Internal variability of surface solar radiation and associated PV production

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Motivation

- Photo Voltaics (PV) harvests the surface solar radiation (SSR) reaching Earth's surface.
- SSR is known to vary on a range of time scales[1,2], from minutes to decades.
- Potential causes range from anthropogenic forcing[3] (e.g. changing aerosol emissions) to internal variability within the climate system[4] (e.g. clouds or El Nino).
- Different causes may be superimposed[5,6] and may change with the time scale of interest.

Question:

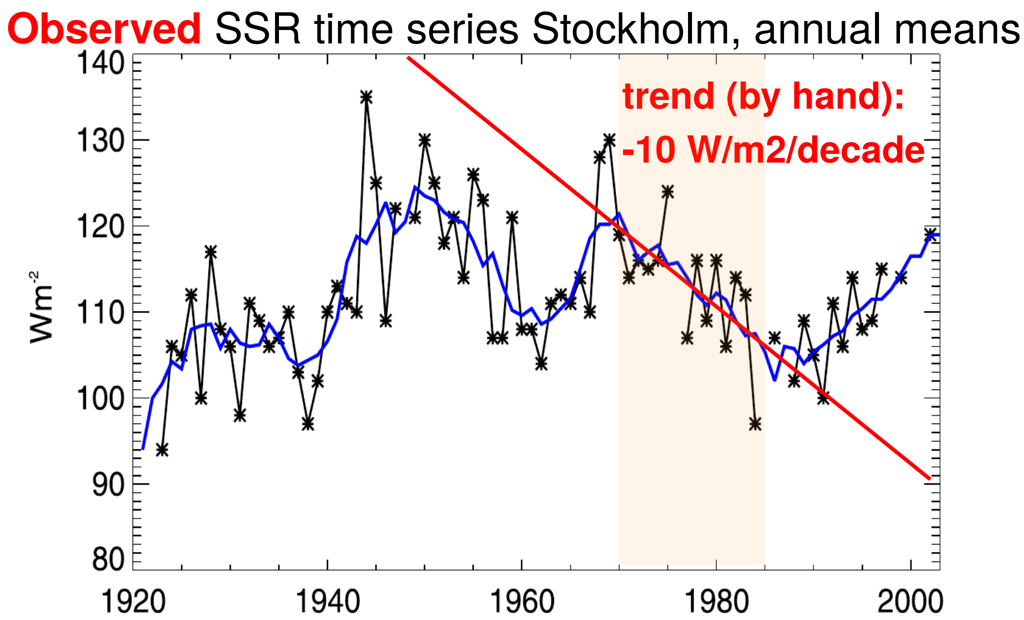
Probability for decadal scales SSR / PV changes of a certain amount solely due to internal (unforced) variability of the climate system?

Approach:

Model data (CMIP5) + satellite + surface observations → internal variability of SSR → (simple) PV model → internal variability of PV

1) Huld & Trentmann (2015), doi: 10.4229/EUPVSEC20152015-5BV.1.3
2) Miglietta et al. (2017), doi: 10.1175/JAMC-D-16-0031.1
3) Sweerts et al. (2019), doi: 10.1038/s41560-019-0412-4
4) Folini et al. (2017), doi: 10.1002/2016JD025869
5) Folini et al. (2011), doi: 10.1029/2011JD016227
6) Folini et al. (2015), doi: 10.1002/2014JD022851

Motivation, example: all sky SSR trends in observations



Stockholm observed, 1968 – 1977:
-12.4 W/m2/decade   P-Value 0.12

Data from GEBA, the Global Energy Balance Archive,
Wild et al. 2017, doi: 10.5194/essd-9-601-2017

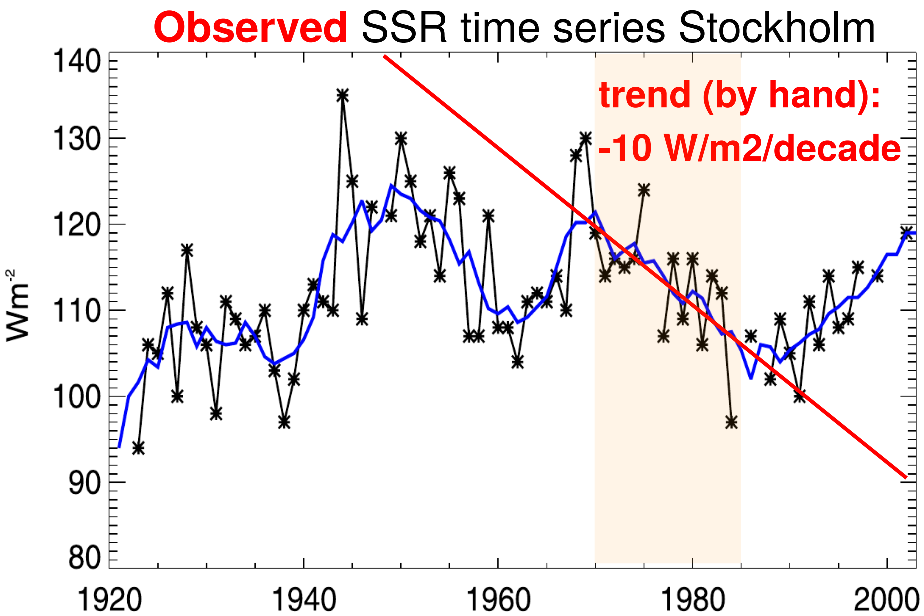
Trend …

a) the result of (aerosol) forcing?
[‘increasing aerosols’ → ‘decreasing SSR’]

b) the result of internal variability? (no forcing involved)
[changes in clouds e.g. in the wake of PDO / ENSO / NAO...]

c) a composite of ‘forcing’ plus ‘internal variability’?
[e.g. -20 W/m2/dec. forced + 10W/m2/dec. internal variability = -10 W/m2/dec. net]

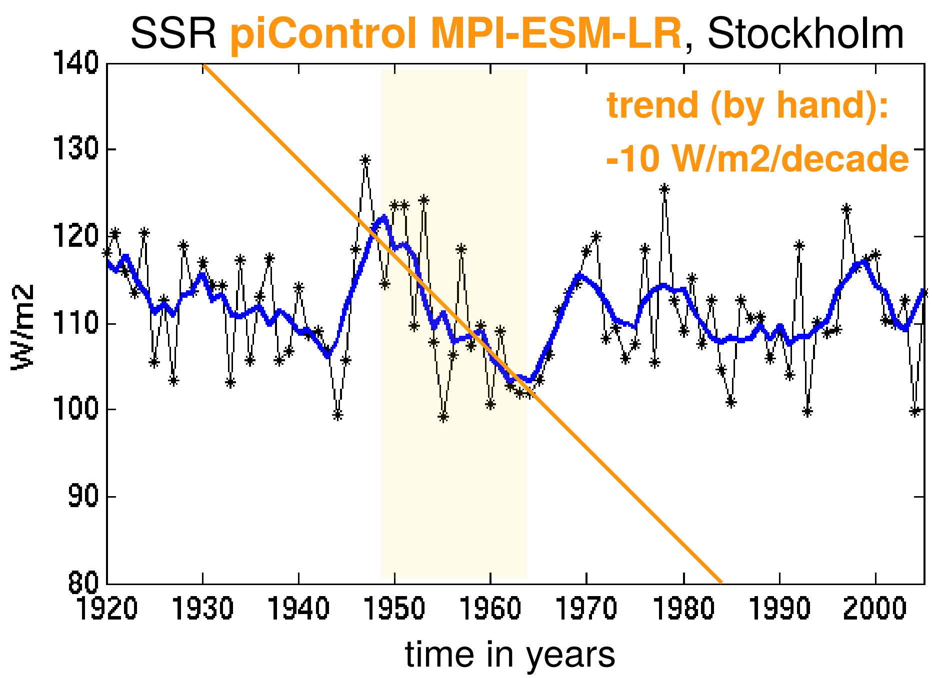
Motivation, example: observations vs. piControl simulation



Similar trends as observed exist in CMIP5 piControl simulations

Stockholm observed, 1968 – 1977:
-12.4 W/m2/decade P-Value 0.12

Stockholm piControl MPI-ESM-LR, 1949 – 1958:
-14.0 W/m2/decade P-Value 0.15



[from 1000 year piControl simulation, arbitrary labeling

[CMIP: Coupled Model Intercomparison Project]

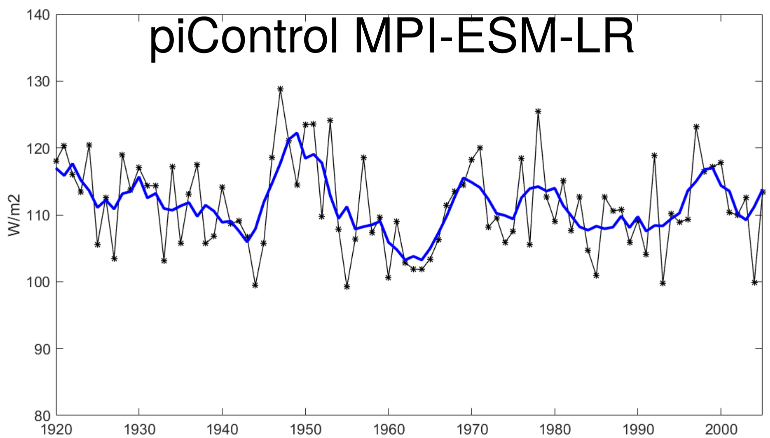
[piControl: pre-industrial control simulation; simulation is run for several hundred years for conditions as of year 1850; arbitrary labeling of years]

[MPI-ESM-LR: one model from CMIP5]

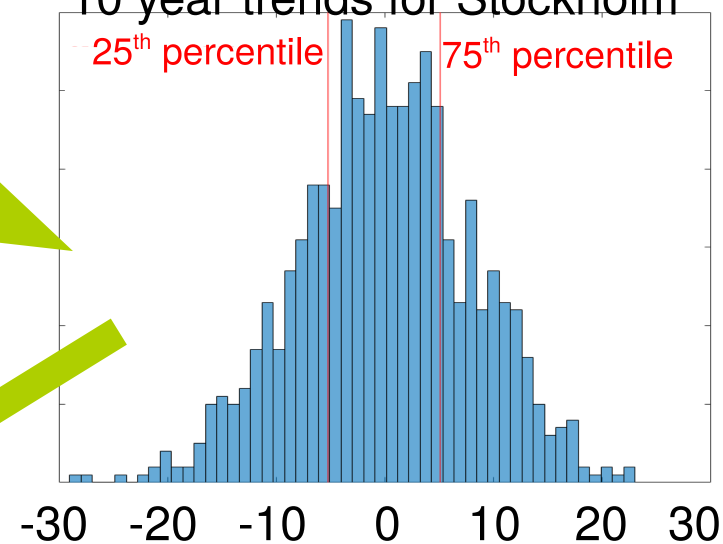
PiControl → long time series → can do statistics of (unforced) trends

grid-box-wise 75th percentile of 10 year all sky SSR trends

modeled SSR time series, Stockholm, piControl MPI-ESM-LR

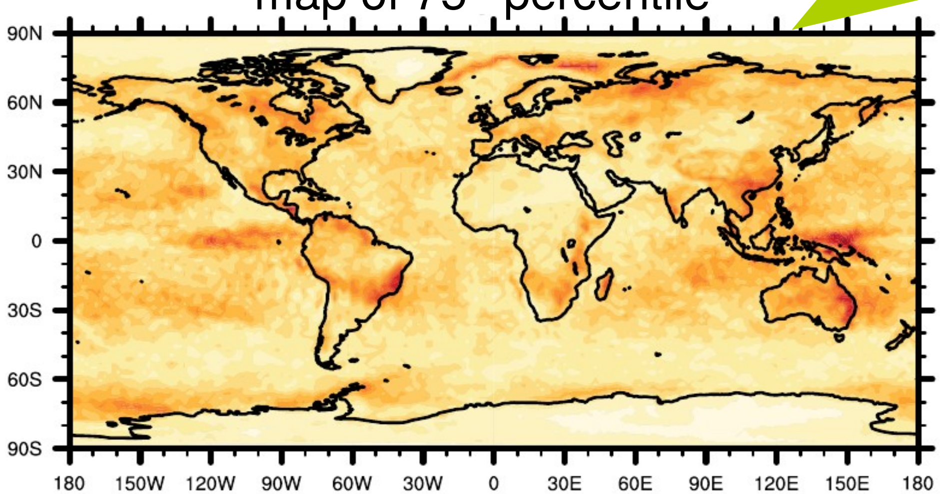


histogram of all possible 10 year trends for Stockholm



trend [W/m2/decade]

map of 75th percentile



do this for each grid box
[not only 'Stockholm']

Folini et al. 2017, JGR

It turns out that...

For single model

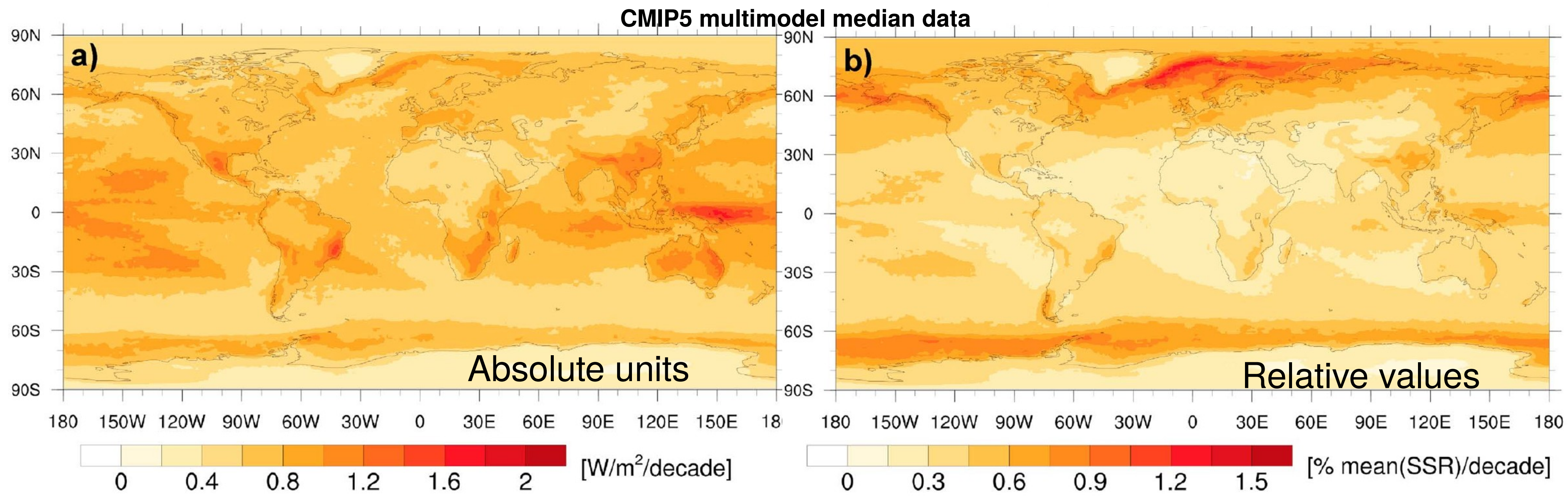
- **→ analytical relation σ(SSR time series) ↔ trend(SSR time series)**
- **→ enough to have map of σ(SSR time series)**
  [↔ map of trend(SSR time series) for any trend length and percentile]
- **→ one for absolute, one for relative units** [‘W/m²/decade’ or ‘%/decade’]

Some dependence on concrete model

Models bracketed by in-situ (surface) and CERES (satellite) observations

[0.7 σ(in-situ) ~ σ(CMIP5) ~ 1.2 σ(CERES)]

For example: due to internal variability alone, there is a 25% chance that over the next 30 years SSR increases by at least



Internal variability of SSR → Folini et al. (2017)

RESEARCH ARTICLE
10.1002/2016JD025869

Key Points:
- Internal variability can produce substantial decadal scale trends of surface solar radiation, which may compensate or enhance forced trends
- Absolute and relative trends depend differently on geographical region, 20 year trends have about 50% smaller magnitude than 15 year trends
- Results suggest that care should be taken when comparing surface solar radiation trends of different length and from different regions

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Trends of surface solar radiation in unforced CMIP5 simulations

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Abstract We consider decadal scale trends of annual mean all-sky surface solar radiation (SSR) that occur solely because of internal variability of the climate system. We give statistical estimates of their magnitude and probability of occurrence. The estimates are based on 43 preindustrial control (piControl) experiments of the Coupled Model Intercomparison Project phase 5 (CMIP5). Trends are found to depend strongly on geographical region and on whether they are quantified in absolute units or relative to the long-term mean SSR. We find it to be sufficient to provide one map for absolute and one for relative trends, as approximate analytical relations are shown to hold between trends of different length and likelihood and the standard deviation of the underlying SSR time series. We estimate that a positive trend over 30 years and with 25% chance of occurrence (75th percentile of all possible trends) has a magnitude between 0.15 and 1.7 W/m^2/decade or 0.11 and 1.4% of long-term mean SSR per decade, depending on geographical location. Comparison with present-day observations and intermodel spread suggests an average uncertainty of these estimates of about 30%. Intermodel spread suggests that regional uncertainties can be up to about 3 times larger or smaller. We give examples of how these results may be used to obtain statistical estimates of how (un)likely it is that observed SSR trends or part thereof are due to internal variability alone.

From SSR to PV

From monthly mean (or annual mean) SSR (and temperature) to PV production

Crook et al. 2011:

TAS SSR

$$\frac{\eta_{\mathrm{cell}}}{\eta_{\mathrm{ref}}} = 1 - \beta\left(T_{\mathrm{cell}} - T_{\mathrm{ref}}\right) + \gamma \log_{10} G_{\mathrm{tot}}$$

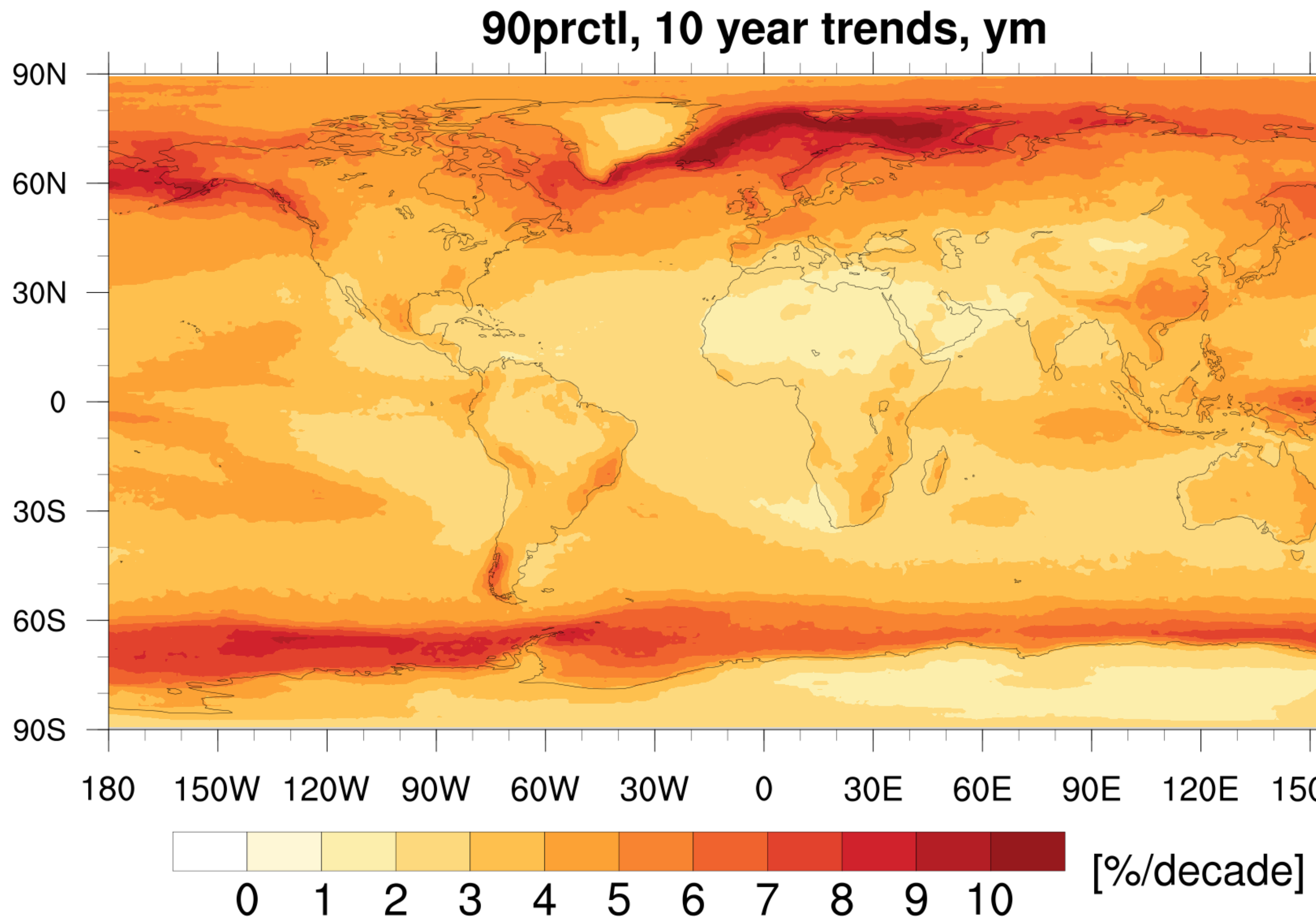
$$P_{\mathrm{PV}} = G_{\mathrm{tot}}\eta_{\mathrm{cell}}$$

→ Change in PV production [in %]:

$$\Delta P_{PV} = (P_{PV} - <P_{PV}>) / <P_{PV}>$$

Same approach as used in master thesis Florian Henschel / Wild et al. 2015

PV trends from internal variability [CMIP5 multimodel median + Crook et al. 2011]



E.g. Europe:

10% chance that over the next decade PV production will change by +/- 5% only because of internal variability of the climate system.

Folini et al. 2020, to be submitted

Thanks for reading