The impact of clouds and aerosols on the radiative fluxes in Germany over the past 70 years from a surface perspective

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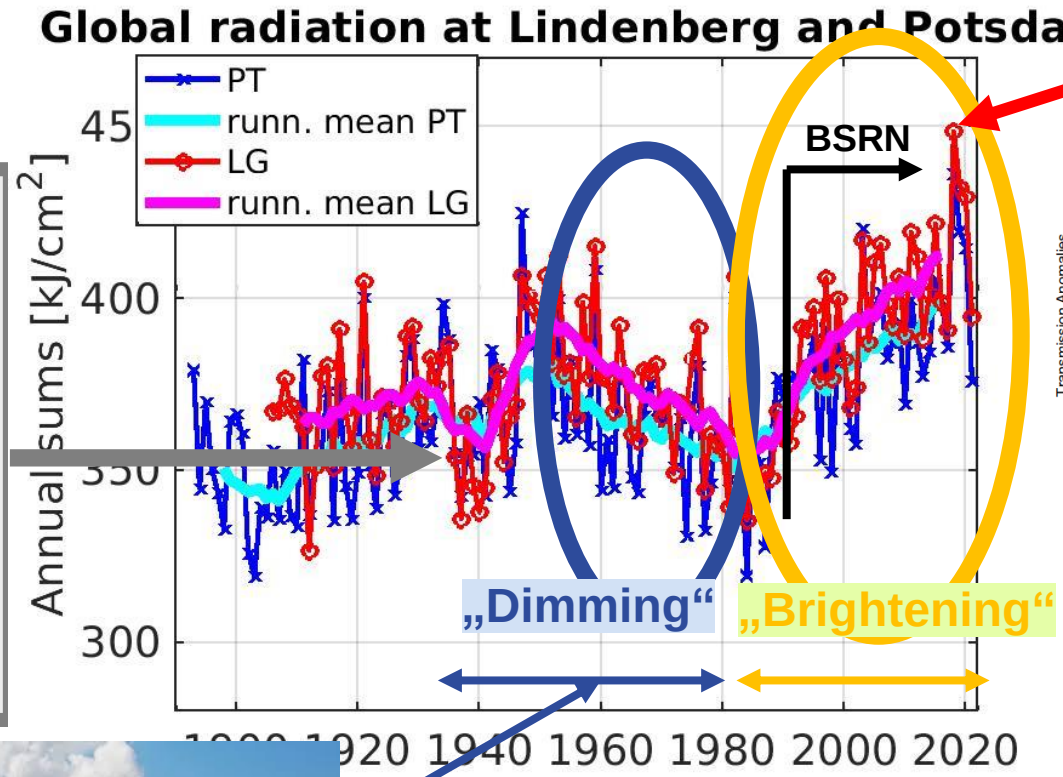
Motivation

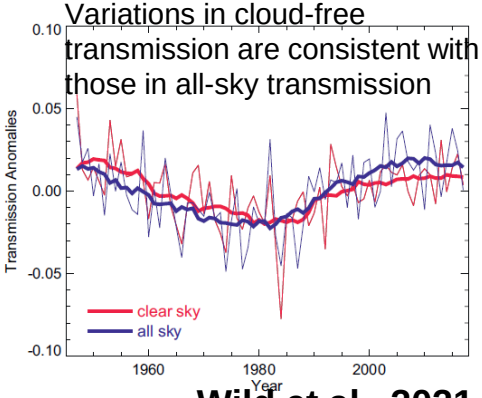
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

1937

Start of Global/Diffuse observations at Potsdam

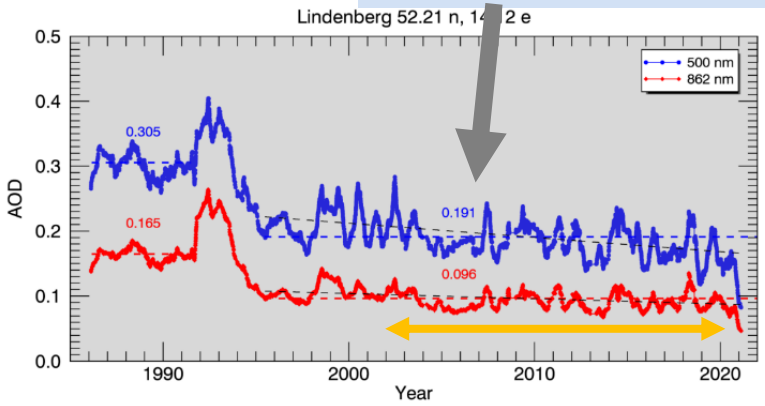


Highest value in 2018



Wild et al., 2021

Slight decreasing AOD since 2005 (Talk Florian F.)



No direct observations of AOD
→ Determination from solar broadband observations (Talk Florian F.)

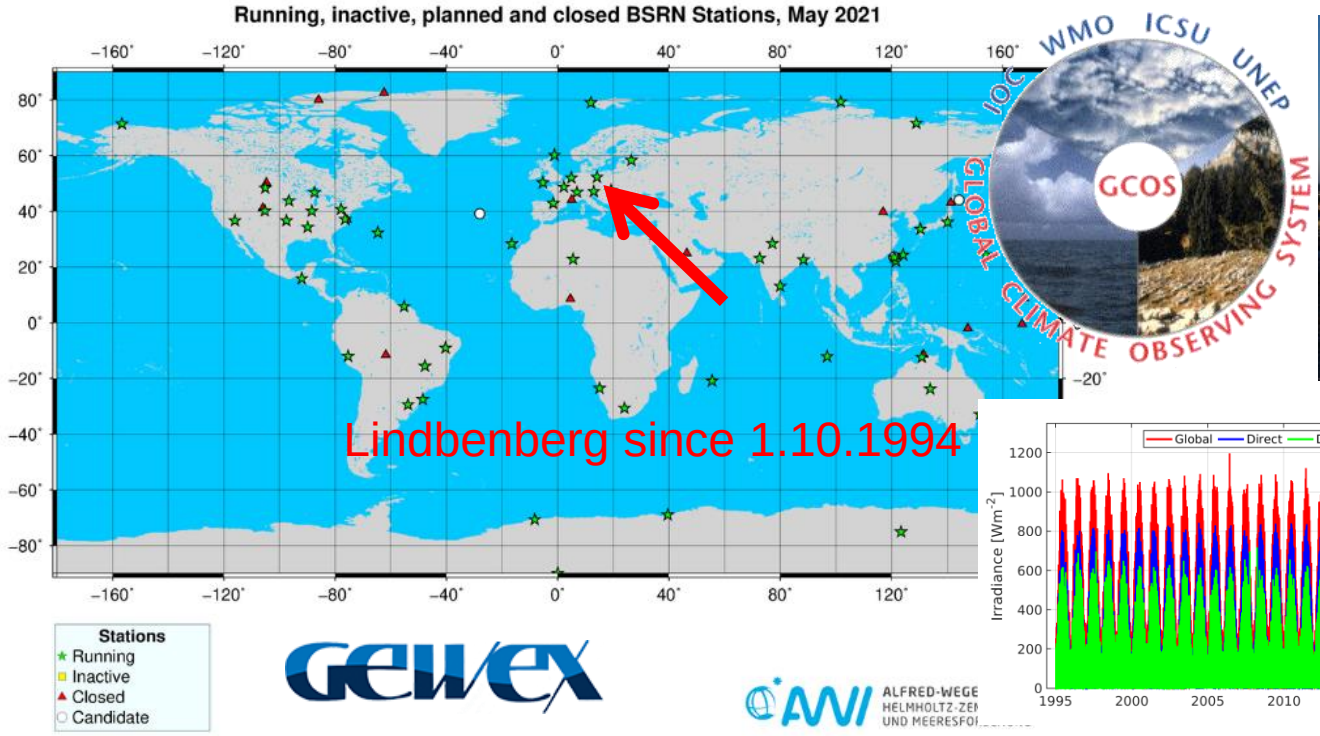
Outline

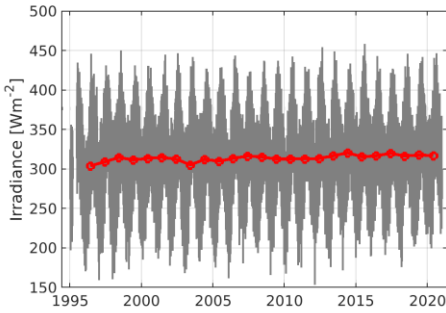
1. Dataset and methods
   - ➔ Radiation observations
   - ➔ Cloud Radiative Effect
   - ➔ Shortwave and Longwave cloud-free models
2. Results
   - ➔ Radiation trends
   - ➔ Trends in Cloud Radiative Effect
3. Conclusions and Outlook

1. Data sets and methods

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

BSRN station at Lindenberg since 1994



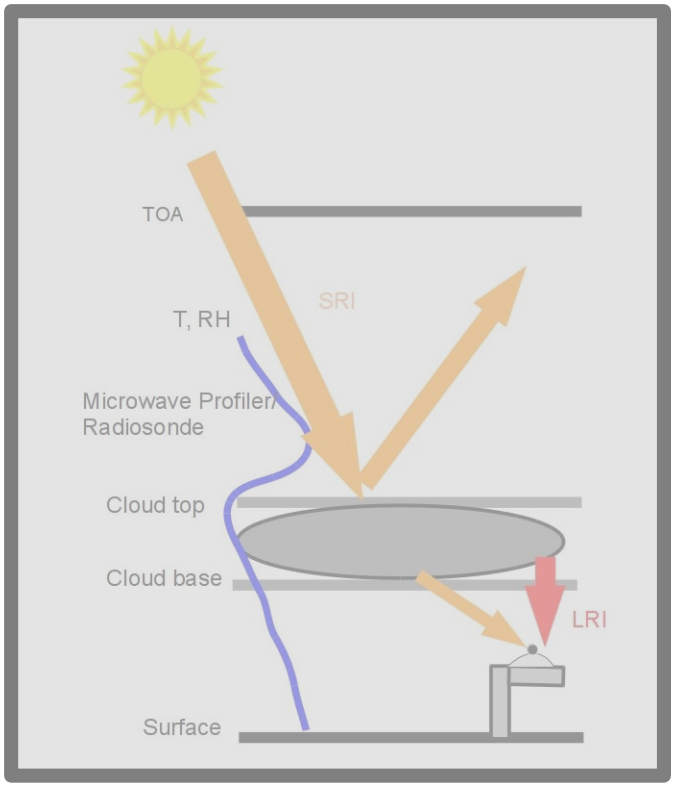


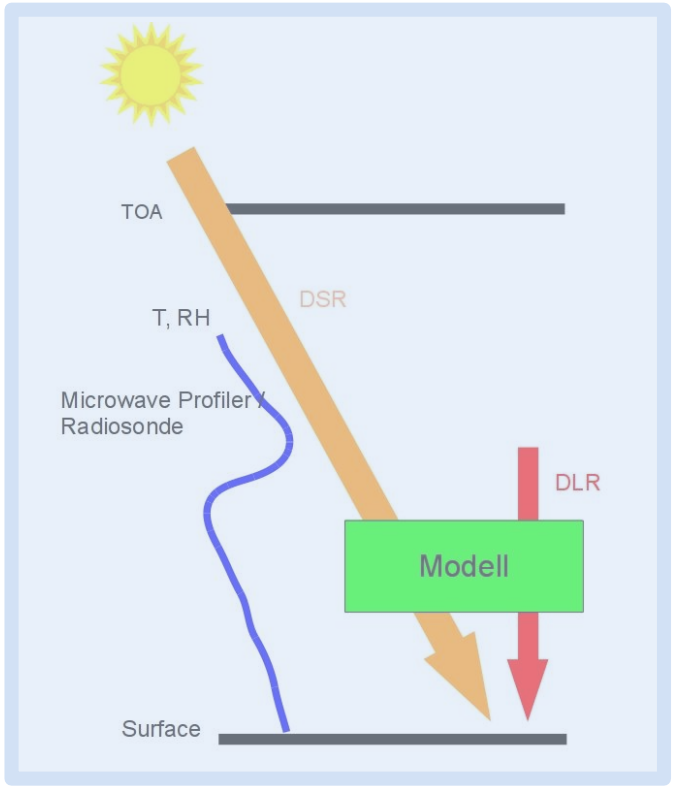
Continuous and redundant high precision observations of broadband downwelling shortwave (direct, diffuse, global) and longwave radiation

+ observations of Aerosol Optical Depth (AOD) using sun photometers since 1986

Cloud radiative effect (CRE)

CRE_i = observed all-sky $flux_{(SW,LW)i}$ – calculated cloud-free $flux_{(SW,LW)\ i}$ = SCE + LCE



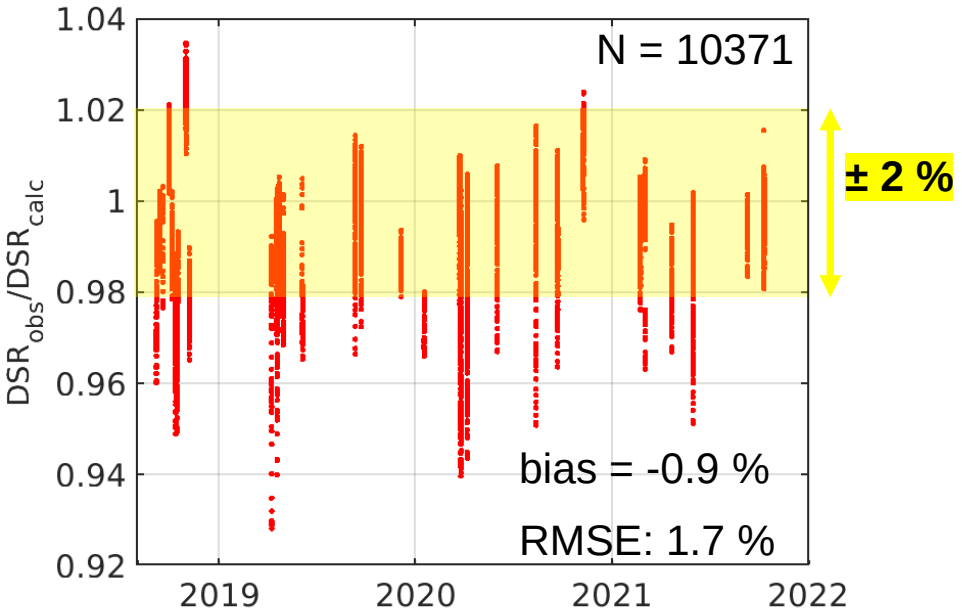


Cloud radiative effect is determined from the observed all-sky short- and longwave irradiances relative to the respective calculated cloud-free fluxes.

Shortwave cloud-free model

- Pre-calculated lookup-tables of global downwelling shortwave radiation
- Inputs: Angstrom Alpha (Angstrom exponent), Angstrom Beta, Integrated Water Vapor, Solar Zenit Angle
- Cloud-free data points for model validation determined using Long and Ackerman (2000) algorithm in combination with visual inspection
- Microphysical aerosol properties not included (not available prior to 2013)

Model validation (1-min data)



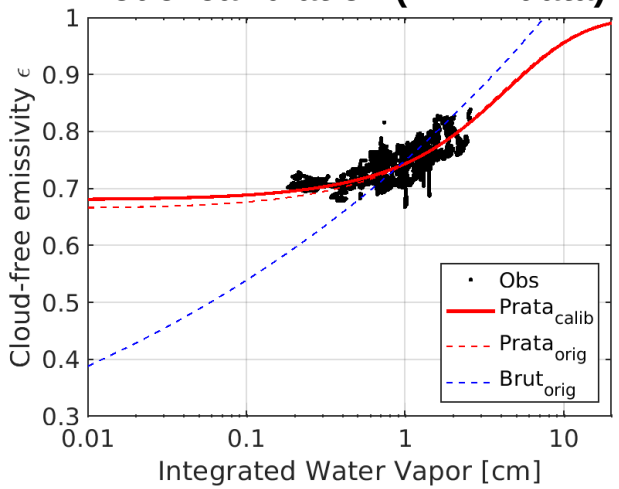
The cloud-free model is in the uncertainty range of the observations (2 %)

Longwave cloud-free models

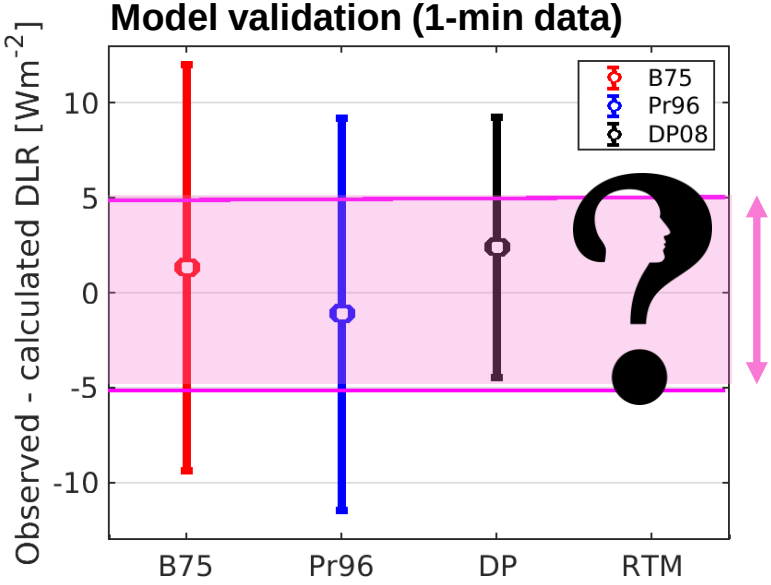
- Parametrization of Brutsaert (1975), Prata (1996), Dupont et al. (2008)
- Input data: Screen-level temperature, Rel. humidity / Integrated Water Vapor
- Models are tuned to observations → determination of leading coefficients
- Two separate cloud-free datasets:
  1. Calibration (N = 26506)
  2. Validation (N = 26506)

The model of Dupont is close to the measurement uncertainty (± 5 Wm^{-2})

Model calibration (1-min data)



Model validation (1-min data)



Cloud radiative effect (CRE) at Lindenberg (1996-2021)

- Longwave cloud effect (**LCE**) is always positive
- Annual total CRE (**TCE**) is dominated by the negative shortwave cloud effect (**SCE**)
- Clouds reduce the available energy at the surface

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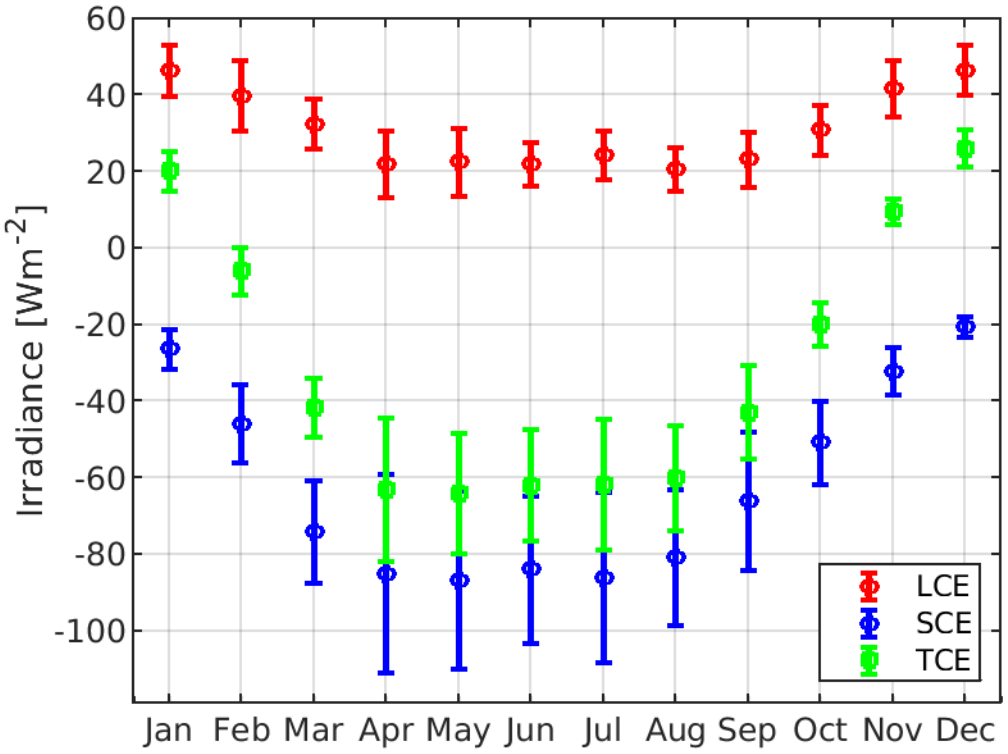
Annual means:

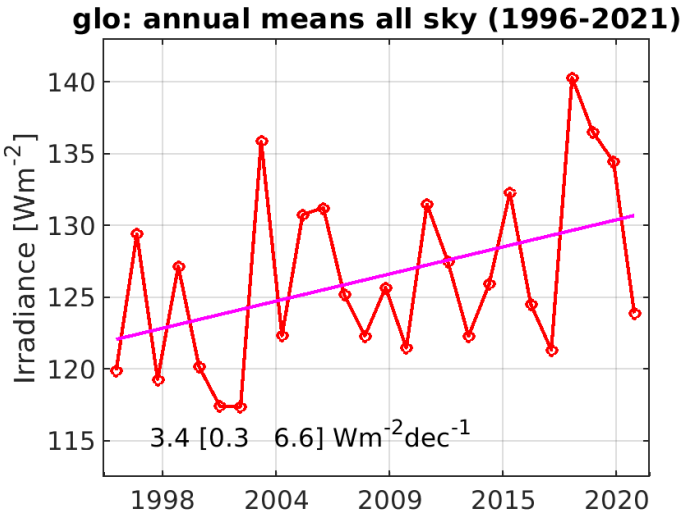
LCE: 31.0 ± 3.1 Wm^{-2}

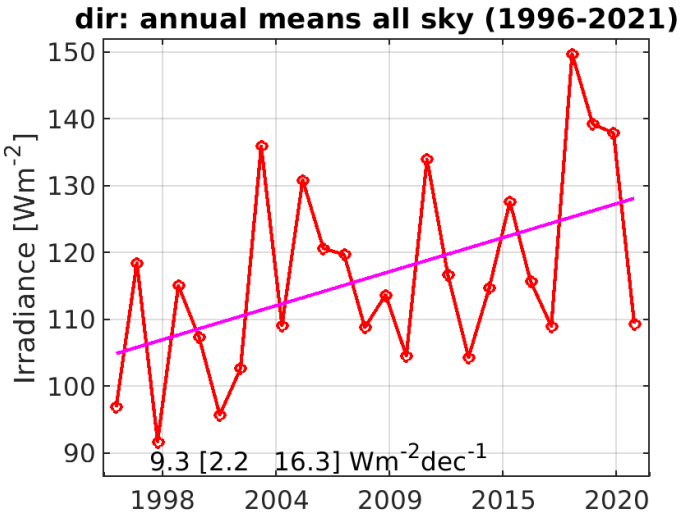
SCE: - 60.7 ± 5.6 Wm^{-2}

TCE: - 29.7 ± 4.3 Wm^{-2}



2. Trend results: shortwave radiation





- Significant increase in global and direct solar radiation since the 90‘s
- Increase in the cloud-free atmosphere is considerably stronger
- Insignificant decrease in diffuse solar radiation
- AOD decrease ≈ 30 % → increase of ≈ 10 and 20 Wm^{-2} in global and direct, respectively.

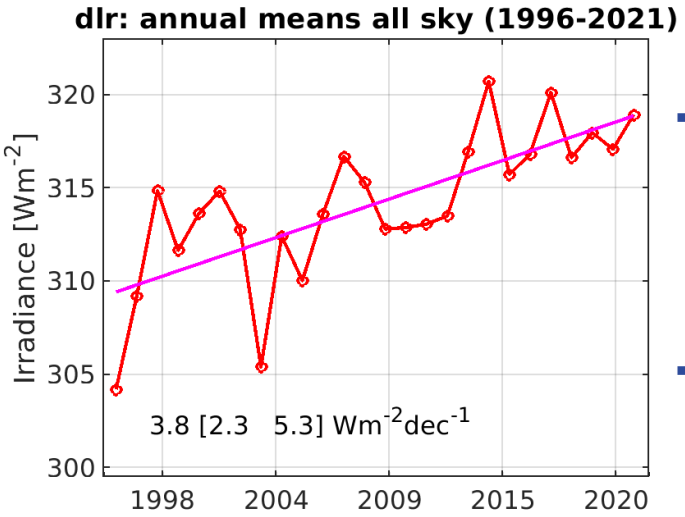
Total changes in Wm^{-2} since 1996 (95 % CI):

	All-sky	Cloud-free
Global:	9.0 ± 8.1 Wm^{-2}	37.6 ± 24.7 Wm^{-2}
$Direkt_N$:	24.1 ± 18.3 Wm^{-2}	81.0 ± 29.3 Wm^{-2}
Diffuse:	-2.2 ± 2.5 Wm^{-2}	-6.6 ± 7.4 Wm^{-2}

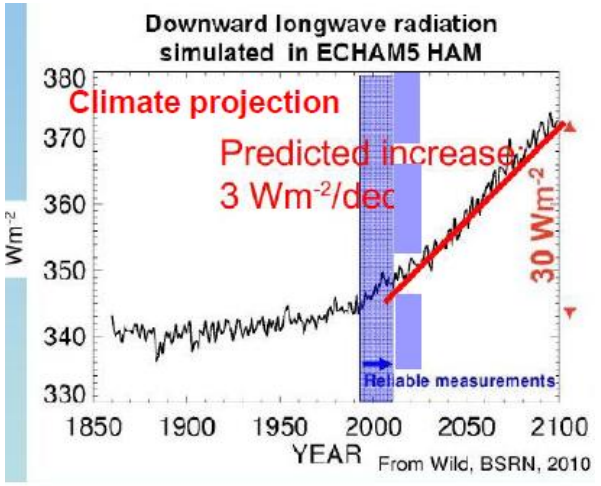
Distinction between cloud-free and all-sky during day and night using the DWD AWO-algorithm (based on Ceilometer observations)

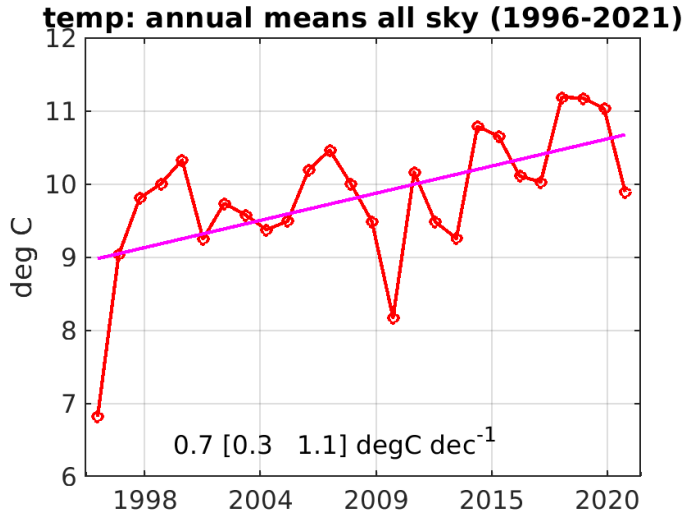
For the trends, the slope of the lin. reg. and its 95 % confidence interval are stated

2. Trend results: longwave radiation



- Significant increase in incoming longwave radiation, mainly due to increasing air temperature
- Trends are consistent with climate model projections





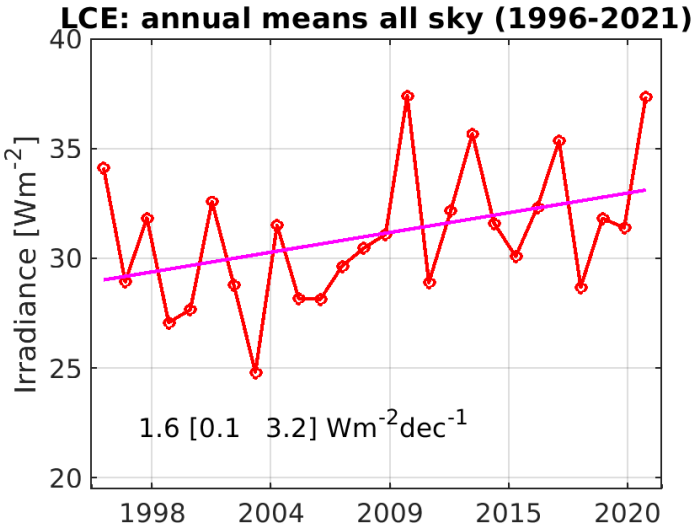
Total changes in Wm^{-2} since 1996 (95 % CI):

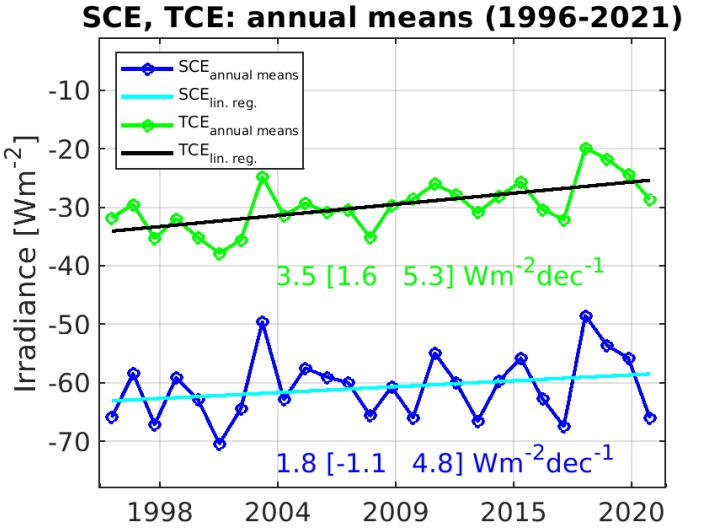
	All-sky	Cloud-free
Longwave:	9.8 ± 3.9 Wm^{-2}	11.5 ± 7.3 Wm^{-2}
Air Temp:	1.8 ± 1.1 deg C	2.0 ± 1.8 deg C
Spec. hum:	0.0 ± 0.3 [1)]	-0.1 ± 0.5 [1)]

1) unit: g H_2O (gas)/kg wet air

For the trends, the slope of the lin. reg. and its 95 % confidence interval are stated

2. Trend results: cloud radiative effect





- Ambiguity in the LCE: significant increase while the all-sky longwave trend is smaller than the cloud-free trend
- Tendency to a less negative SCR, but not significant
- Magnitude of net total cloud effect has decreased → decrease in cloud cover, shift towards a different cloud type and/or changes in microphysical cloud properties

Total changes in Wm^{-2} since 1996

LCE: 4.3 ± 4.1 Wm^{-2}

SCE: 4.8 ± 7.7 Wm^{-2}

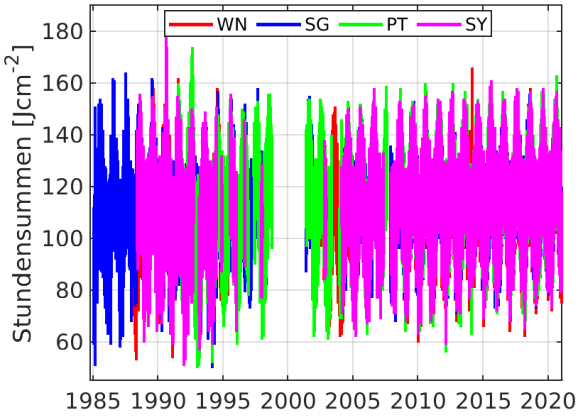
TCE: 9.1 ± 4.9 Wm^{-2}

For the trends, the slope of the lin. reg. and its 95 % confidence interval are stated

3. Conclusions and Outlook

- ➔ Strong solar brightening and increasing greenhouse effect are evident
- ➔ Trends in the total cloud radiative effect over past 25 year are not conclusive due to model uncertainties (mainly in the longwave)
  - ➔ Reduction of the uncertainties in cloud-free models (including their input parameters) is necessary
- ➔ The causes for the strong increase in global/direct radiation need to be clarified:
  - Contamination in the cloud-free dataset?
  - Changes in microphysical aerosol properties?
- ➔ Additional activities:
  - Include more stations for the calculation of CRE
  - Study variations in optical aerosol properties
  - Include longterm series of microphysical cloud properties (available at Lindenberg)

Longwave radiation from DWD network



Thank you for your attention!