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From point to are:

Worldwide assessment of the representativeness of monthly surface solar radiation records

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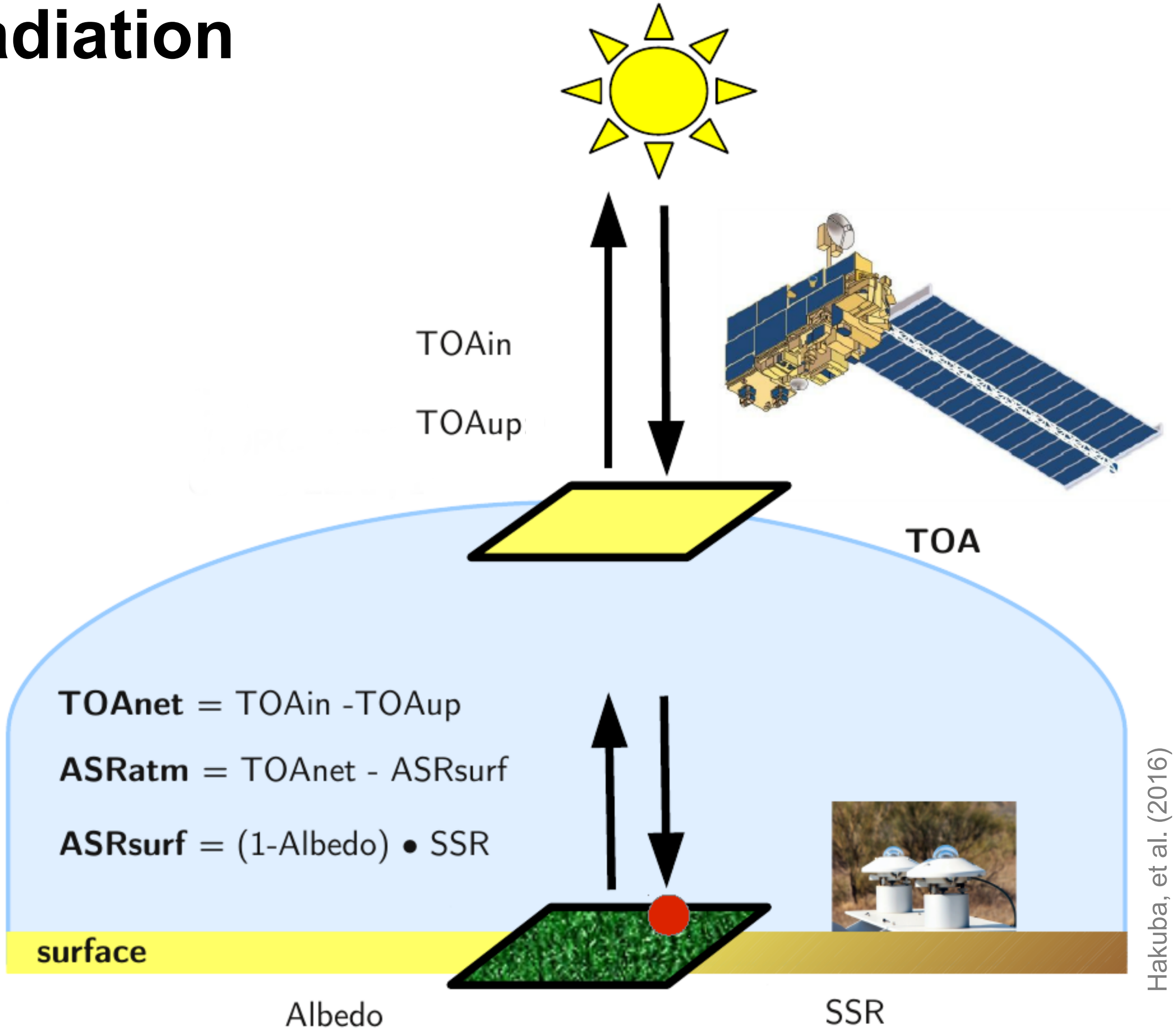
Work from:

Schwarz, et al. (2017).

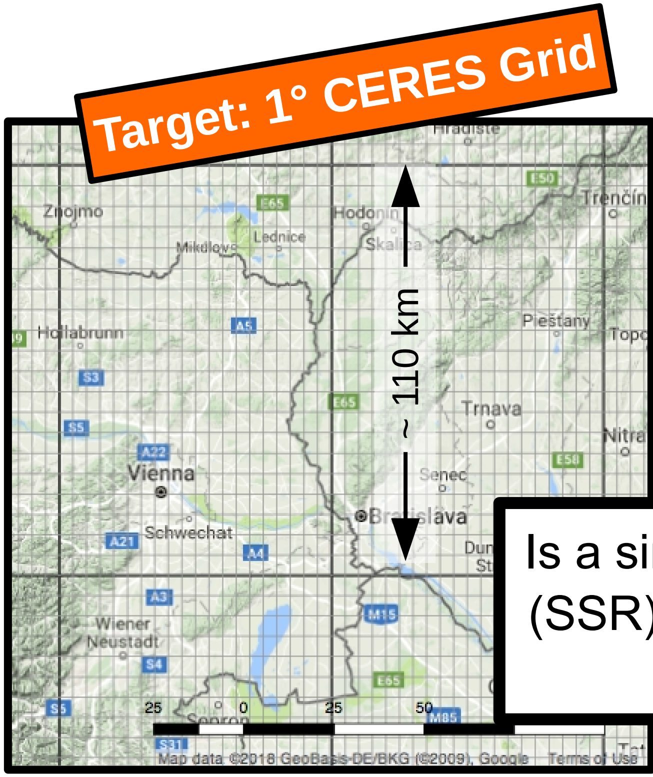
Schwarz, et al. (in preperation)

Overarching Goal: Studying Temporal Variability in Partitioning of Solar Radiation



→ *see also science poster: Towards observation-based time series for the partitioning of solar energy in the climate system.*

Research Question



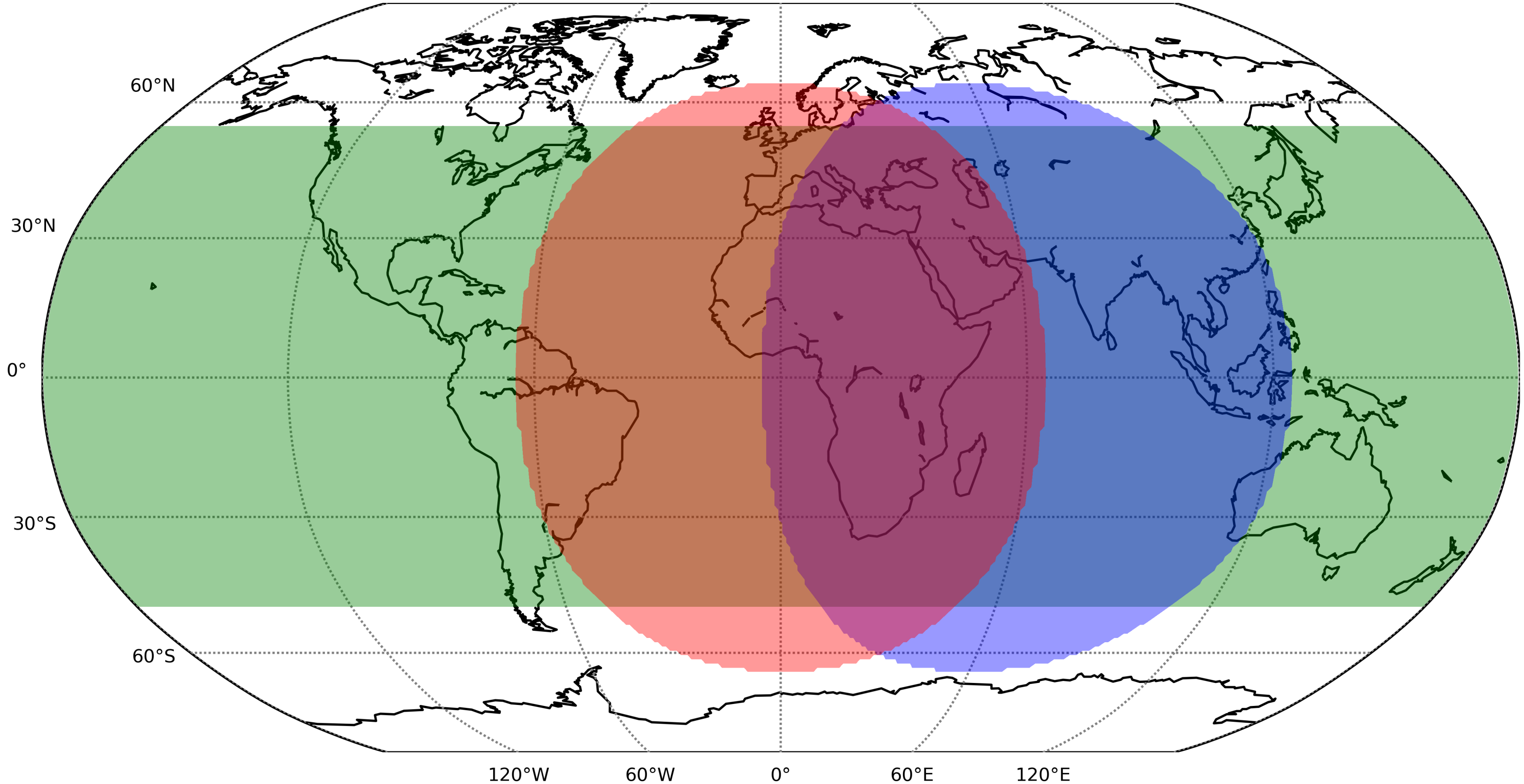
Is a single surface solar radiation (SSR) time series representative for a 1° gridbox?

Observation with Pyranometer

High Resolution Satellite-derived SSR Data

Global scale analysis with **monthly mean** satellite derived SSR from CM-SAF

- SARAH-P V002 (0.05 x 0.05°) Pfeifroth, et al. (2018)
- SARAH-E V001 (0.05 x 0.05°) Huld, et al. (2016)
- CLARA-A2 (0.25 x 0.25°) Karlsson, et al. (2017)



Method

Is a single surface solar radiation (SSR) time series representative for a 1° gridbox?

Three aspects of representativeness:

I. Spatial correlations (R^2): decorrelation length (δ)

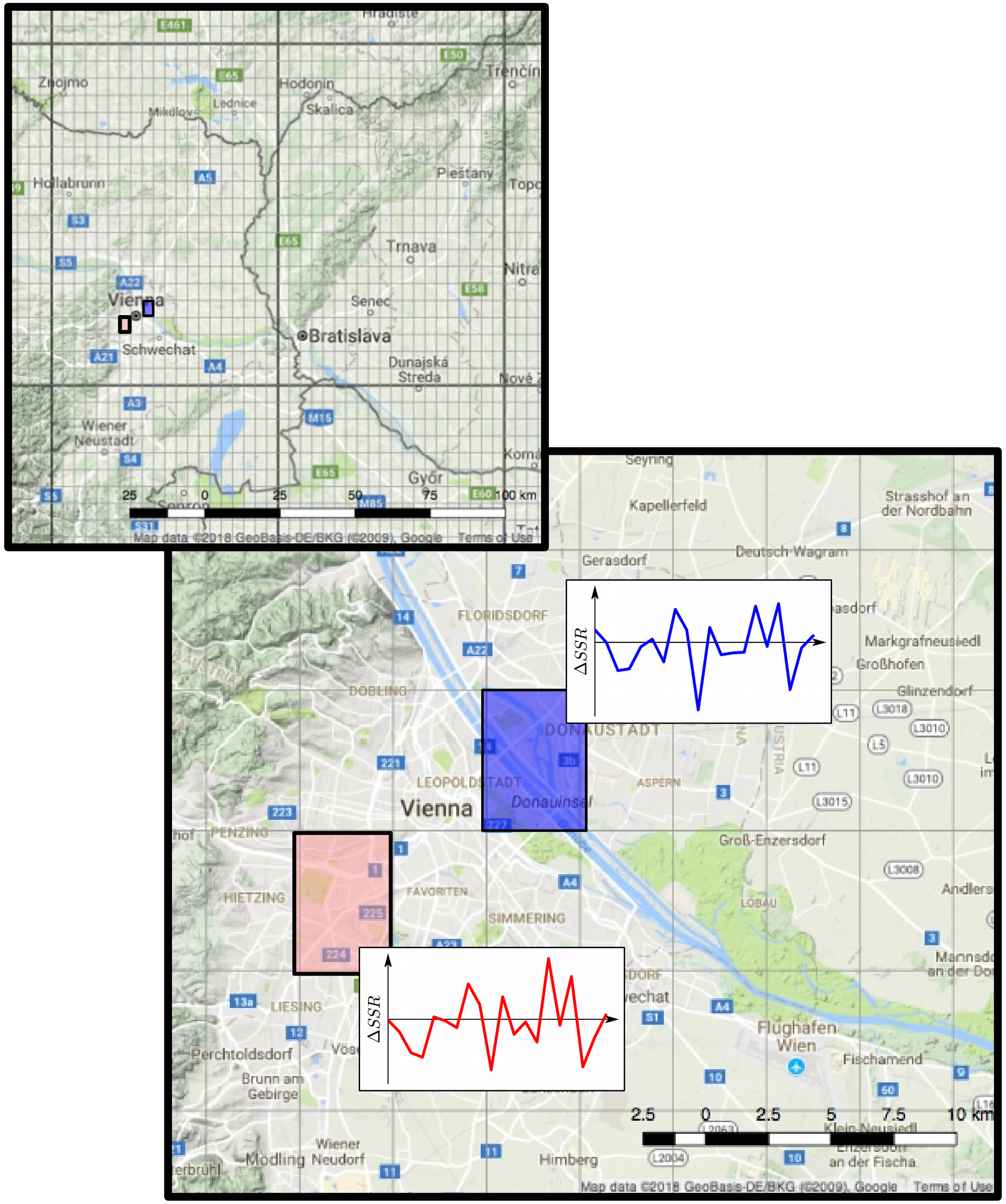
II. Spatial Sampling Biases (β): differences in climatological means

III. Spatial Sampling Errors (ε): differences in anomaly time series

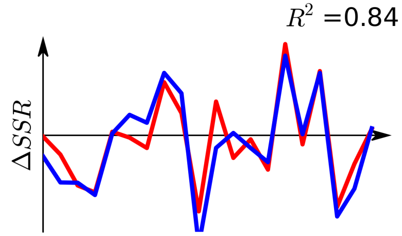
Target: 1° CERES Grid on monthly mean time sclae

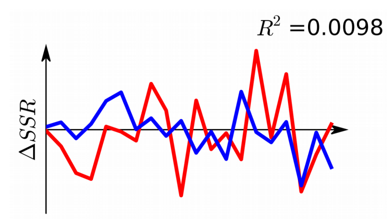
Spatial Correlations (R^2)

CERES 1° GRID

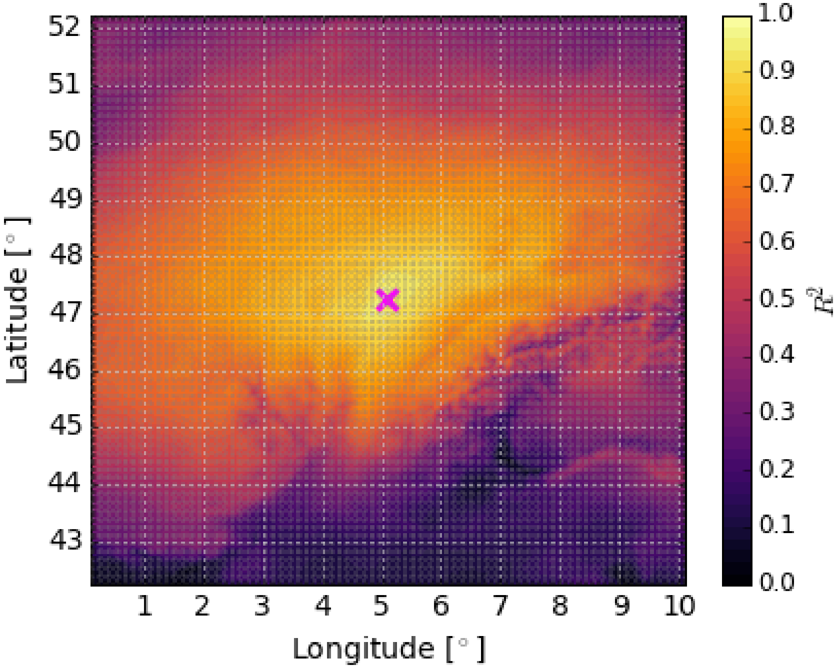


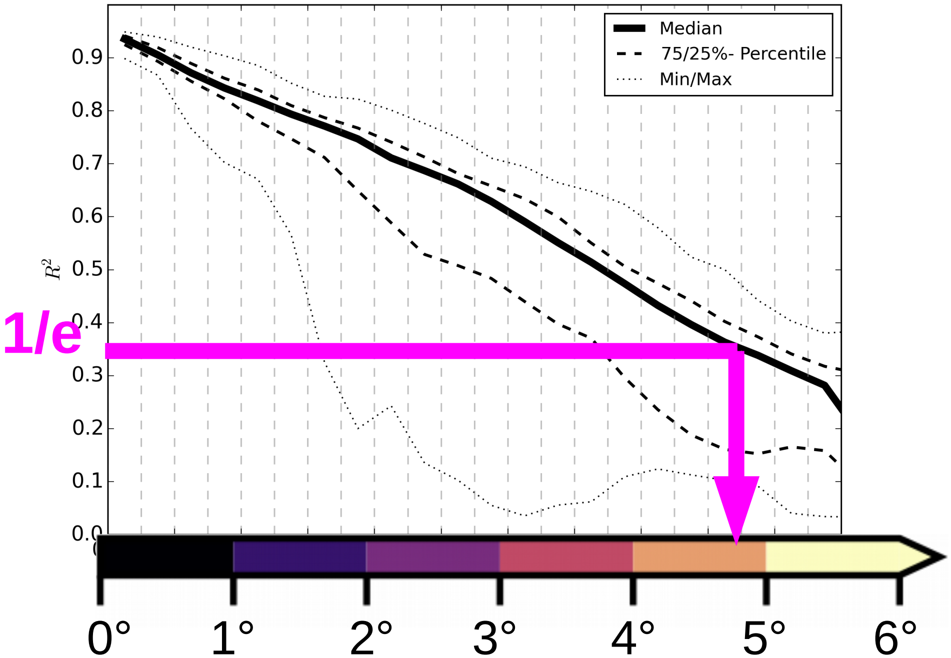
$$R(a,b)^2 = \left(\frac{\mathrm{cov}(a,b)}{\sigma(a)\sigma(b)} \right)^2$$





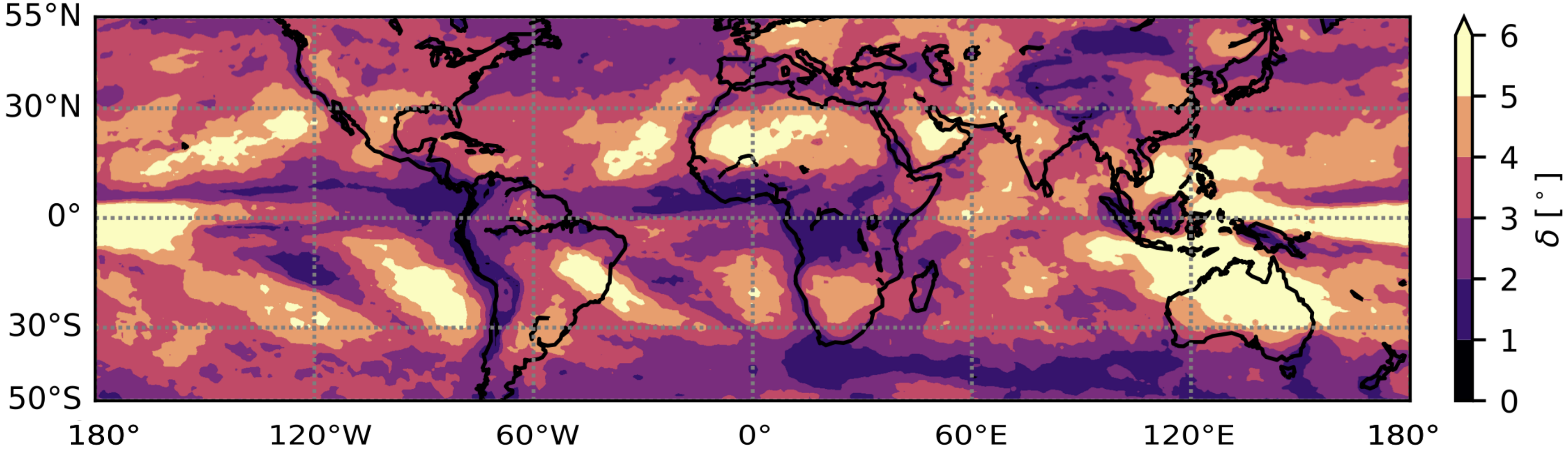
Decorrelation Length (δ)





1° ≈ 111km

Decorrelation Length (δ) from CLARA



- Near-global (50S-55N) mean δ ≈ 3.4°
- Roughly
  - ~2% of 1° boxes have average δ < 1°
  - ~5% of 1° boxes have average δ < 2°

Combination of SSR from point observations with 1° gridded data is feasible in most regions!

Method

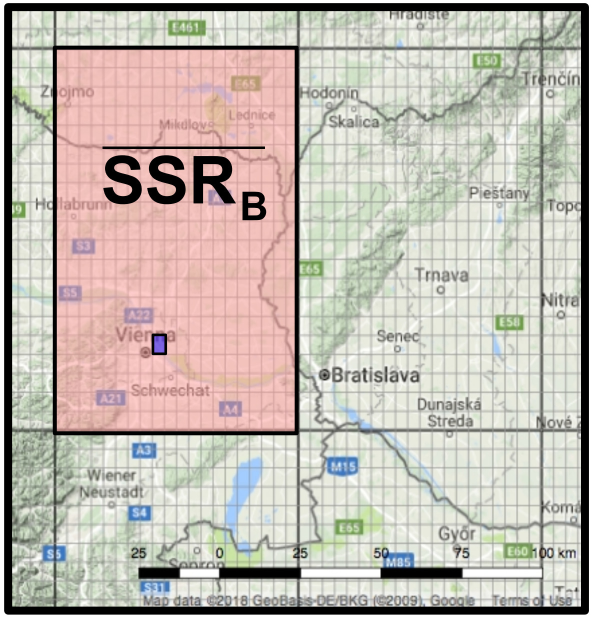
Three aspects of representativeness:

I. Spatial correlations (R^2): decorrelation length (δ)

II. Spatial Sampling Biases (β): differences in climatological means Hakuba, et al. (2013 & 2014)

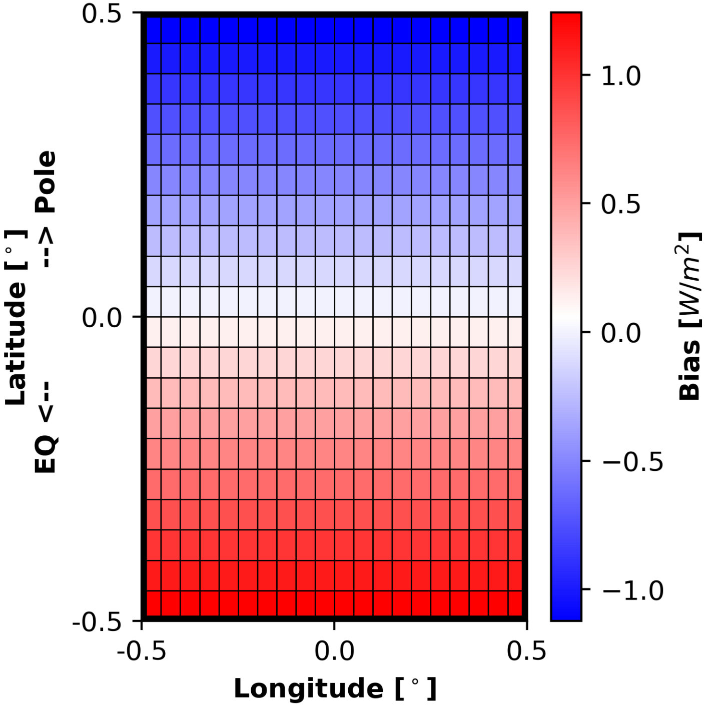
III. Spatial Sampling Errors (ε): "maximum" differences in anomaly time series

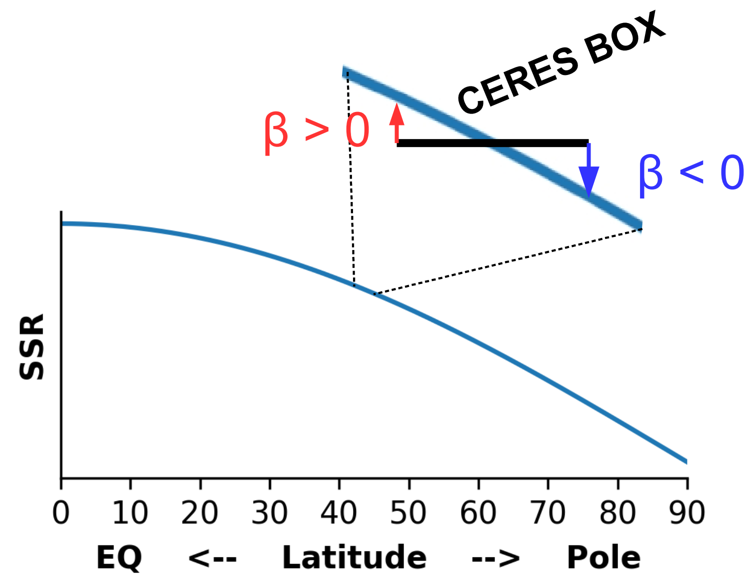
CM-SAF 0.05° Pixel vs. **CERES 1° Box mean**



$$\beta_P = \overline{SSR}_P - \overline{SSR}_B$$

Spatial Sampling Biases – Pixel Based

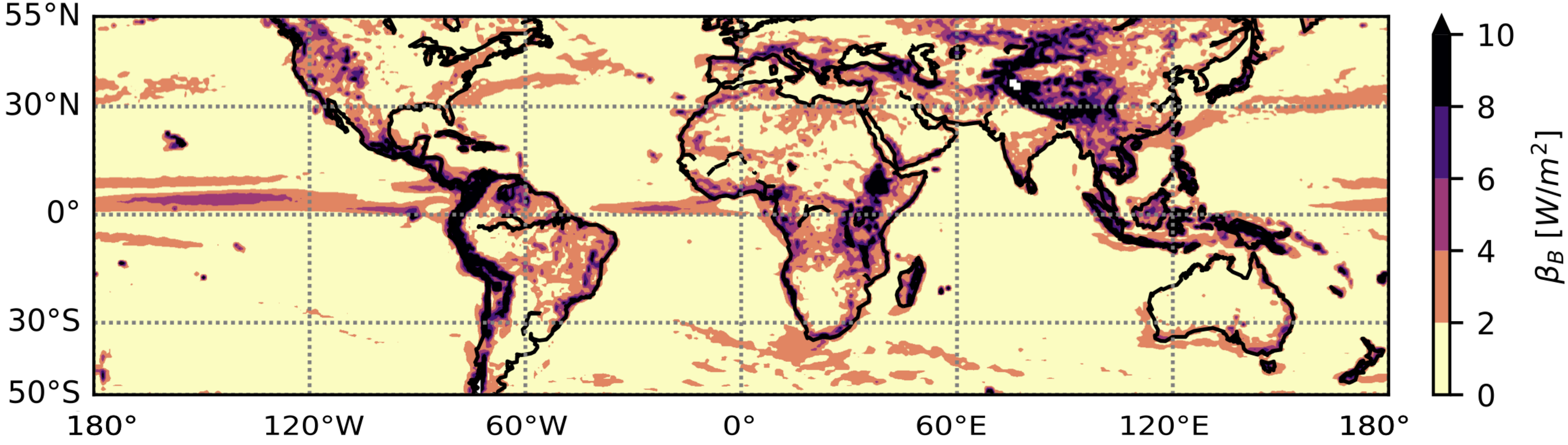




“Typical” magnitude of biases within 1° box

$$\beta_B = \sqrt{\frac{1}{N}\sum_N \left(\beta_P - \overline{\beta_P}\right)}$$

Spatial Sampling Biases – Box Aggregated



- Near-global (50S-55N) β_B ≈1.4 W/m^2
- Magnitudes of biases vary across regions

- Bias of station depends on position within 1° box
- Biases can be corrected (if known)
- (biases have annual cycle)

Method

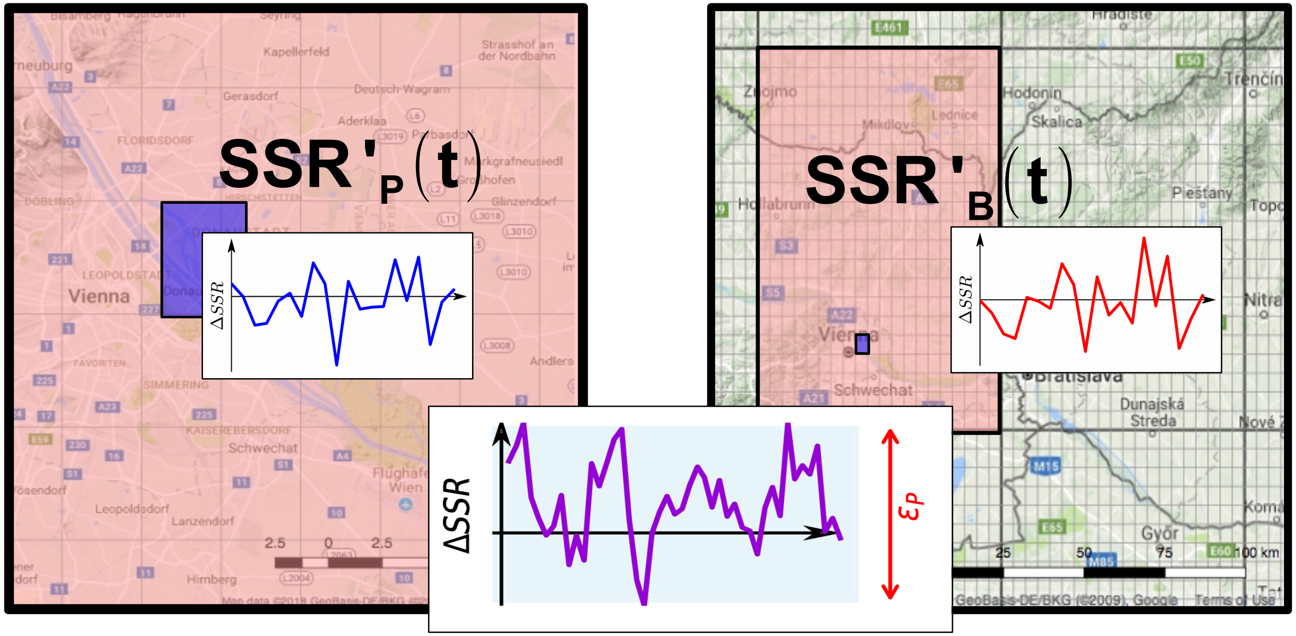
Three aspects of representativeness:

I. Spatial correlations (R^2): decorrelation length (δ)

II. Spatial Sampling Biases (β): differences in climatological means

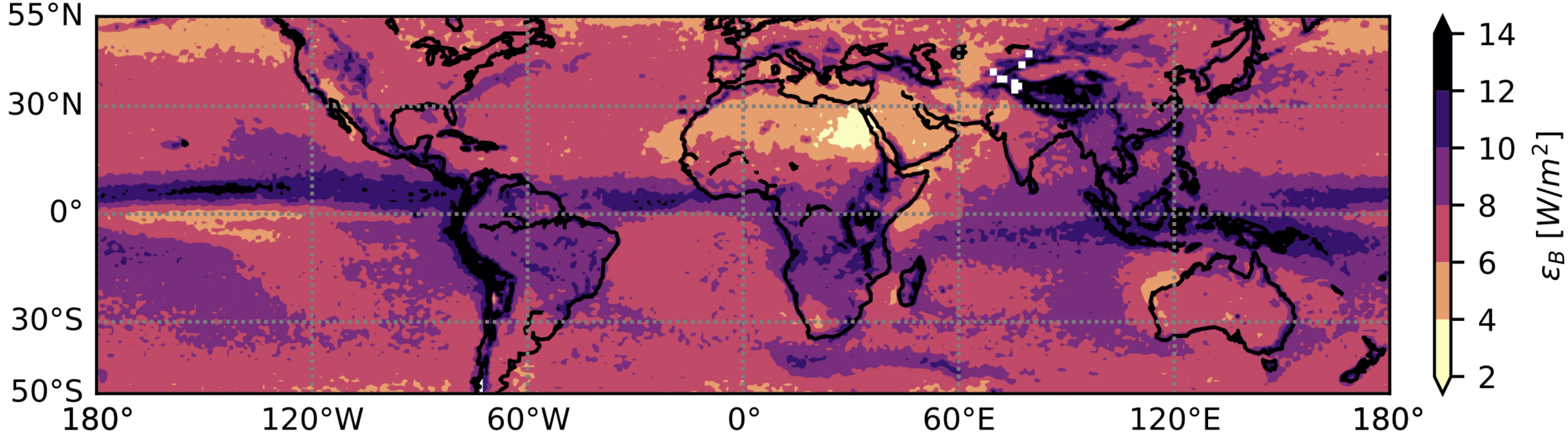
III. Spatial Sampling Errors (ε): differences in anomaly time series

CM-SAF 0.05° Pixel vs. **CERES 1° Box mean**



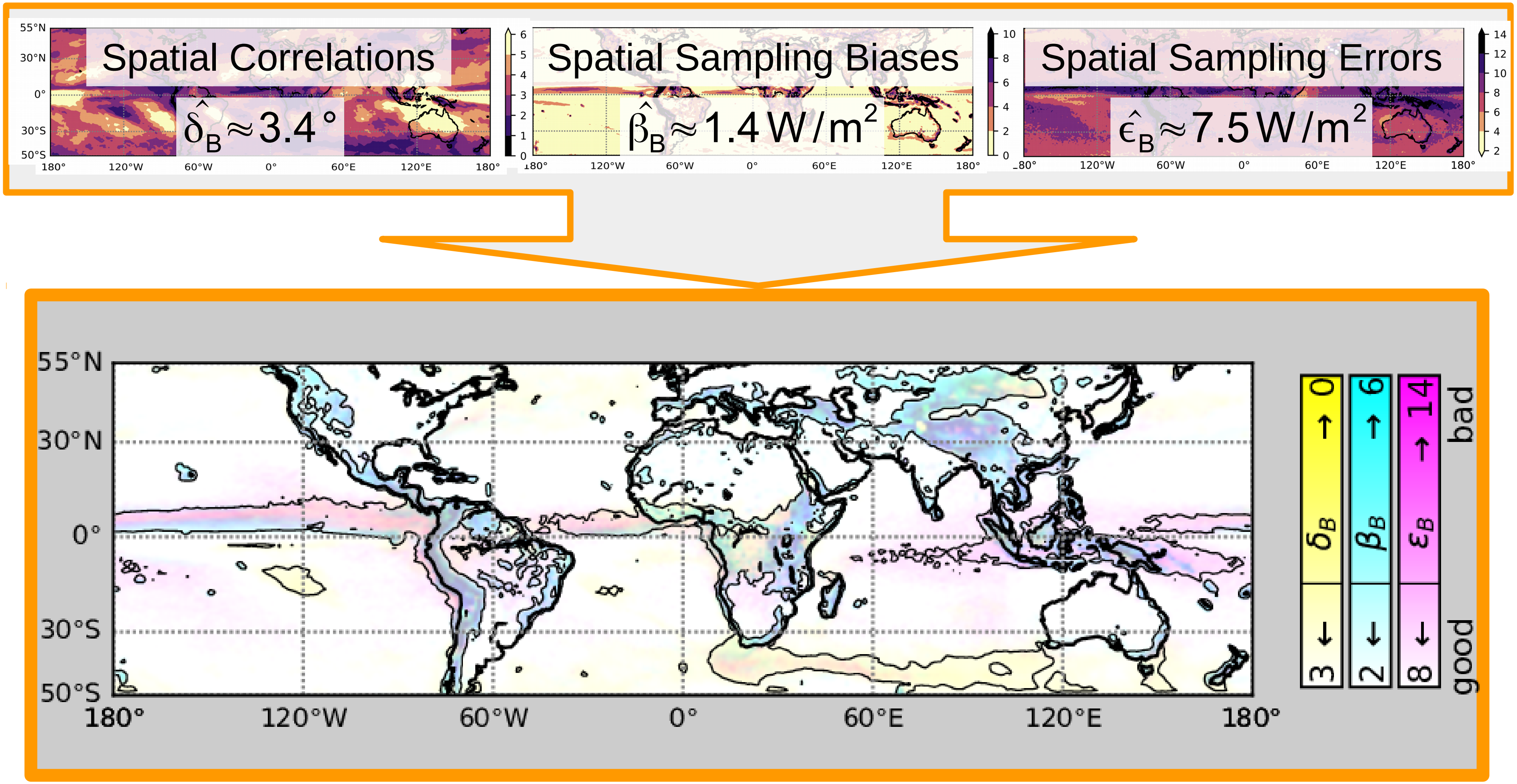
$$\epsilon_P = P^{95}\left(\left|SSR'_P(t) - SSR'_B(t)\right|\right) \qquad \epsilon_B = P^{68.2}(\epsilon_P)$$

Spatial Sampling Errors – Box Aggregated



- Global mean (50S-55N) $\varepsilon_B \approx 7.5$ W/m^2
- Errors are calculated form individually deseasonalized time series → implicit bias correction
- Without bias correction errors are 10-15% higher
- Errors for other grids:
  - 0.5°x 0.5° grid ~ 30% smaller
  - 2.5° x 2.5° grid ~ 60% larger

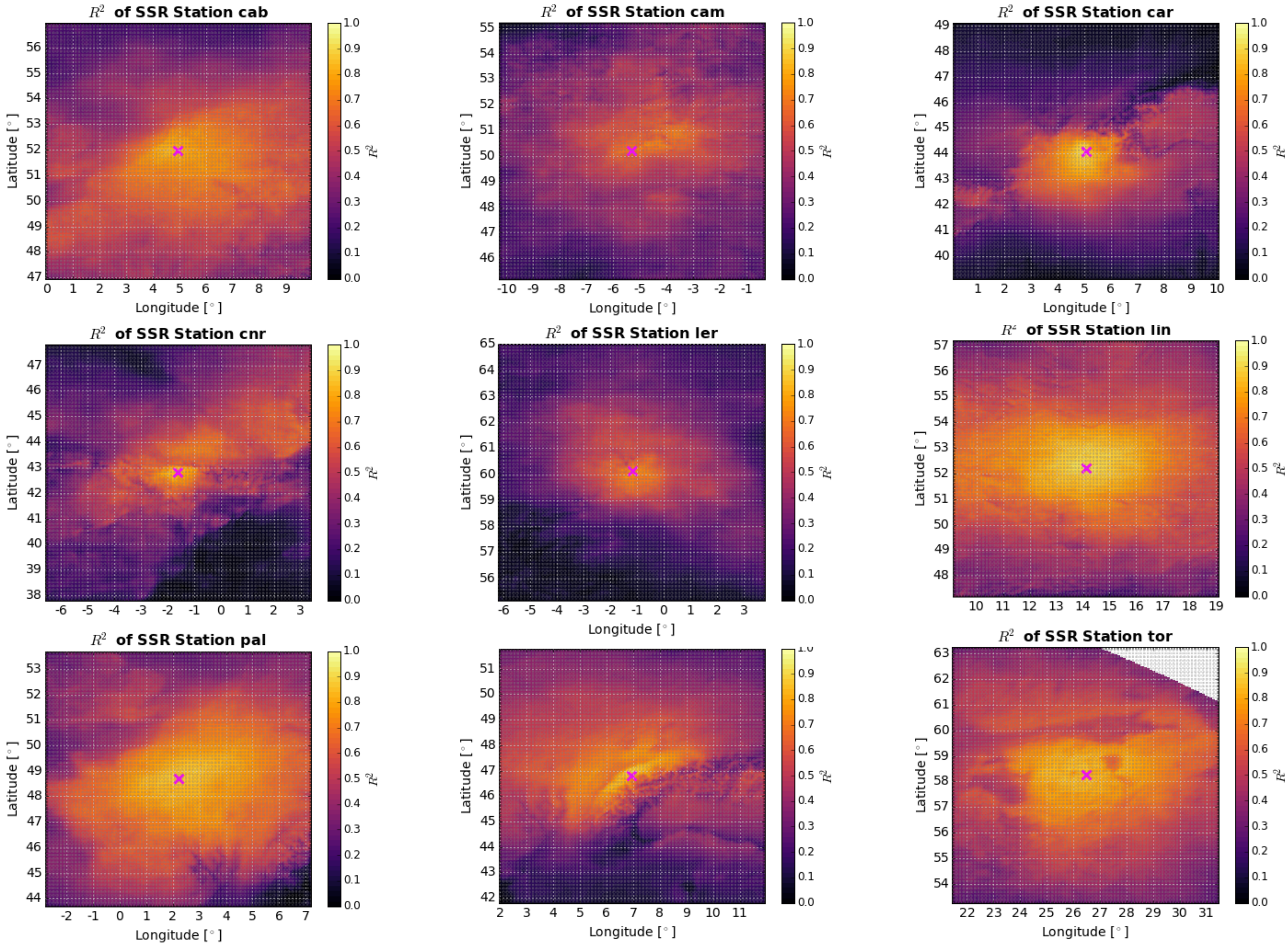
Combining the metrics



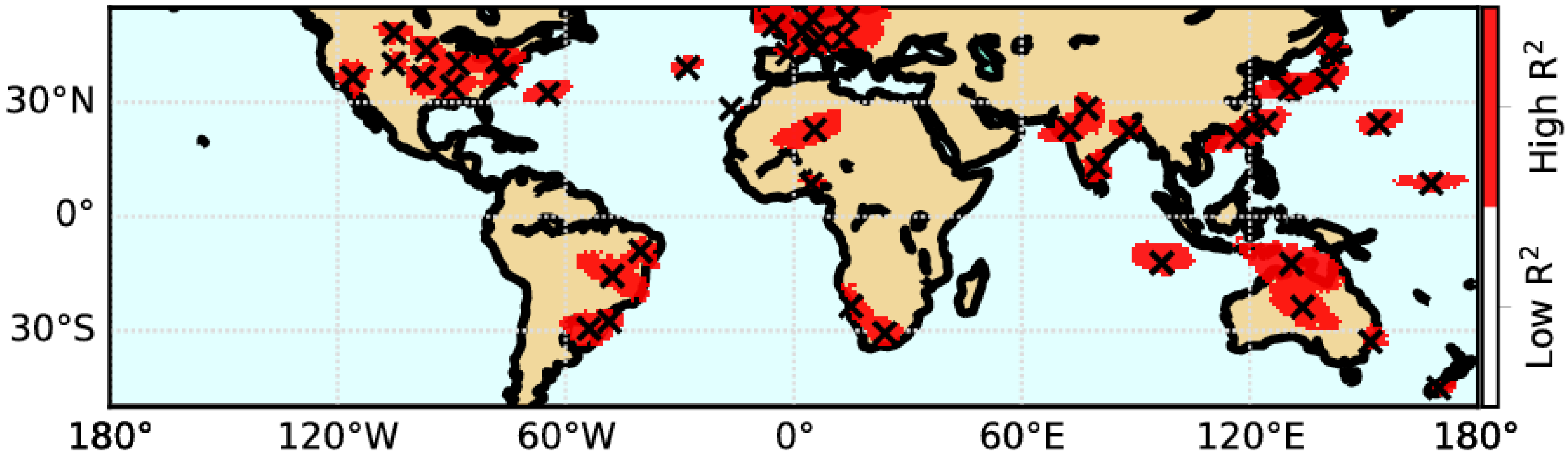
→ Different metrics limit representativeness in different regions

Case Study:
The Baseline Surface Radiation Network

Case Study BSRN



Case Study BSRN
Direct sampling capacity (monthly mean SSR)



The 47 BSRN stations inside domain can together directly ($R^2 > 1/e$) sample

- 16% of the domains land pixels
- 7% of the domains total pixels

Case Study BSRN

#	Station	LAT [°]	LON [°]	δ [°]	β_B [Wm⁻²]	β_p [Wm⁻²]	ε_B [Wm⁻²]	ε_p [Wm⁻²]
1	Alice Springs	-23.8	133.89	5.6				
3	Bermuda	32.27	-64.67	3.4				
4	Billings	36.61	-97.52	3.6				
5	Bondville	40.07	-88.37	3.4				
7	Boulder	40.13	-105.2	2.9				
8	Brasilia	-15.6	-47.71	5.9				
9	Cabauw	51.97	4.927	5.1				
10	Camborne	50.22	-5.317	3.6				
12	Carpentras	44.08	5.059	3.2				
13	Cener	42.82	-1.601	2.4				
14	Chesapeake Light	36.91	-75.71	2.9				
15	Cocos Island	-12.19	96.835	4.5				
18	Darwin Met Office	-12.42	130.89	5.6				
19	De Aar	-30.67	23.993	4.1				
20	Desert Rock	36.63	-116	3.6				
21	Dongsha Atoll	20.7	116.73	3.9				
22	Eastern North Atlantic	39.09	-28.03	3.0				
24	Florianopolis	-27.61	-48.52	3.4				
25	Fort Peck	48.32	-105.1	2.9				
26	Fukuoka	33.58	130.38	3.9				
27	Gandhinagar	23.11	72.628	3.9				
29	Gobabeb	-23.56	15.042	2.5				
30	Goodwin Creek	34.26	-89.87	3.9				

#	Station	LAT [°]	LON [°]	δ [°]	β_B [Wm⁻²]	β_p [Wm⁻²]	ε_B [Wm⁻²]	ε_p [Wm⁻²]
31	Gurgaon	28.43	77.16	3.8				
32	Howrah	22.55	88.31	2.8				
33	Ilorin	8.533	4.567	2.8				
34	Ishigakijima	24.34	124.2	3.3				
35	Izaña	28.31	-16.5	0.2				
36	Kwajalein	8.72	167.7	3.1				
37	Langley Research Center	37.1	-76.39	3.1				
38	Lauder	-45	169.7	1.6				
40	Lindenberg	52.21	14.12	4.9				
41	Lulin	23.47	120.9	2.3				
42	Minamitorishima	24.29	154	3.6				
45	Newcastle	-32.88	151.7	2.4				
47	Palaiseau, SIRTA Obs.	48.71	2.208	4.9				
48	Payerne	46.82	6.944	4.6				
49	Petrolina	-9.068	-40.32	3.9				
51	Rock Springs	40.72	-77.93	3.4				
53	Sapporo	43.06	141.3	2.6				
55	Sioux Falls	43.73	-96.62	3.1				
57	Sonnblick	47.05	12.96	1.2				
59	Southern Great Plains	36.61	-97.49	3.6				
61	São Martinho da Serra	-29.44	-53.82	4.4				
62	Tamanrasset	22.79	5.529	4.8				
63	Tateno	36.06	140.1	3.4				
65	Tiruvallur	13.09	79.97	3.7				
	Station Mean			**3.5**				
	Station Absolute Mean							

δ
>4°
>5°

Case Study BSRN

#	Station	LAT [°]	LON [°]	δ [°]	β_B [Wm⁻²]	β_p [Wm⁻²]	ε_B [Wm⁻²]	ε_p [Wm⁻²]
1	Alice Springs	-23.8	133.89	5.6	1.2	-0.8		
3	Bermuda	32.267	-64.667	3.4	1.7	-0.1		
4	Billings	36.605	-97.516	3.6	1.6	-1.2		
5	Bondville	40.067	-88.367	3.4	1.2	0.9		
7	Boulder	40.125	-105.24	2.9	7.3	10.8		
8	Brasilia	-15.6	-47.713	5.9	2.5	-3.2		
9	Cabauw	51.971	4.927	5.1	1.5	-0.4		
10	Camborne	50.217	-5.317	3.6	1.5	-3.8		
12	Carpentras	44.083	5.059	3.2	10.5	14.5		
13	Cener	42.816	-1.601	2.4	11.1	-10.7		
14	Chesapeake Light	36.905	-75.713	2.9	1.0	-0.9		
15	Cocos Island	-12.19	96.835	4.5	0.4	-0.6		
18	Darwin Met Office	-12.42	130.89	5.6	1.8	-0.1		
19	De Aar	-30.67	23.993	4.1	1.1	-1.5		
20	Desert Rock	36.626	-116	3.6	3.1	-2.6		
21	Dongsha Atoll	20.7	116.73	3.9	3.1	-0.2		
22	Eastern North Atlantic	39.091	-28.029	3.0	1.7	-1.1		
24	Florianopolis	-27.61	-48.523	3.4	4.9	1.8		
25	Fort Peck	48.317	-105.1	2.9	2.3	1.7		
26	Fukuoka	33.582	130.38	3.9	3.0	0		
27	Gandhinagar	23.11	72.628	3.9	0.7	-0.2		
29	Gobabeb	-23.56	15.042	2.5	3.3	1.6		
30	Goodwin Creek	34.255	-89.873	3.9	2.0	1.8		

#	Station	LAT [°]	LON [°]	δ [°]	β_B [Wm⁻²]	β_p [Wm⁻²]	ε_B [Wm⁻²]	ε_p [Wm⁻²]
31	Gurgaon	28.43	77.16	3.8	1.3	1		
32	Howrah	22.55	88.31	2.8	2.4	-1.2		
33	Ilorin	8.533	4.567	2.8	5.8	0.6		
34	Ishigakijima	24.34	124.2	3.3	3.2	-2.6		
35	Izaña	28.31	-16.5	0.2	12.9	-6.6		
36	Kwajalein	8.72	167.7	3.1	2.1	-0.3		
37	Langley Research Center	37.1	-76.39	3.1	2.3	4		
38	Lauder	-45	169.7	1.6	8.0	6.5		
40	Lindenberg	52.21	14.12	4.9	1.2	2.3		
41	Lulin	23.47	120.9	2.3	12.9	-15.9		
42	Minamitorishima	24.29	154	3.6	1.1	0.8		
45	Newcastle	-32.88	151.7	2.4	5.3	3.6		
47	Palaiseau, SIRTA Obs.	48.71	2.208	4.9	2.2	-0.5		
48	Payerne	46.82	6.944	4.6	6.4	1.6		
49	Petrolina	-9.068	-40.32	3.9	4.2	3.1		
51	Rock Springs	40.72	-77.93	3.4	2.7	-3.2		
53	Sapporo	43.06	141.3	2.6	4.9	5.6		
55	Sioux Falls	43.73	-96.62	3.1	1.3	-0.8		
57	Sonnblick	47.05	12.96	1.2	6.9	-4.5		
59	Southern Great Plains	36.61	-97.49	3.6	1.6	-1.5		
61	São Martinho da Serra	-29.44	-53.82	4.4	2.5	0.6		
62	Tamanrasset	22.79	5.529	4.8	3.1	-3.1		
63	Tateno	36.06	140.1	3.4	3.4	0.7		
65	Tiruvallur	13.09	79.97	3.7	3.2	0.1		
	Station Mean			**3.5**	**3.6**	**2.8**		
	Station Absolute Mean					**10.0**		

δ	β_B	β_p [Wm⁻²]
>4°	>1 Wm^{-2}	>0.5 Wm^{-2}
>5°	>2 Wm^{-2}	>1.0 Wm^{-2}

Case Study BSRN

#	Station	LAT [°]	LON [°]	δ [°]	β_B [Wm^{-2}]	β_p [Wm^{-2}]	ε_B [Wm^{-2}]	ε_p [Wm^{-2}]
1	Alice Springs	-23.8	133.89	5.6	1.2	-0.8	7.5	7.3
3	Bermuda	32.27	-64.67	3.4	1.7	-0.1	7.2	5.5
4	Billings	36.61	-97.52	3.6	1.6	-1.2	6.7	4.6
5	Bondville	40.07	-88.37	3.4	1.2	0.9	6.5	6.0
7	Boulder	40.13	-105.2	2.9	7.3	10.8	11.9	13.3
8	Brasilia	-15.6	-47.71	5.9	2.5	-3.2	8.9	7.5
9	Cabauw	51.97	4.927	5.1	1.5	-0.4	6.9	7.8
10	Camborne	50.22	-5.317	3.6	1.5	-3.8	7.9	11.1
12	Carpentras	44.08	5.059	3.2	10.5	14.5	12.9	13.4
13	Cener	42.82	-1.601	2.4	11.1	-10.7	11.5	11.8
14	Chesapeake Light	36.91	-75.71	2.9	1.0	-0.9	7.1	6.8
15	Cocos Island	-12.19	96.835	4.5	0.4	-0.6	8.7	8.9
18	Darwin Met Office	-12.42	130.89	5.6	1.8	-0.1	9.4	6.6
19	De Aar	-30.67	23.993	4.1	1.1	-1.5	5.5	5.2
20	Desert Rock	36.63	-116	3.6	3.1	-2.6	5.0	4.3
21	Dongsha Atoll	20.7	116.73	3.9	3.1	-0.2	8.6	6.5
22	Eastern North Atlantic	39.09	-28.03	3.0	1.7	-1.1	6.5	9.6
24	Florianopolis	-27.61	-48.52	3.4	4.9	1.8	10.8	5.9
25	Fort Peck	48.32	-105.1	2.9	2.3	1.7	8.2	6.0
26	Fukuoka	33.58	130.38	3.9	3.0	0	8.3	5.2
27	Gandhinagar	23.11	72.628	3.9	0.7	-0.2	6.3	7.0
29	Gobabeb	-23.56	15.042	2.5	3.3	1.6	6.9	8.7
30	Goodwin Creek	34.26	-89.87	3.9	2.0	1.8	7.2	5.4

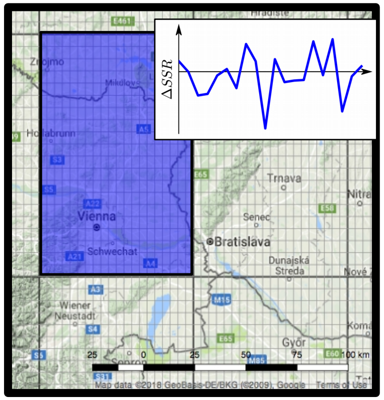
δ	β_B	β_p [Wm^{-2}]	ε_B / ε_p
>4°	>1 Wm^{-2}	>0.5 Wm^{-2}	< 8 Wm^{-2}
>5°	>2 Wm^{-2}	>1.0 Wm^{-2}	< 6 Wm^{-2}

#	Station	LAT [°]	LON [°]	δ [°]	β_B [Wm^{-2}]	β_p [Wm^{-2}]	ε_B [Wm^{-2}]	ε_p [Wm^{-2}]
31	Gurgaon	28.43	77.16	3.8	1.3	1	6.5	6.0
32	Howrah	22.55	88.31	2.8	2.4	-1.2	7.8	7.3
33	Ilorin	8.533	4.567	2.8	5.8	0.6	7.6	5.0
34	Ishigakijima	24.34	124.2	3.3	3.2	-2.6	8.3	6.5
35	Izaña	28.31	-16.5	0.2	12.9	-6.6	21.2	50.4
36	Kwajalein	8.72	167.7	3.1	2.1	-0.3	8.2	7.1
37	Langley Research Center	37.1	-76.39	3.1	2.3	4	6.7	6.7
38	Lauder	-45	169.7	1.6	8.0	6.5	9.4	8.6
40	Lindenberg	52.21	14.12	4.9	1.2	2.3	6.2	6.4
41	Lulin	23.47	120.9	2.3	12.9	-15.9	12.9	14.4
42	Minamitorishima	24.29	154	3.6	1.1	0.8	8.3	8.4
45	Newcastle	-32.88	151.7	2.4	5.3	3.6	10.6	10.2
47	Palaiseau, SIRTA Obs.	48.71	2.208	4.9	2.2	-0.5	6.3	5.3
48	Payerne	46.82	6.944	4.6	6.4	1.6	11.8	9.7
49	Petrolina	-9.068	-40.32	3.9	4.2	3.1	9.0	8.7
51	Rock Springs	40.72	-77.93	3.4	2.7	-3.2	7.4	6.6
53	Sapporo	43.06	141.3	2.6	4.9	5.6	8.4	7.1
55	Sioux Falls	43.73	-96.62	3.1	1.3	-0.8	6.8	4.5
57	Sonnblick	47.05	12.96	1.2	6.9	-4.5	14.6	29.4
59	Southern Great Plains	36.61	-97.49	3.6	1.6	-1.5	6.7	4.1
61	São Martinho da Serra	-29.44	-53.82	4.4	2.5	0.6	7.2	5.2
62	Tamanrasset	22.79	5.529	4.8	3.1	-3.1	6.6	6.6
63	Tateno	36.06	140.1	3.4	3.4	0.7	8.2	8.0
65	Tiruvallur	13.09	79.97	3.7	3.2	0.1	8.6	6.7
	Station Mean			**3.5**	**3.6**	**2.8**	**8.5**	**8.8**
	Station Absolute Mean					**10.0**		

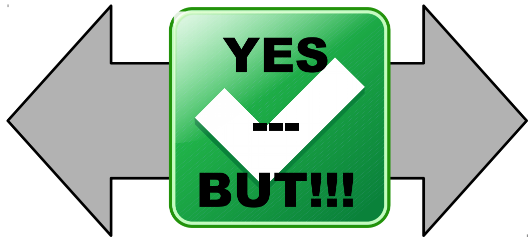
Case Study: The Baseline Surface Radiation Network

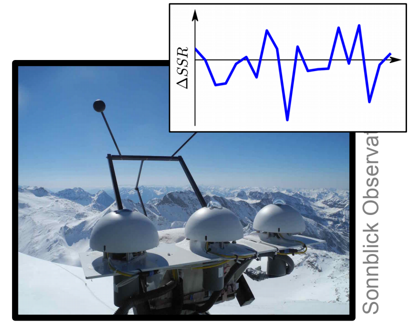
- 47 BSRN stations inside domain
- Multi station averages:
  - $\langle\delta\rangle_{BSRN} \approx 3.5°$
  - $\langle\beta_B\rangle_{BSRN} \approx 3.7\ W/m^2$ $\langle|\beta_P|\rangle_{BSRN} \approx 2.9\ W/m^2$
  - $\langle\varepsilon_B\rangle_{BSRN} \approx 8.6\ W/m^2$ $\langle\varepsilon_P\rangle_{BSRN} \approx 8.9\ W/m^2$
- 3 sites $\delta < 1°$
- 11 sites $1° \leq \delta_P < 2°$;
- 26 sites $\delta_P > 3°$
- 14 sites $\varepsilon_P > 8\ W/m^2$
- 14 sites $\varepsilon_P < 6\ W/m^2$ (4 sites $\varepsilon_P > 5\ W/m^2$)

Synthesis

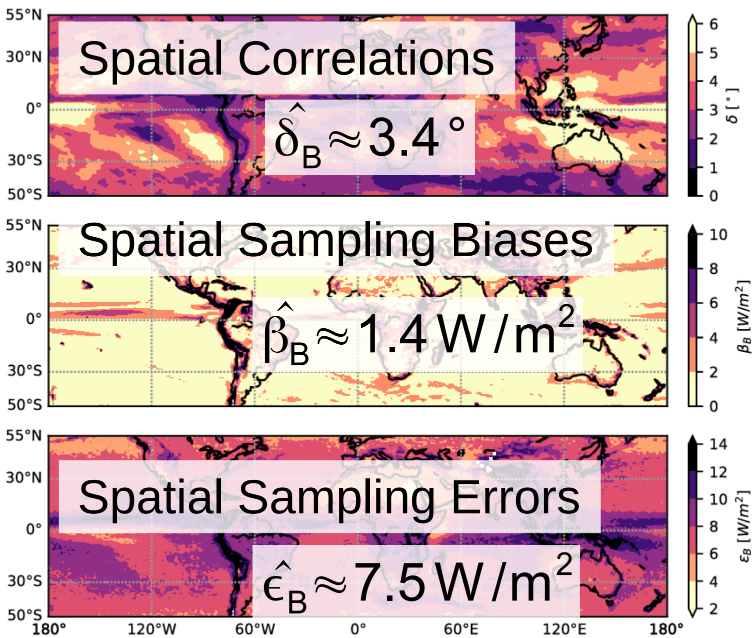


CERES 1° GRID





Observation with Pyranometer



- Combining point and (1°) gridded data is possible in most regions
- Grid specific bias correction is advisable
- Combined uncertainty (1° grid):

  Measurement uncertainty
  + spatial sampling error (ε)

  Total uncertainty ~40-50% higher than measurement uncertainty alone

- Large regional differences!
- Representativeness is limited in different regions due to different reasons!

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Pixel as Surrogate for Point Observation

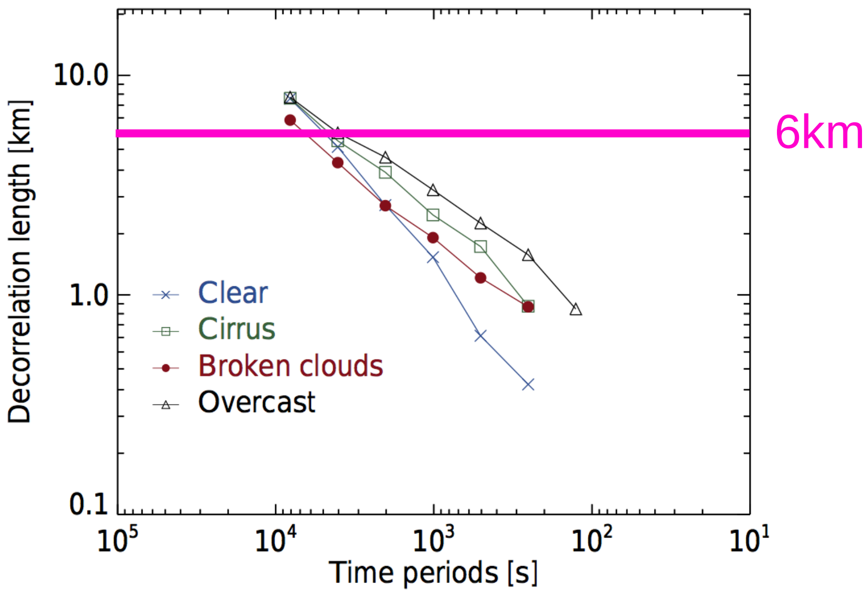
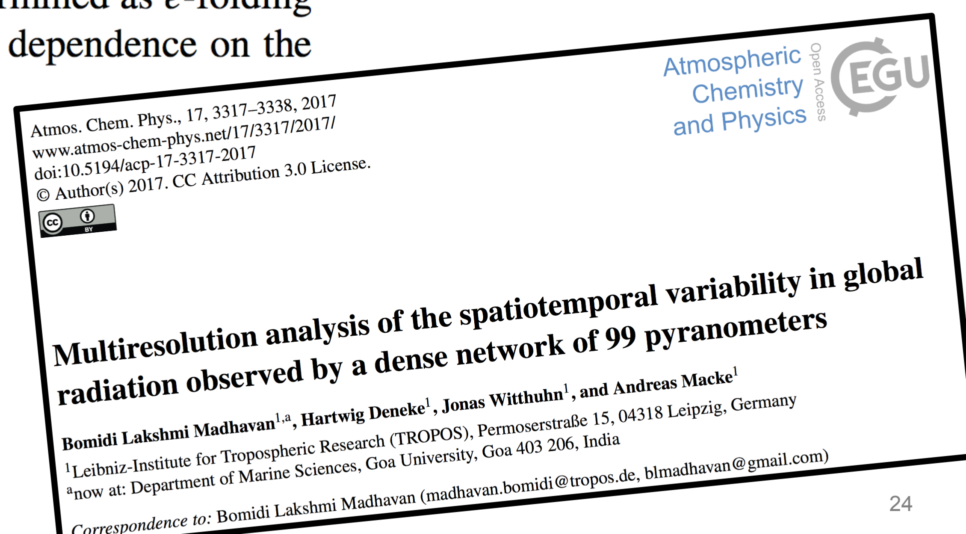


Figure 7. Decorrelation lengths *a* (in km), determined as *e*-folding time of the spatial correlation function, and its dependence on the time period of variations.



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doi:10.5194/acp-17-3317-2017

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Multiresolution analysis of the spatiotemporal variability in global radiation observed by a dense network of 99 pyranometers

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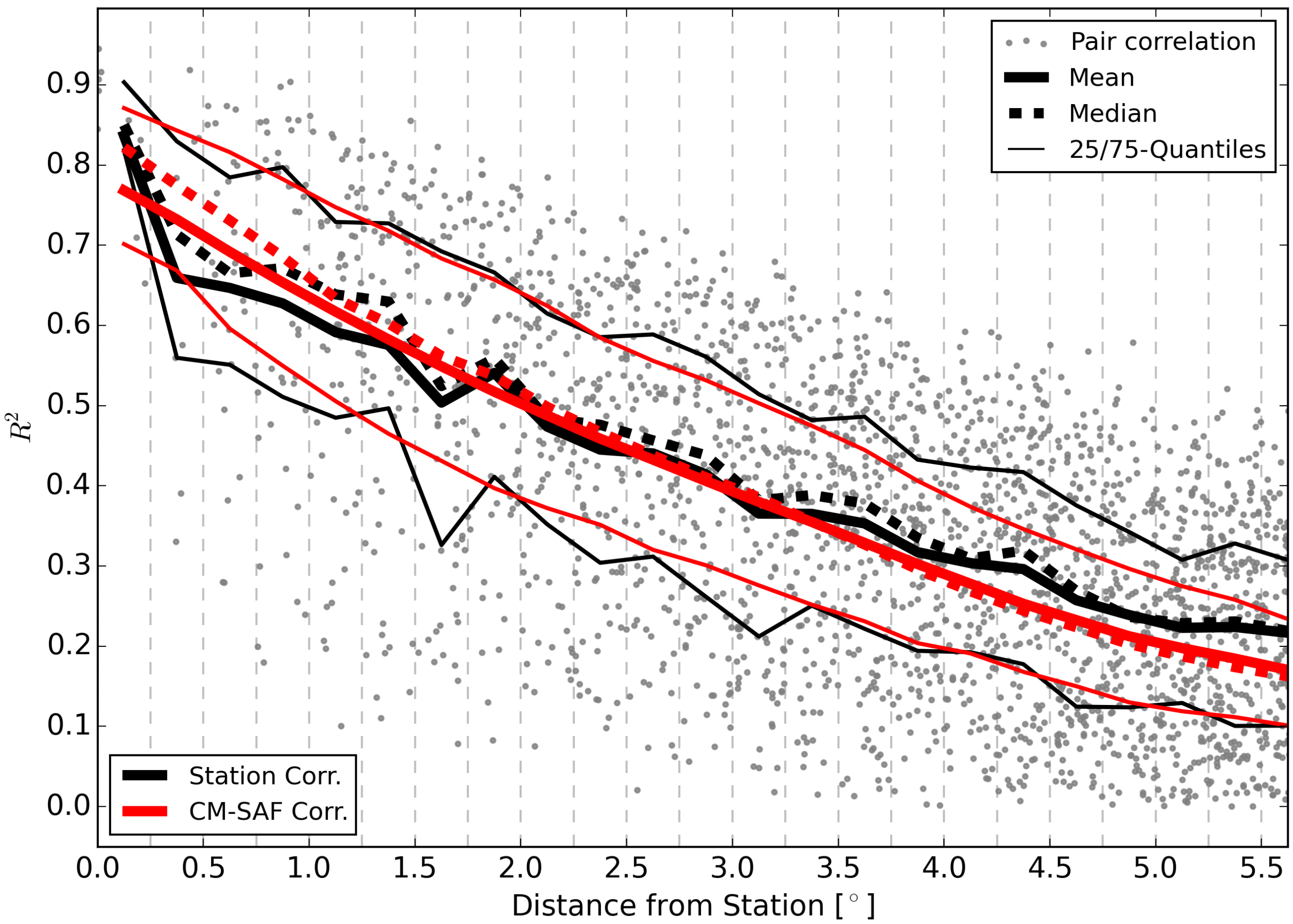
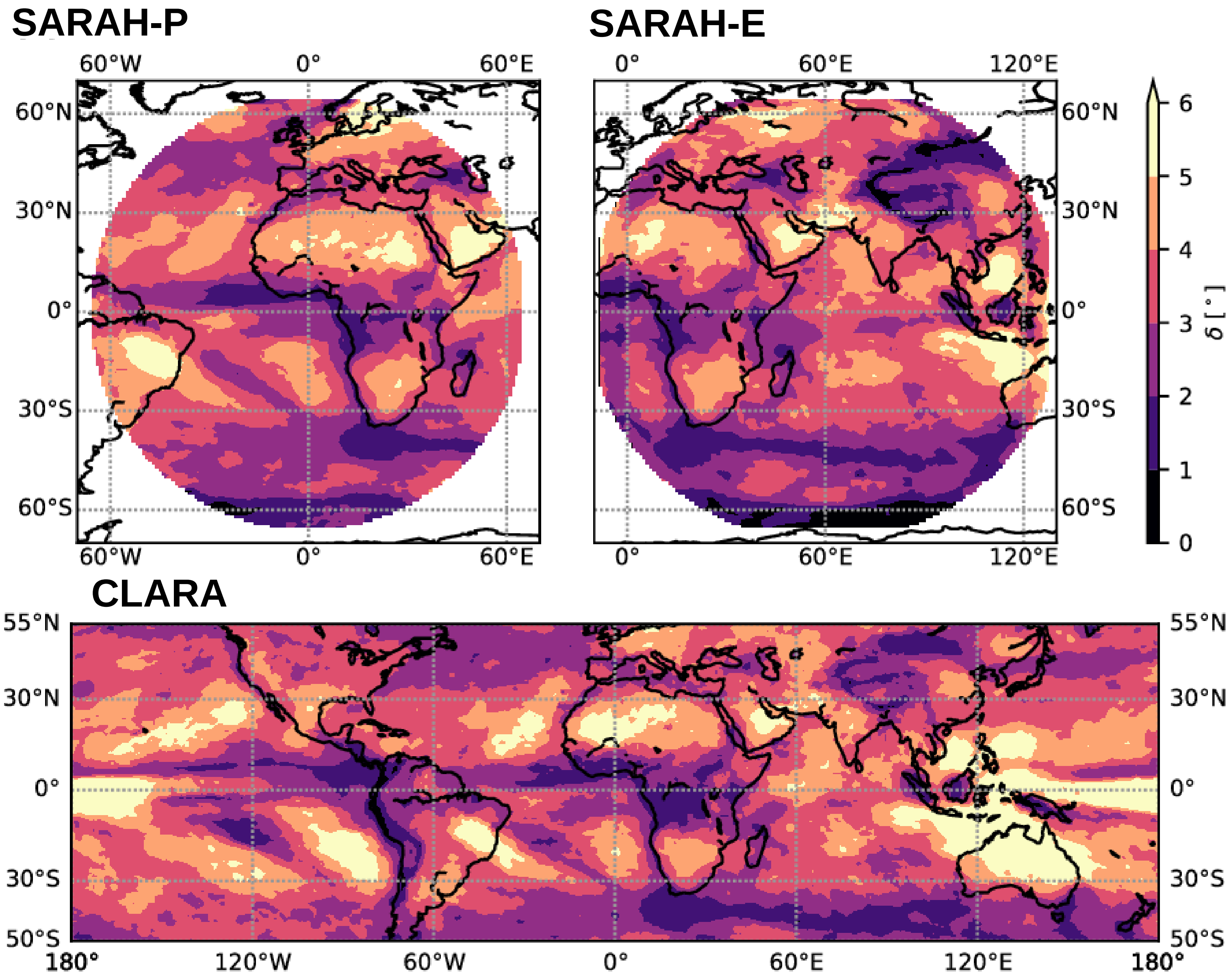
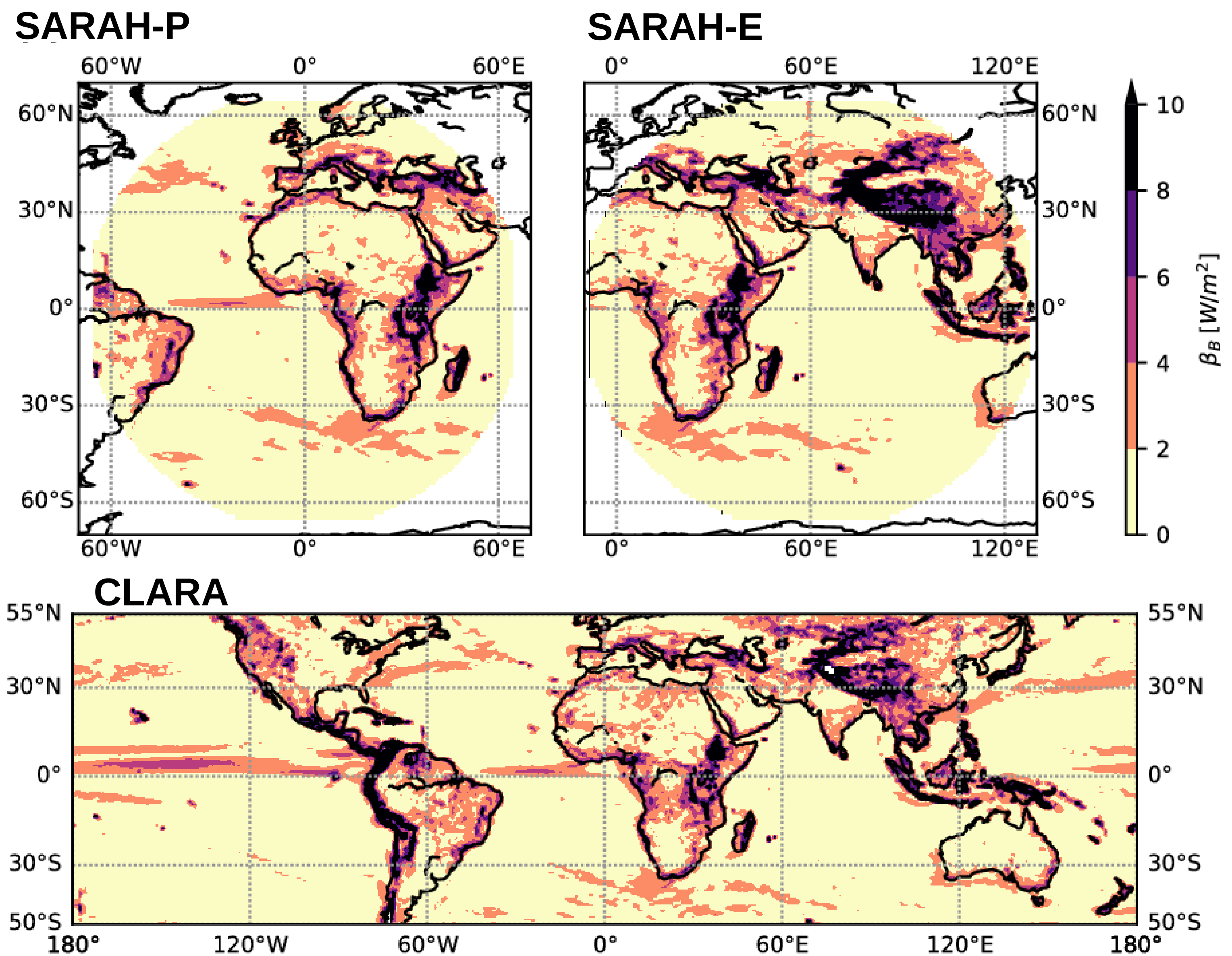
Site-to-Site vs Site-to-Pixel correlations



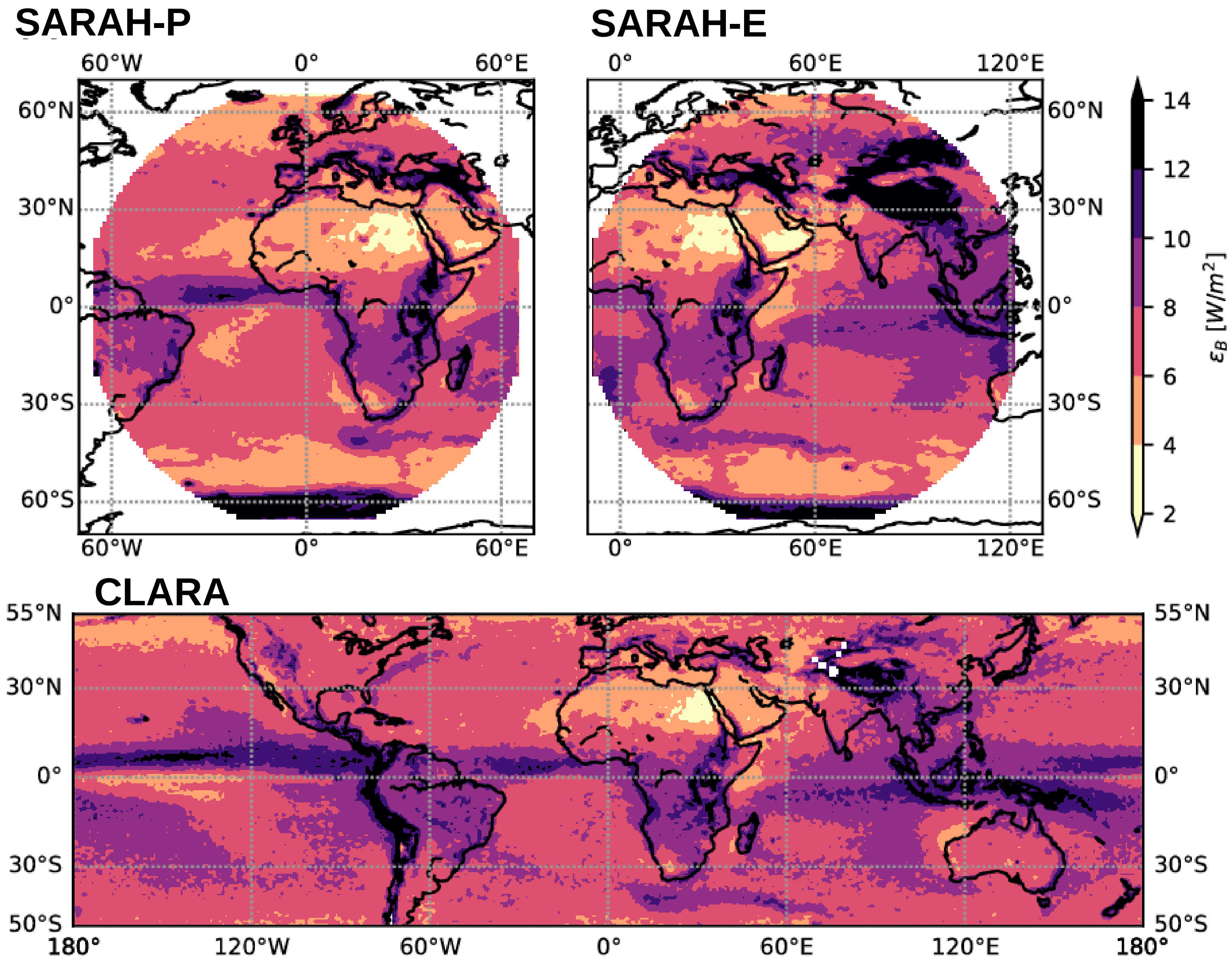
Decorrelation length (δ)



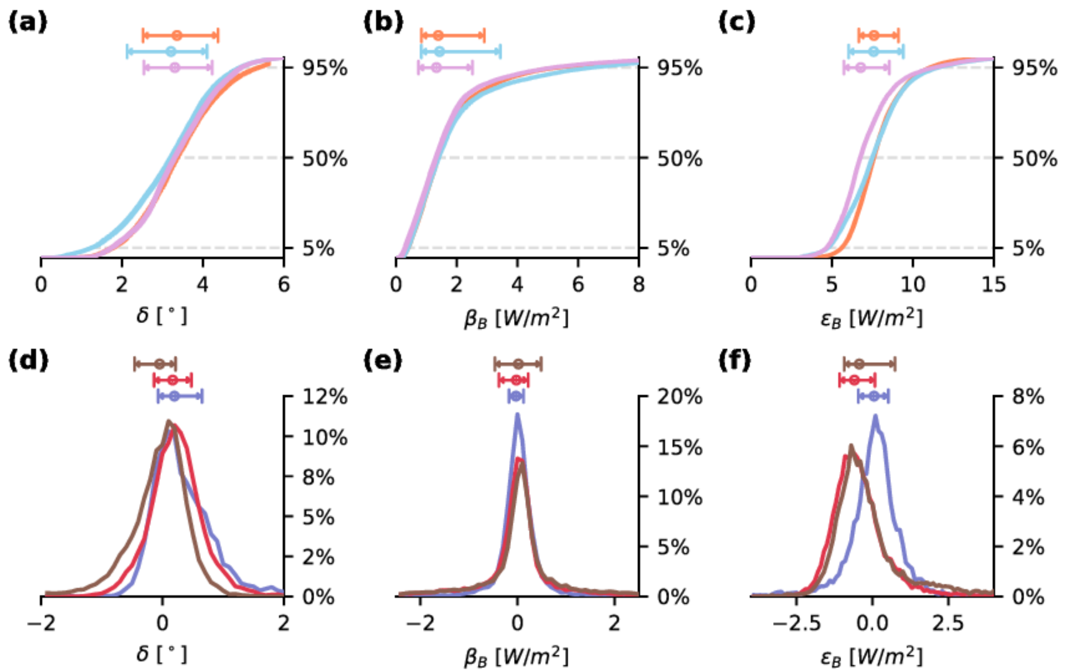
Biases – box aggregated



Errors – box aggregated



Decorrelation length & Biases & Errors



	$\delta_B[^\circ]$	β_B [$\mathrm{Wm^{-2}}$]	ϵ_B [$\mathrm{Wm^{-2}}$]
SARAH-P	3.31 (2.41, 4.36)	1.33 (0.57, 2.69)	6.96 (5.56, 9.06)
SARAH-E	3.21 (2.00, 4.23)	1.43 (0.66, 3.61)	7.75 (5.82, 9.95)
CLARA	3.36 (2.39, 4.50)	1.39 (0.67, 3.08)	7.58 (6.32, 9.39)
SARAH-P - SARAH-E	0.20 (-0.16, 0.74)	-0.03 (-0.28, 0.23)	0.05 (-0.63, 0.70)
SARAH-P - CLARA	0.17 (-0.22, 0.56)	-0.02 (-0.49, 0.33)	-0.41 (-1.08, 0.45)
SARAH-E - CLARA	-0.05 (-0.55, 0.30)	0.02 (-0.57, 0.59)	-0.23 (-0.91, 1.08)