Global Trends in Downward Surface Solar Radiation from Spatial Interpolated Ground Observations during 1961-2019

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EGU22, Vienna, May 2022

Background and Research Question

- Surface solar radiation (SSR) is a crucial climate variable and a main component of the global energy balance, playing an important role in temperature change and the hydrological cycle.
- However, there is no existing dataset of observational SSR with extensive spatial coverage and a long history.
- This study **aims to conduct a spatial interpolation** (based on a machine learning method) to construct an SSR dataset with complete land surface coverage (no missing locations) and historical records (no interruptions in times series).
- Based on the constructed dataset, we further conduct a **trend analysis of global SSR** and reveal the temporal and spatial patterns of SSR during the last six decades.

Method–Random Forest Algorithm

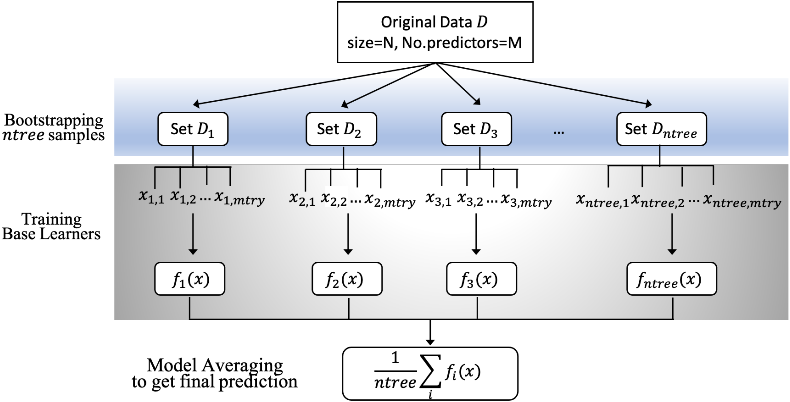


Figure 1 Flowchart of Random Forest.

Datasets

Table 1 Predictors summary

Variable Category	Symbol	Definition
Climatic Variables	cld	monthly average cloud cover as percentage
	dtr	monthly average diurnal temperature range in $^\circ C$
	frs	number of days with ground frost in a month
	pre	monthly total precipitation data in mm/month
	tmn	monthly average minimum temperature in $^\circ C$
	tmp	monthly average mean temperature in $^\circ C$
	tmx	monthly average maximum temperature in $^\circ C$
	vap	monthly average vapor pressure in hPa
	wet	number of rainy days in a month
Geographical Variables	lat	latitude of the location
	lon	longitude of the location
	alt	terrain altitude in m
	urban	1 if urban, 0 if rural
Temporal Variables	year	year of the observation/estimation
	mon	month of the observation/estimation

Datasets

- Ground-based all-sky SSR observations were obtained from the Global Energy Balance Archive (GEBA; Wild et al., 2017).

  We used more than 328,000 monthly observations collected from $\sim$1500 global climate stations covering the period from the early 1950s until 2013.

- The climatic variables used as predictors for SSR are available from the Climate Research Unit Time-series data version 4.04 (CRU-TS v.4.04; Harris et al., 2020).

  Note that *anomalies* are calculated for climate variables such that only long-term trends are teased out from total variations which comprise interannual and seasonal variations.

- A $0.5^\circ \times 0.5^\circ$ global altitude map is available from NESDIS (1995).
- The GRUMP dataset V1 (CIESIN, 2004) provides a 30 arc-second urban extents grid based on 1995 snap data.

Results–Model Performance Validation

- 10-fold cross-validation for each continent. Model performance is affected by:
  - The amount of data available to train the model;
  - The density of station distribution;
  - The length of history of stations.

Table 2 Error measures for Random Forest simulations. Units of MAE and RMSE: Wm^{-2}

Continent	No.of stations	No.of years[a]	MAE.ano	RMSE.ano	R.Squared.ano[b]
Europe	516	21.42	7.90	12.03	0.56
North America	214	14.57	8.37	12.13	0.49
Oceania	76	15.97	9.39	13.60	0.43
Asia	312	26.49	10.48	14.92	0.51
Africa	234	12.16	11.50	15.74	0.34
South America	134	8.31	11.87	16.55	0.59
		Global Avg.	9.92	14.16	0.49

a. Average number of years of valid data GEBA stations have;
b. R.Squared.ano stands for the percentage of explained variance in interannual variations of SSR by the RF model.

Results–Predictor Importance

- The predictors that provide the largest explanatory power for interannual variability of SSR are *diurnal temperature range* (DTR) and *cloud cover* (CLD).

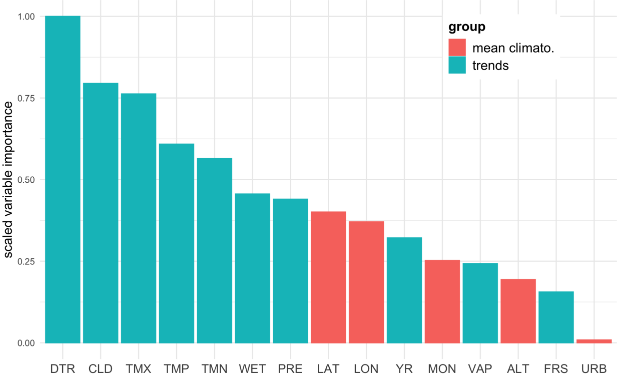
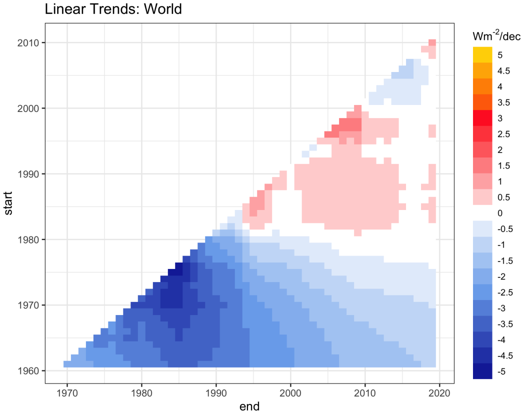


Figure 2 Random Forest permutation variable importance.

Results–Trend Analysis

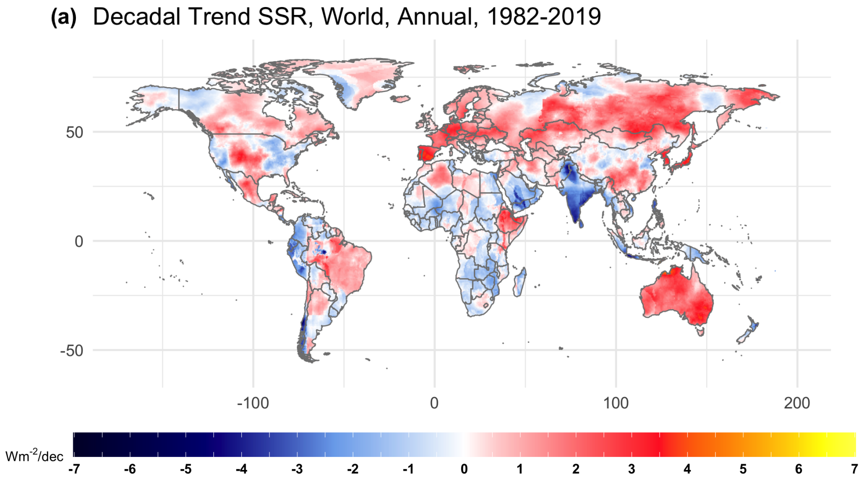
- The output of the spatial interpolation is a $0.5^\circ \times 0.5^\circ$ monthly gridded dataset of SSR anomalies with complete land coverage over the period 1961-2019, which is used afterwards in a comprehensive trend analysis.



Results–Trend Analysis

- We detected structural breakpoints in SSR time series such that significant changes in long-term SSR trends are reported. Eg. for global average SSR, one breakpoint from dimming to brightening is found in 1981.

Results–Trend Analysis



Results–Decadal Linear Trends

Table 3 Decadal linear trends divided by detected breakpoints.

Continent	Segment	Slope[a]	Slope std	*t* value	Pval	Pval.symbol[b]
World	1961-1981	-3.068	0.172	-17.874	0.000	***
	1982-2019	0.328	0.079	4.164	0.000	***
Europe	1961-1976	2.791	0.759	3.675	0.002	**
	1977-2019	1.169	0.169	6.935	0.000	***
North America	1961-1977	-5.068	0.483	-10.496	0.000	***
	1978-2019	0.249	0.121	2.051	0.047	*
Africa	1961-1969	1.991	1.175	1.694	0.134	
	1970-1981	-3.255	0.695	-4.681	0.001	***
	1982-2019	-0.221	0.139	-1.587	0.121	
Asia	1961-1992	-5.383	0.231	-23.287	0.000	***
	1993-2019	-0.643	0.165	-3.908	0.001	***

a. Slope unit: Wm^{-2} decade^{-1};
b. Pval.symbol: *** indicates $p < 0.001$, ** for $p < 0.01$, * for $p \leq 0.05$, **.** for $p \leq 0.1$, and no symbol if $p > 0.1$.

Conclusions

- Climatic variables could explain a fair percentage of long-term variability of SSR. Among the predictors, *diurnal temperature range* and *cloud cover* provide the largest explanatory power.
- SSR trends are nonstationary over time. A reversal from dimming to brightening has been observed in Europe, Oceania, and North America. Whereas Asia, Africa, and South America are still undergoing dimming trends, a mitigation of the dimming has been found.
- SSR trends are profoundly heterogeneous over areas. What factors contribute to the differences remain interesting to investigate.

References I

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Appendix–Continental Average Annual Trends