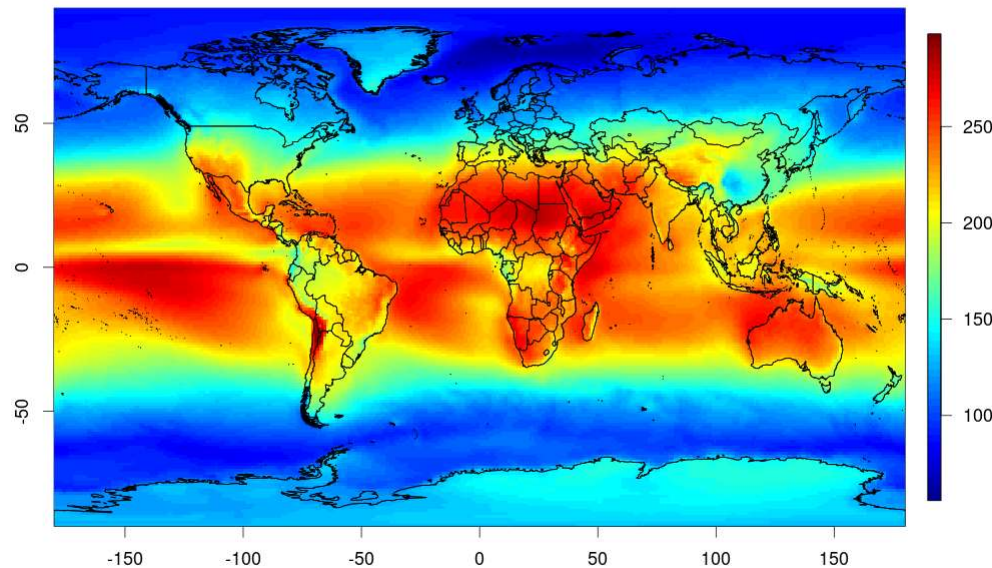
➜ Spatially averaged surface irradiance:

188 W/m^2

Surface Radiation Ensemble Climatology II

➔ Regions with largest (relative) range between data set:

   ➔ Southern polar ocean

   ➔ Himalaya

   ➔ West Coast of South America

Range [%] of climatologies, 2000-2017

Mean of climatologies [W/m2], 2000-2017

Evaluation by reference dataset

Ref Data	CERES			CLARA			ESA_CCI			ERA-5			MERRA-2		
	bias	MAB	cor	bias	MAB	cor	bias	MAB	cor	bias	MAB	cor	bias	MAB	cor
BSRN	**-0.6**	**8.4**	**.90**	-1.8	9.8	.89	0.7	10.2	.84	2.7	10.1	.85	8.5	19	.76
GEBA/WRDC	2.6	**9.3**	.85	**2.3**	10.4	**.85**	5.3	11.1	.81	7.3	12.2	.81	20	23	.73
Buoys	2.9	**7.9**	.86	6.0	9.5	**.88**	4.3	9.6	.83	**-0.7**	10.8	.79	-6.3	19	.67

MAB= mean absolute bias [W/m^2]; bias in W/m^2; cor= anomaly correlation

➔ Comparable performance for all reference data sets

➔ No systematic uncertainty in any reference data set of monthly mean surface irradiance

➔ The correlation with BSRN data is highest for all gridded data sets

Validation: Stability / Trend

Times series of the mean bias [W/m2] vs. all stations

Legend: CERES_EBAF, CLARA-A2, ESA-CCI, GEWEX-SRB, ERA5, MERRA2
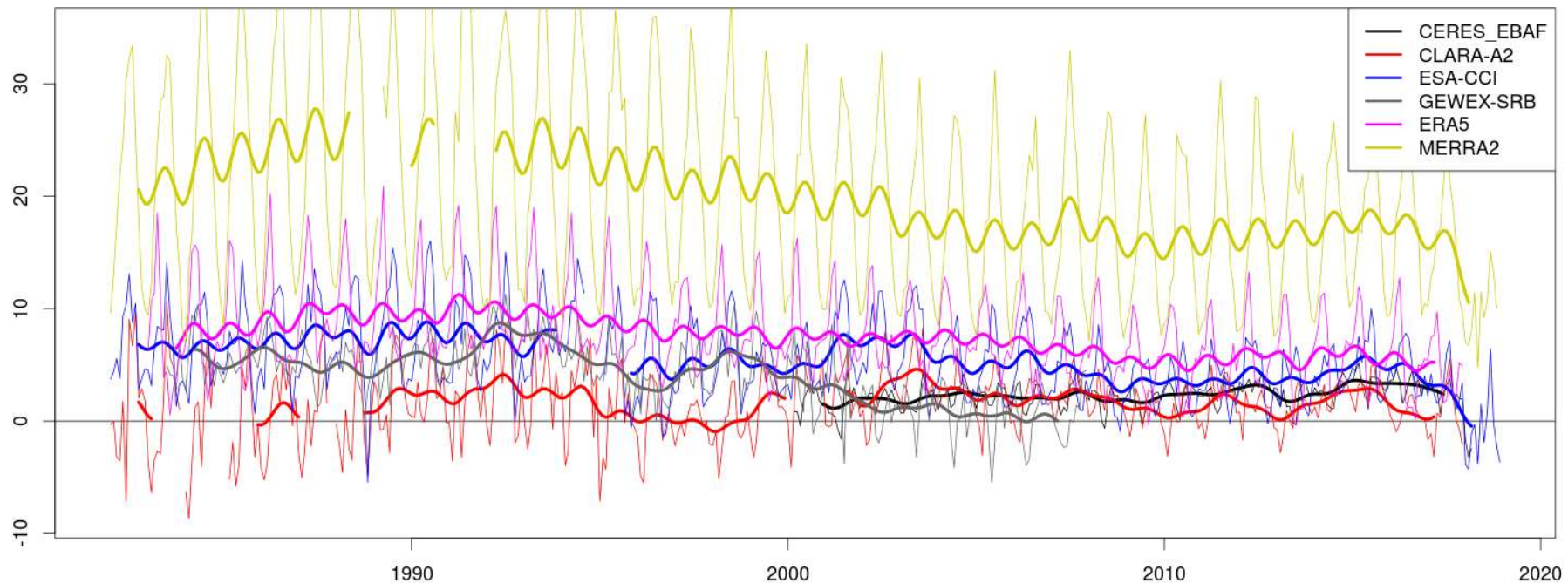
➔ Constant bias required for high quality estimates of trends / changes

Evaluation of Trends, correlation (2000 – 2017)
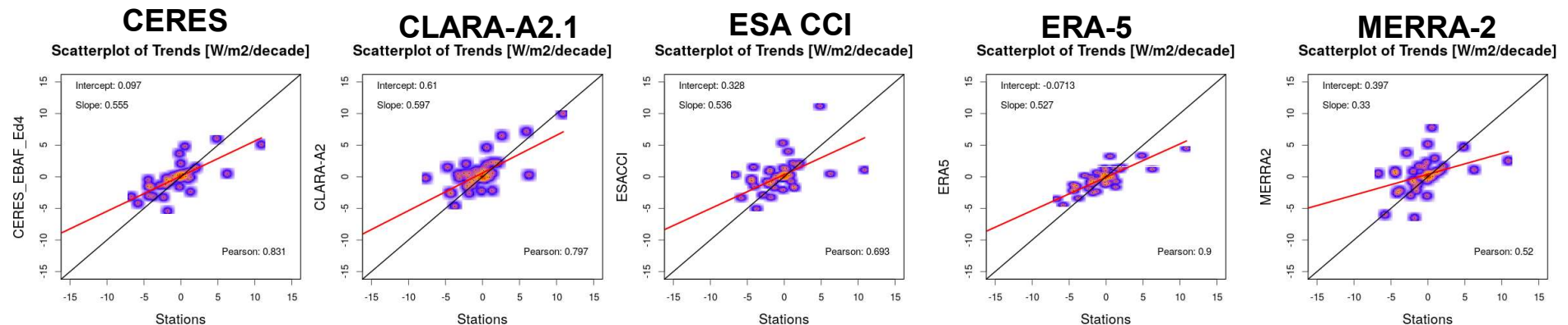
→ Most station-based trends (2000 – 2017) are within ±3 W/m2/dec

→ Correlation coefficients > ~0.7 for all data sets except MERRA-2

→ Gridded data sets tends to underestimate the absolute value of the trend, ie., slopes are always well below 1.

Average trend based on gridded data sets[*]

Mean trend [W/m2/decade], 2000-2017
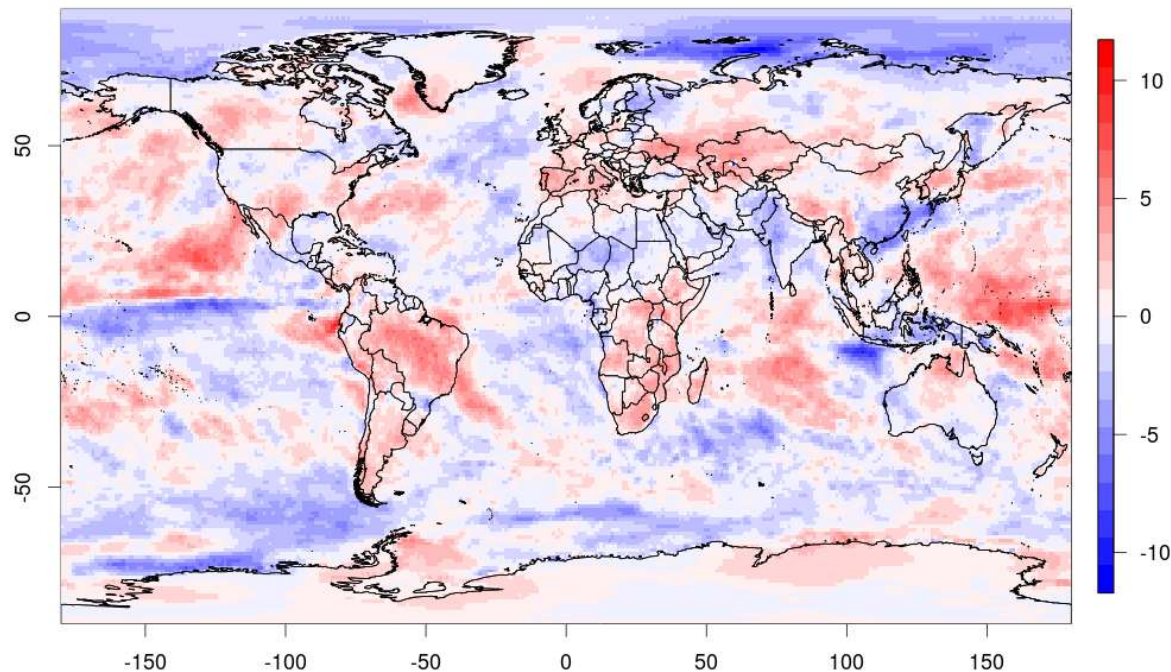
→ Substantial regional differences in the mean trend

→ See the trends for the individual data sets in the Appendix

[*]Results from MERRA-2 not included in the average

Range of the trends based on gridded data sets[*]

Range of trends [W/m2/decade], 2000-2017
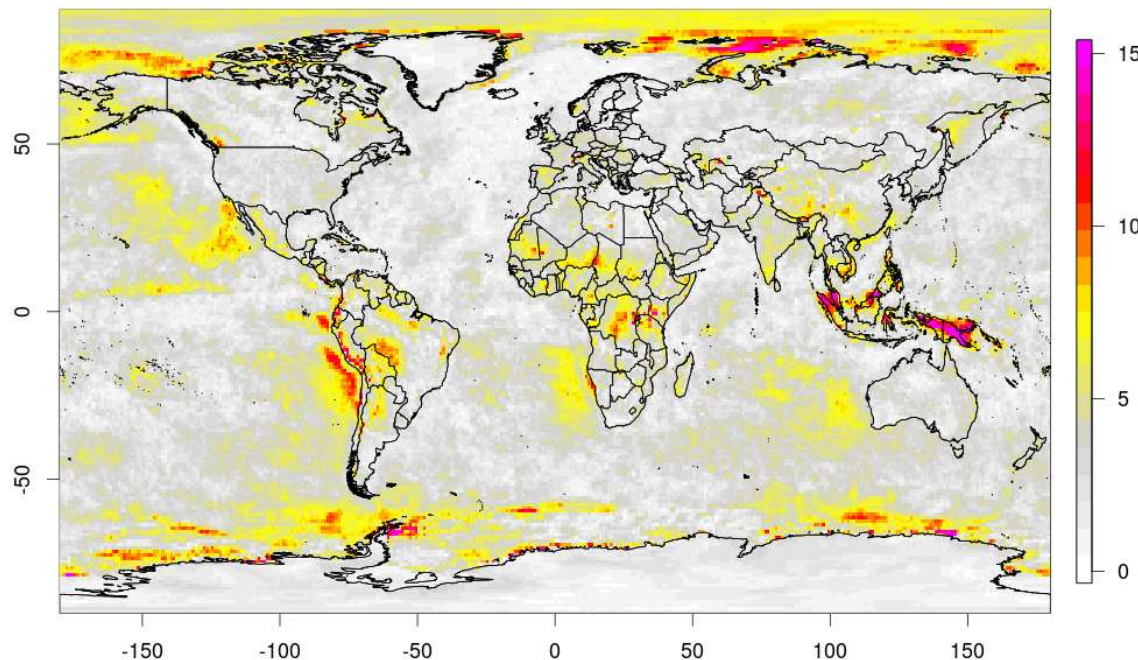
Mean trend [W/m2/decade], 2000-2017
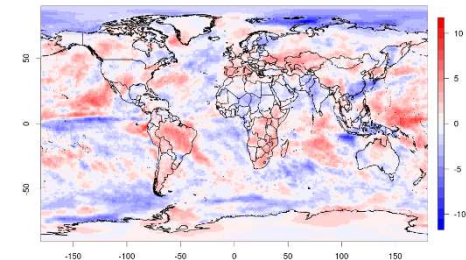
➔ Data sets agree on the trend in many regions

➔ Regions with higher range include Indo-Pacific, Arctic, Western South America

[*]Results from MERRA-2 not included in the average

Summary

→ Satellite-based data sets of surface irradiance outperfom reanalysis data set

→ ERA-5 performs significantly better than MERRA-2

→ Measurements from buoy networks are a useful source of irradiance data

→ Best estimate of Global Surface Irradiance:

   188 W/m^2

→ Trends vary regionally
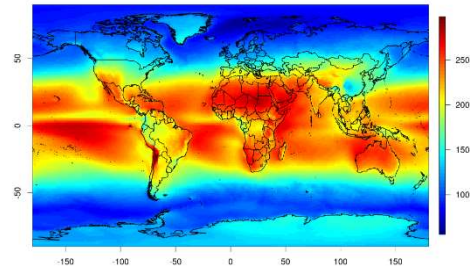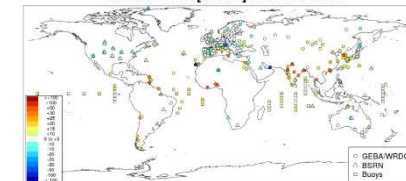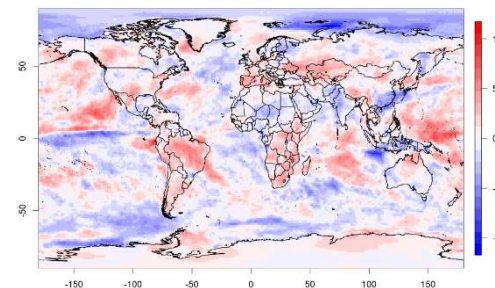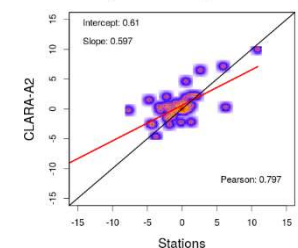
Appendix

CM SAF CLARA-A2

➔ **Variables**

  ➔ Cloud properties

  ➔ Surface albedo

  ➔ Surface Radiation

➔ **Resolution**

  ➔ Spatial: 0.25° × 0.25°

  ➔ Temporal: daily-, pentad-, monthly mean

➔ **Coverage**

  ➔ Spatial: global

  ➔ Temporal: 1982 to 2015

    (2016 to 2019 available upon request)

➔ Available at www.cmsaf.eu

CM SAF CLARA Surface Downwelling Longwave Flux
Mean July 2008

Surface Downwelling Longwave Flux [W/m^2]
50 140 230 320 410 500
Data Min = 42, Max = 499, Mean = 352
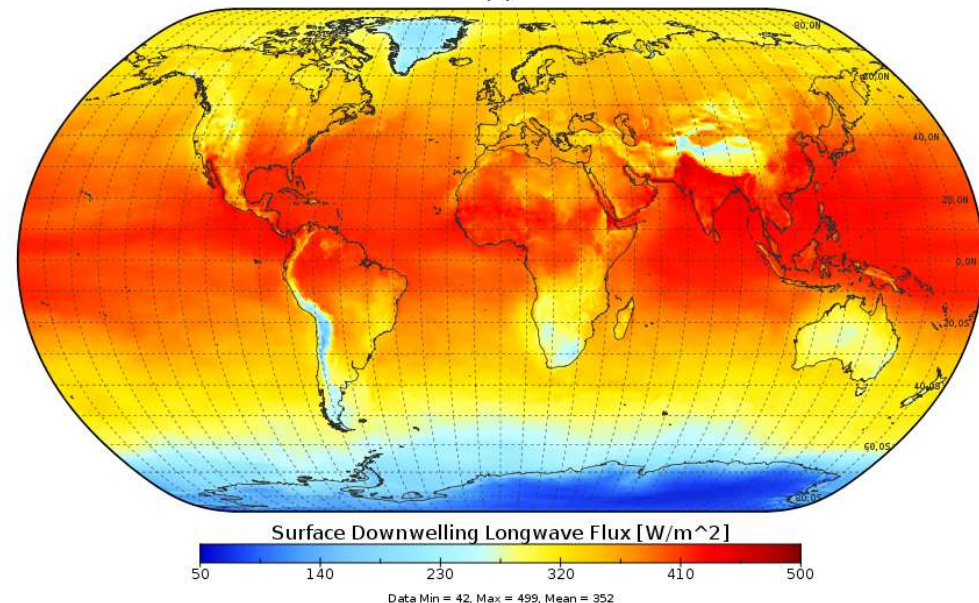
Karlsson, K.-G. et al., (2017) CLARA-A2: the second edition of the CM SAF cloud and radiation data record from 34 years of global AVHRR data, *Atmos. Chem. Phys., 17*, 5809-5828, doi:10.5194/acp-17-5809-2017
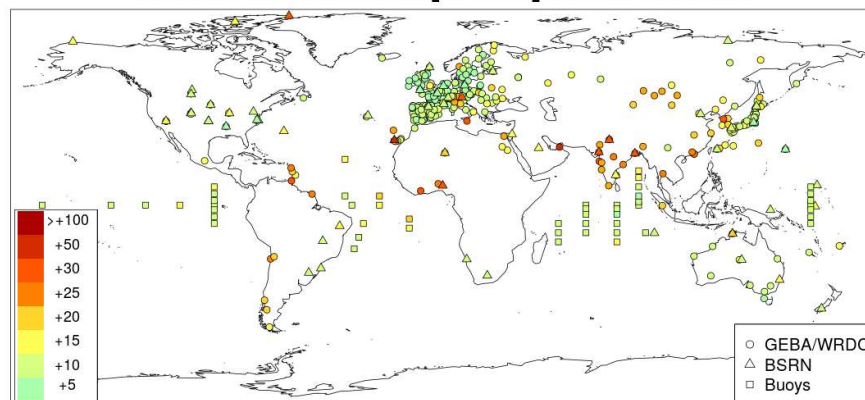
DOI:10.5676/EUM_SAF_CM/CLARA_AVHRR/V002

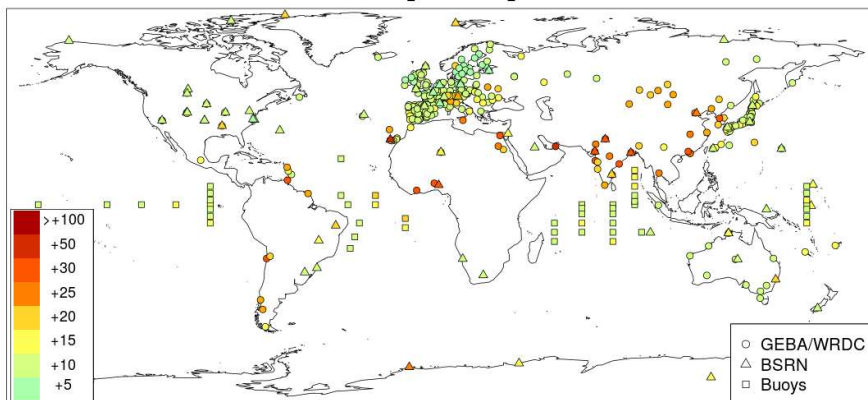# Regional Results: abs. bias, common period, satellite data sets

CERES_EBAF_Ed4 abs. bias [W*m-2] vs. all stations
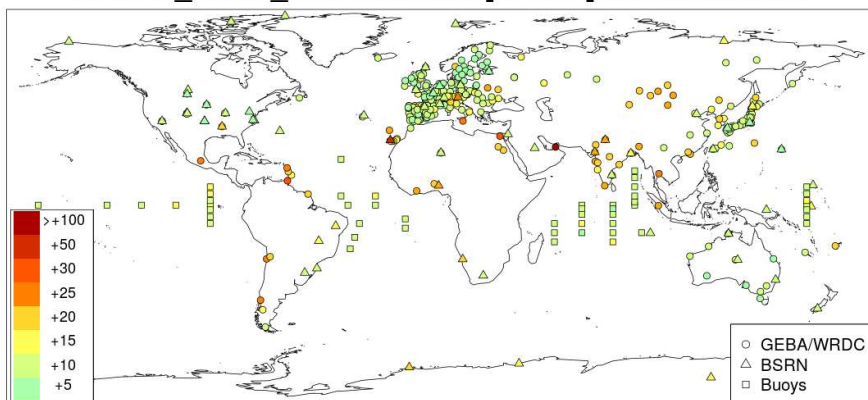
CLARA-A2 abs. bias [W*m-2] vs. all stations

ESACCI abs. bias [W*m-2] vs. all stations
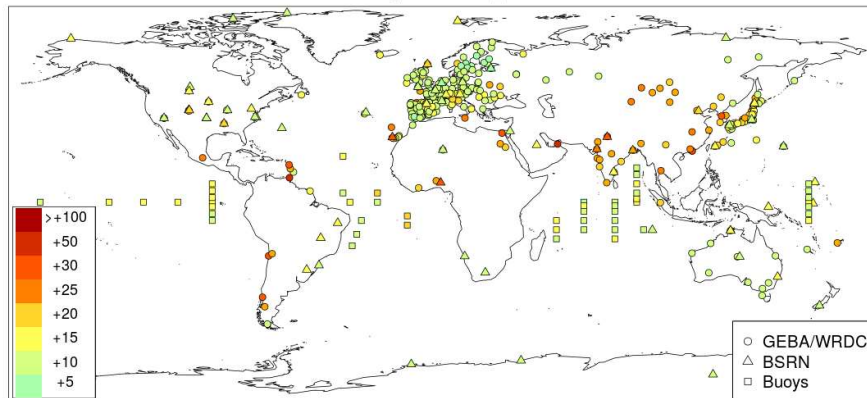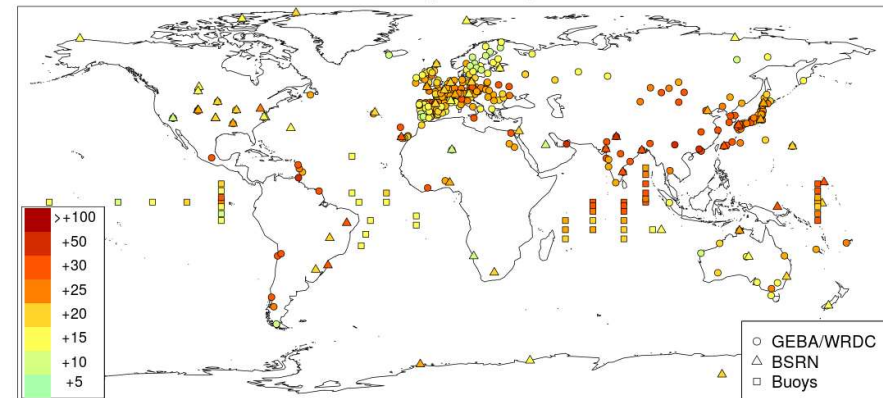

➔ Comparable spatial distribution*

*Please zoom-in for the details

Regional Results: abs. bias, common period, reanalysis data sets

ERA5 abs. bias [W*m-2] vs. all stations
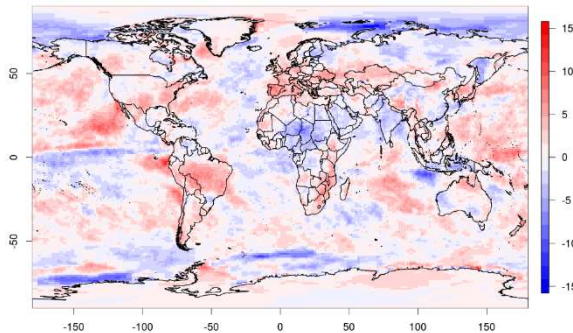

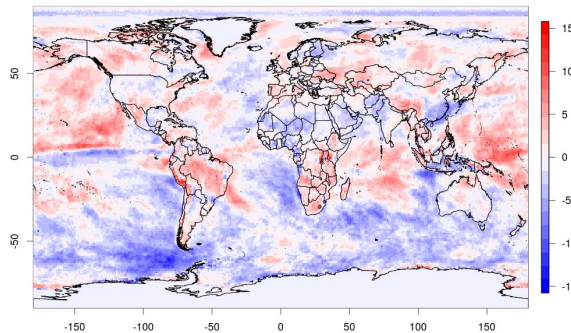MERRA2 abs. bias [W*m-2] vs. all stations

*Please zoom-in for the details

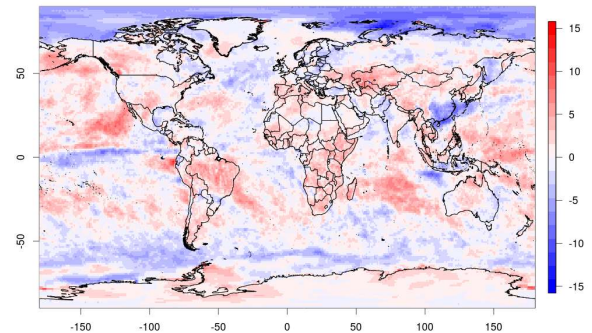# Trends (2000 – 2017), satellite and reanalysis data

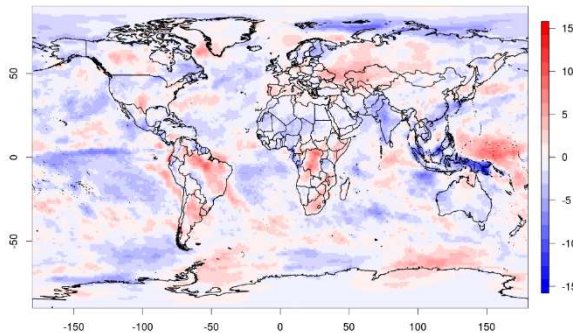CERES, Global Radiation Trend [W/m2/decade], 2000-2017
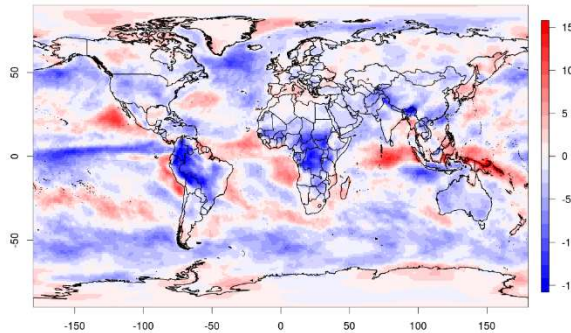
CLARAA2, Global Radiation Trend [W/m2/decade], 2000-2017

ESACCI, Global Radiation Trend [W/m2/decade], 2000-2017

ERA5, Global Radiation Trend [W/m2/decade], 2000-2017

MERRA2, Global Radiation Trend [W/m2/decade], 2000-2017

➔ Many regions with consistent trends

➔ MERRA-2 has different pattern compared to the other data sets