Developing an AVHRR-based CDR of TOA radiative fluxes within the CMSAF Project

Akkermans, T., Clerbaux, N., Baudrez, E., Velazquez, A., Moreels, J., Moutier, W., Ipe, A.

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NCAR, Boulder CO

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Overview

1. **Introduction:** CM-SAF, CLARA, radiative flux products
2. **Developing** the CDR: details of algorithm
3. **Results and validation** with CERES datasets
4. **Conclusions** and outlook

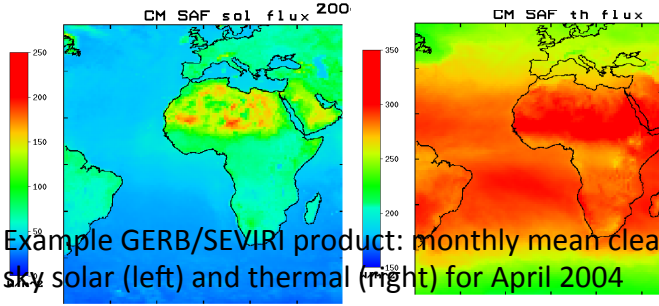
1. Introduction

What is CM SAF?

- Project generating and delivering Climate Data Records from weather satellites (part of EUM ground segment)
- Products target the energy and water cycles: radiation, IWV, clouds, precip, turb.fluxes,..
- Polar and geo satellites (regional+global products)

TOA radiation products in CMSAF:

- Until now, all based on geostationary satellites (Meteosat) with GERB instrument, in combination with imager SEVIRI/MVIRI
- Currently released datasets:
  - MVIRI/SEVIRI data record (Urbain et al.,2017); 1982-2015, GERB used “offline”, Resolution 0.05°x0.05°
  - GERB/SEVIRI data record (Clerbaux et al.,2017); 2004-2015, Drift corrected, All-sky and clear-sky fluxes, Resolution 0.1°x0.1°

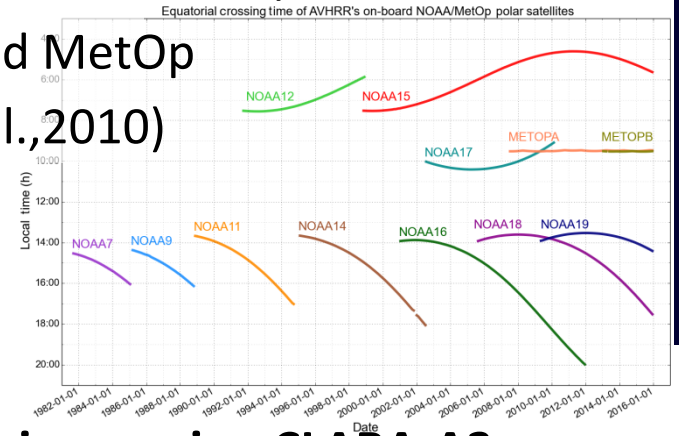


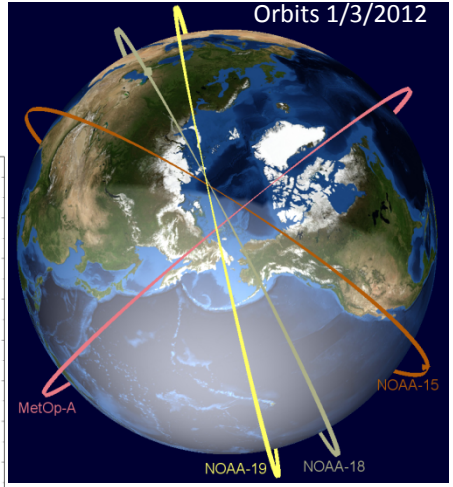
Example GERB/SEVIRI product: monthly mean clear sky solar (left) and thermal (right) for April 2004

1. Introduction

<u>What is CLARA?</u> "**<u>C</u>**M SAF c**<u>L</u>**oud, **<u>A</u>**lbedo and **<u>RA</u>**diation dataset from AVHRR data" (=*Similar to Patmos-X)*

- Polar orbiting satellites NOAA and MetOp
- FCDR from NOAA (Heidinger et al.,2010)
- Currently released versions:
  - CLARA-A1 (1982-2009)
  - CLARA-A2 (1982-2015)





Some of the modifications in upcoming version CLARA-A3:

- Inclusion of AVHRR-1 sensor (TIROS-N, NOAA-6, -8, -10): extension of time range to 1978-2019 i.e. 42yr
- Updated FCDR, from Fiduceo project (http://www.fiduceo.eu) Fiduceo
- Updated cloud treatment algorithms (NWCSAF/PPS v.2018; Karlsson et al.) SMHI
- Addition of new product "TOA radiative fluxes" -> this presentation

2. Development of algorithm

PART 1

Land use map
1. USGS
2. **IGBP**

AVHRR NB reflectances

Cloud mask
1. **Binary (0 or 100)**
2. Probabilistic

NB-to-BB
1. Hucek & Jacobowitz, 1995 (ERBE)
2. **Regression AVHRR-CERES *(NOAA-Aqua) using SSF Aqua-FM3 Ed4A***

BB reflectance
BB radiance

ADM's
1. Suttles et al., 1988 (ERBE)
2. **Loeb et al., 2003,2005 (CERES-TRMM, + CERES-TERRA for snow/ice) Ed.-2B**

BB flux
BB albedo

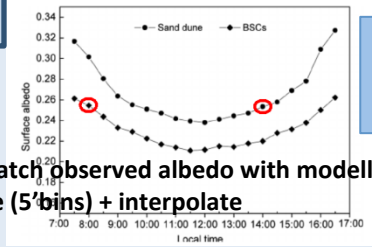
PART 2

Instantaneous **swath** grid

Spatial aggreg. regridding 0.25°
1. **Simple/fast: reproject pixel centre**
2. Complex: reproject pixel area

Instantaneous **regular** grid

PART 3



Per pixel: match observed albedo with modelled diurnal cycle (5'bins) + interpolate

Diurnal cycle modeling

Daily mean

PART 4

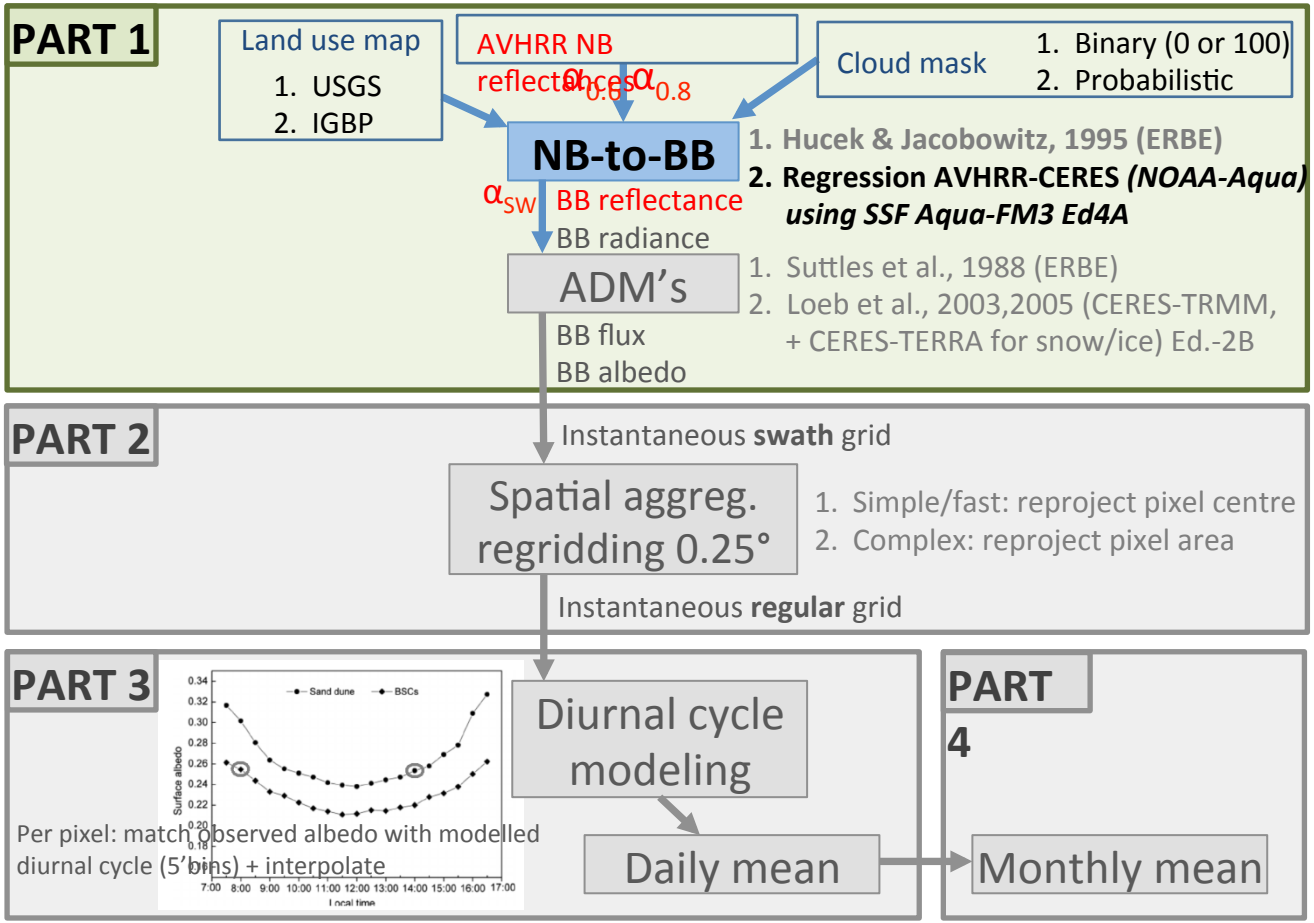
Monthly mean

2. Development of algorithm

Narrowband-to-broadband (NB-to-BB) conversion:

Newly derived regressions AVHRR-CERES

$$\alpha_{SW} = b_0 + b_1 \cdot \alpha_{0.6} + b_2 \cdot \alpha_{0.8} + b_3 \cdot ln\left(\frac{1}{\mu_0}\right)$$



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Large database of collocated NB and BB observations is needed!

Requirements:

- **Simultaneous**
- **Coangular**

PART 1

Land use map
1. USGS
2. IGBP

AVHRR NB reflectances $\alpha_{0.6}$ $\alpha_{0.8}$

Cloud mask
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NB-to-BB

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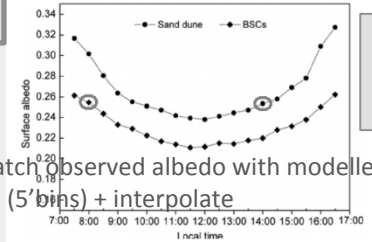


Per pixel: match observed albedo with modelled diurnal cycle (5' bins) + interpolate

Diurnal cycle modeling

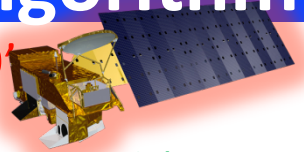
Daily mean

PART 4

Monthly mean

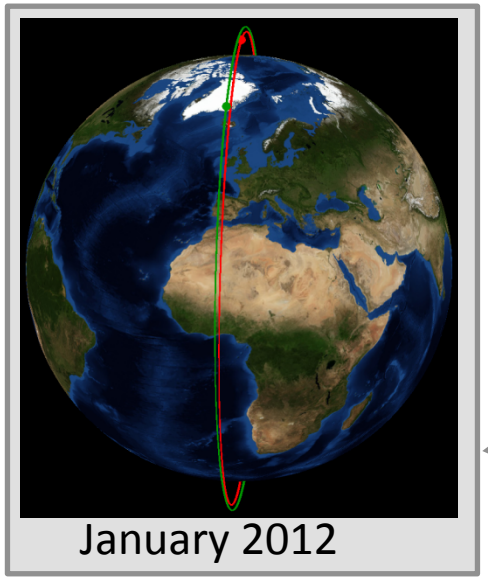
2. Development of algorithm

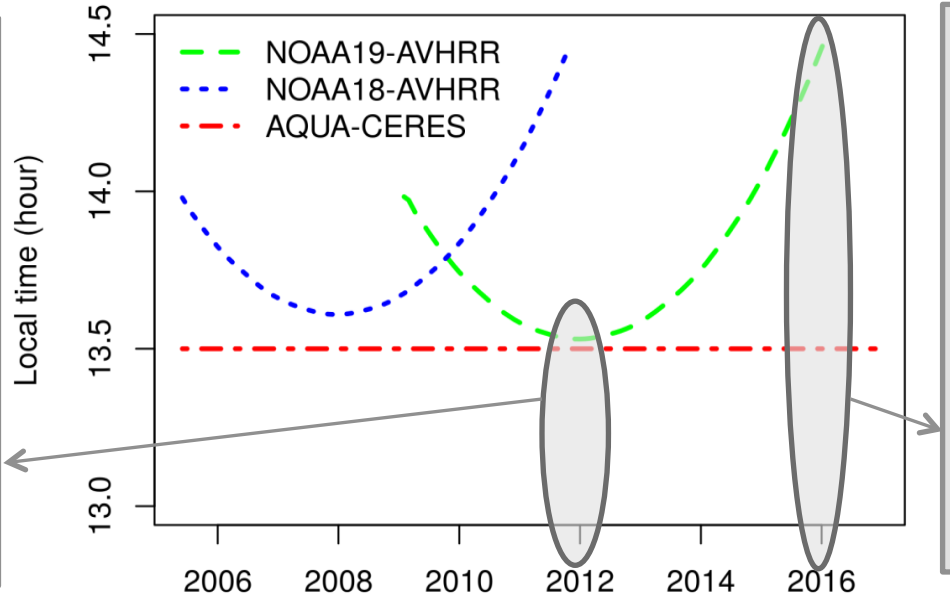
- CERES -> AQUA orbit: stationary, 700km, period 99’

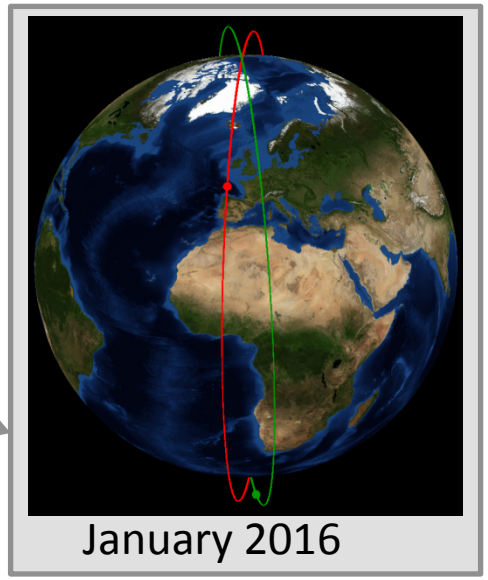


- AVHRR -> NOAA19 orbit: orbital drift, 850km, period 102’ (slower)

Coangular observations occur with similar viewing geometry, so mainly with coïnciding orbital plane (=similar local solar time); hence, focus on these months to gather data:





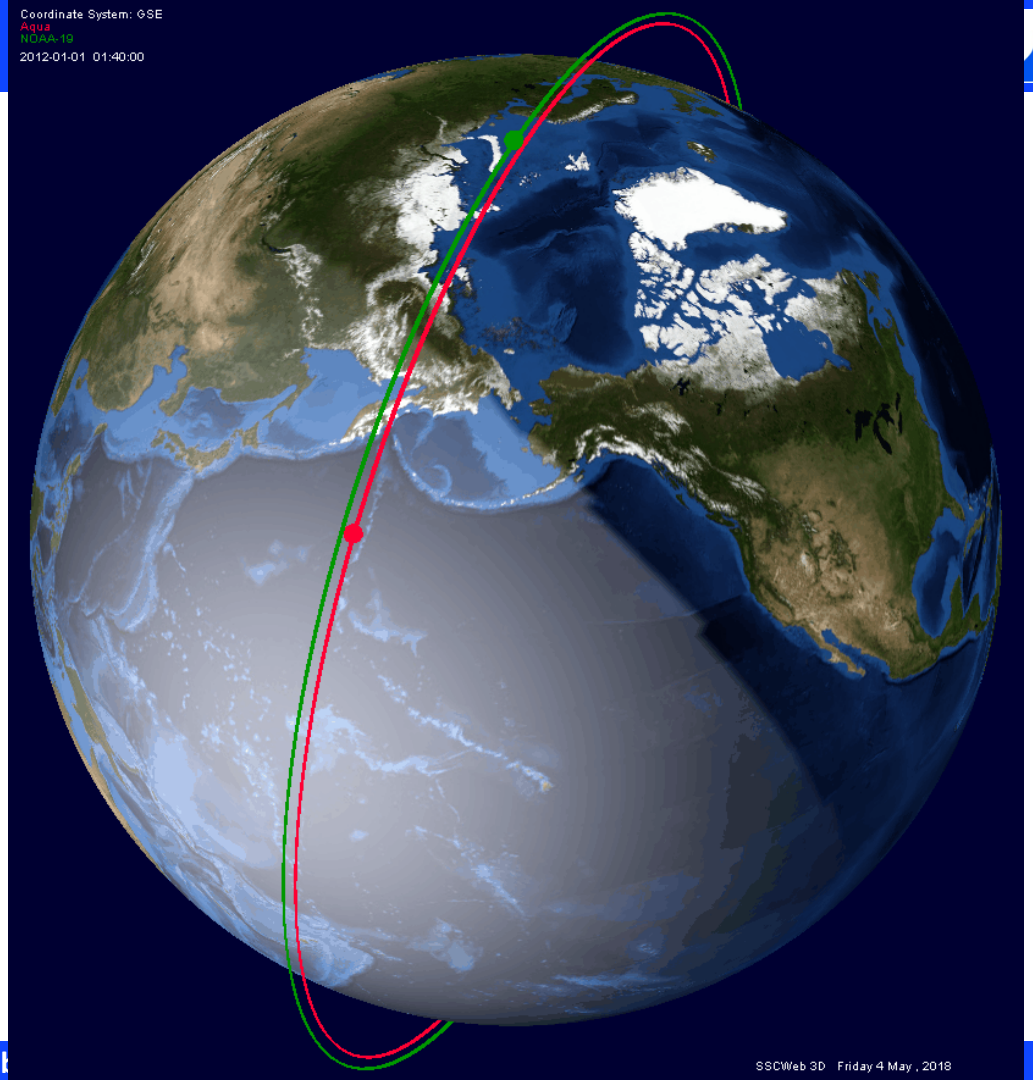


Within coïnciding orbital plane:

- CERES -> AQUA orbit: 700km, period 99’ (faster)
- AVHRR -> NOAA19 orbit: 850km, period 102’ (slower)

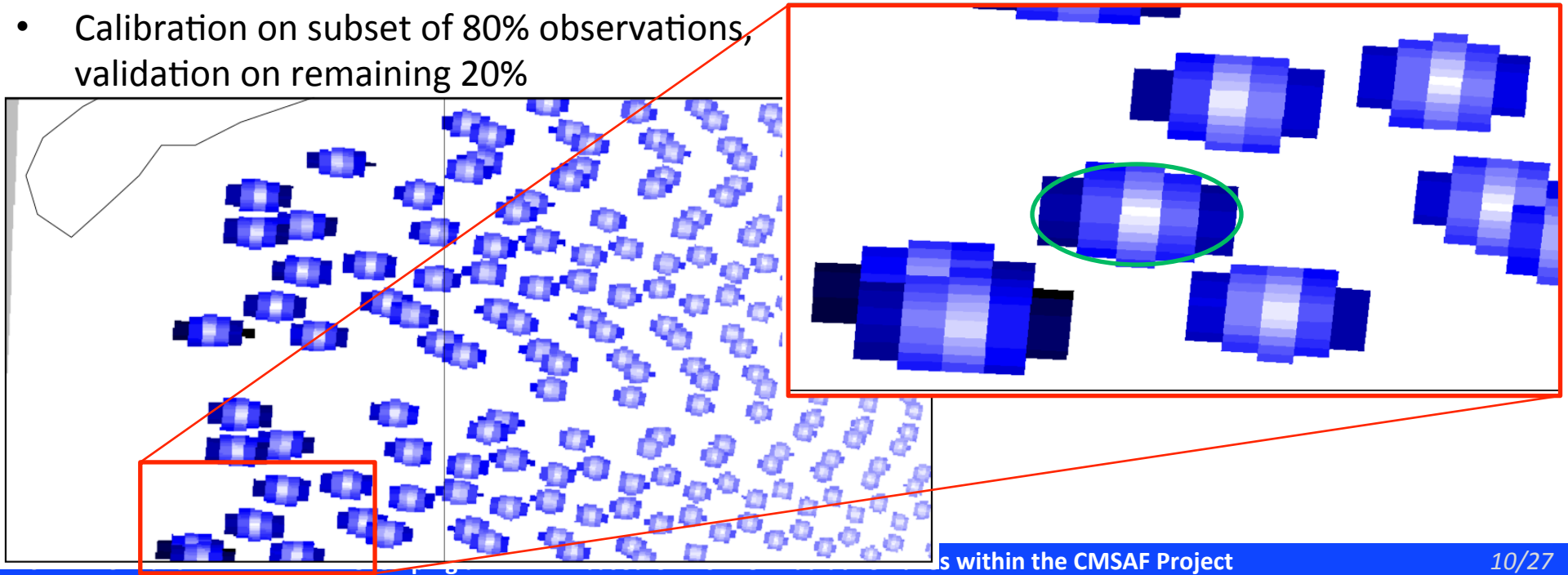
At least once every 48 hours, the faster AQUA catches up with the slower NOAA19: near this point, collocated observations from both satellites have:

- Minimal time lag ~**simultaneous** observation
- Similar viewing geometry ~**coangular** observation



2. Development of algorithm

- Temporal (<450s) and angular (<4.5°) constraints are used in matching algorithm.
- CERES pixel dimensions (size,shape) increase with viewing zenith angle due to an increasingly spread-out projected area (which is even more magnified by the earth's curvature)
- AVHRR pixels inside CERES footprint are identified, aggregated, and compared with CERES
- Calibration on subset of 80% observations, validation on remaining 20%



2. Development of algorithm

Equation:

$$\alpha_{SW} = b_0 + b_1 \cdot \alpha_{0.6} + b_2 \cdot \alpha_{0.8} + b_3 \cdot ln\left(\frac{1}{\mu_0}\right)$$

CERES BB reflectance

AVHRR channels 1 and 2

cosine of solar zenith angle

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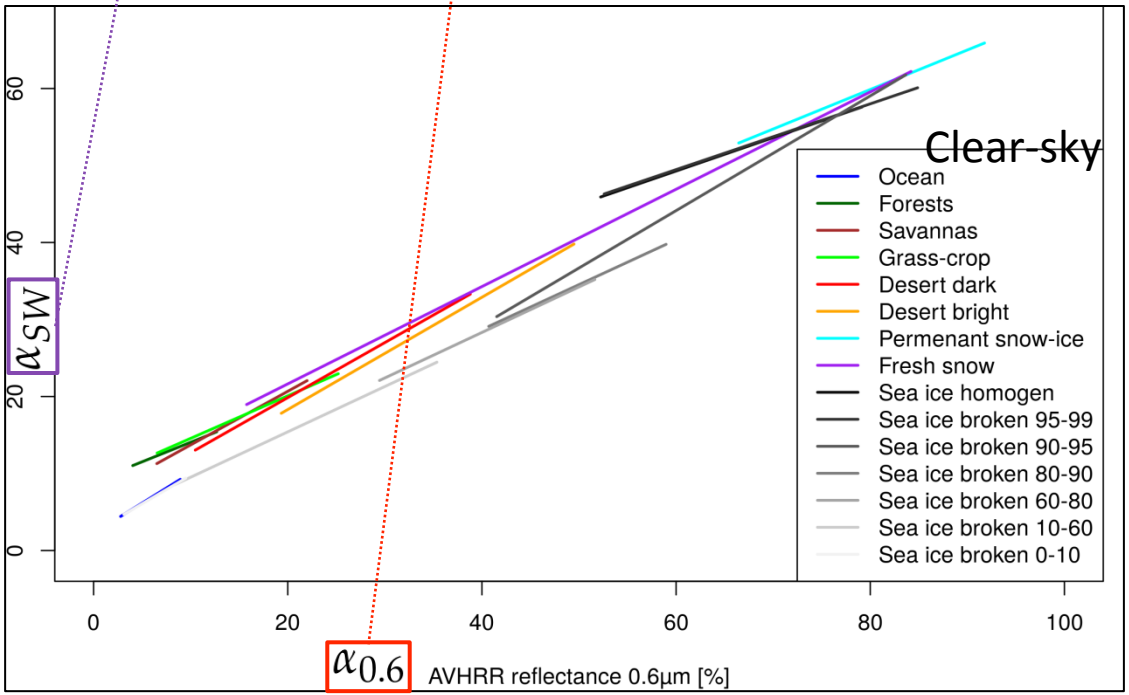

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CERES BB reflectance

AVHRR channels 1 and 2

cosine of solar zenith angle

Table 3. Resulting coefficients (from regression on calibration subset; 80% of sample) for clear, overcast, and allsky conditions; period: 1/7/2011-30/6/2012 (NOAA-19).

	Clear-sky				Overcast				All-sky			
Surface type	b_0	b_1	b_2	b_3	b_0	b_1	b_2	b_3	b_0	b_1	b_2	b_3
Ocean	1.806	1.265	-0.724	-0.365	4.819	0.293	0.449	0.261	3.560	0.318	0.448	0.283
Forests	0.213	0.644	0.400	0.778	3.439	0.322	0.433	1.029	3.111	0.394	0.366	0.975
Savannas	1.087	0.430	0.427	2.055	3.607	0.404	0.344	3.525	3.122	0.415	0.351	1.503
Grass/crop	1.770	0.450	0.372	1.306	3.885	0.376	0.373	1.410	3.256	0.415	0.348	0.932
Dark deserts	2.280	0.312	0.424	1.352	2.642	0.168	0.596	1.634	1.892	0.383	0.394	1.498
Bright deserts	3.295	0.369	0.327	1.702	0.719	0.439	0.338	3.589	1.940	0.551	0.195	2.587
Perm. snow/ice	5.949	0.171	0.523	-0.675	18.891	0.100	0.494	-2.018	24.195	0.000	0.509	-2.595
Fresh snow	2.375	0.246	0.464	1.164	2.751	0.239	0.529	0.794	2.989	0.217	0.519	0.780
Sea ice 100%	-1.359	0.190	0.591	0.383	-0.352	0.284	0.525	1.685	20.062	0.125	0.419	-2.419
Sea ice 95-99%	2.385	0.157	0.579	-0.203	8.370	0.138	0.578	-0.425	12.417	0.224	0.414	-1.176
Sea ice 90-95%	7.368	0.198	0.464	-0.152	9.583	0.142	0.556	-0.599	8.914	0.152	0.547	-1.007
Sea ice 80-90%	-1.496	0.408	0.367	1.547	9.191	0.165	0.534	-0.359	9.182	0.043	0.667	-1.007
Sea ice 60-80%	2.496	0.492	0.192	0.523	5.833	0.248	0.492	0.247	3.987	0.214	0.555	0.394
Sea ice 10-60%	4.000	0.468	0.144	-0.020	5.075	0.212	0.540	-0.023	4.056	0.221	0.547	0.170
Sea ice 0-10%	1.237	1.392	-0.662	-0.820	5.076	0.219	0.534	-0.156	4.044	0.280	0.490	0.082

2. Development of algorithm

***R**oot-**M**ean-**S**quare **r**esidual (*RMSr*):*

$$\sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} [(\hat{\alpha}_{SW,i} - \alpha_{SW,i})^2]}$$

***r**elative **R**oot-**M**ean-**S**quare **r**esidual (*rRMSr*):*

$$\frac{\sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} [(\hat{\alpha}_{SW,i} - \alpha_{SW,i})^2]}}{\frac{1}{n} \cdot \sum_{i=1}^{n} \alpha_{SW,i}}$$

***r**elative **M**ean **B**ias (*rMB*):*

$$\frac{\frac{1}{n} \cdot \sum_{i=1}^{n} (\hat{\alpha}_{SW,i} - \alpha_{SW,i})}{\frac{1}{n} \cdot \sum_{i=1}^{n} \alpha_{SW,i}}$$

Table 4. Overview of linear regression performance statistics (on validation subset; 20% of the observations) for clear, overcast, and allsky conditions; period: 1/7/2011-30/6/2012 (NOAA-19).

	Clear-sky		Overcast		All-sky	
Surface type	rMB	rRMSr	rMB	rRMSr	rMB	rRMSr
Ocean	-0.04%	4.82%	0.00%	4.17%	0.00%	6.55%
Forests	-0.04%	3.12%	0.06%	3.87%	-0.02%	6.09%
Savannas	0.07%	3.03%	-0.41%	5.17%	-0.08%	5.91%
Grass/crop	0.01%	3.58%	0.06%	3.82%	-0.04%	6.07%
Dark deserts	0.01%	3.48%	-0.14%	4.21%	0.05%	5.86%
Bright deserts	0.00%	2.61%	-0.12%	4.01%	0.01%	3.77%
Perm. snow/ice	0.00%	0.86%	-0.01%	2.33%	0.01%	2.73%
Fresh snow	-0.05%	2.82%	-0.03%	3.14%	0.00%	4.64%
Sea ice 100%	0.03%	1.55%	0.00%	2.09%	0.01%	3.46%
Sea ice 95-99%	0.01%	1.51%	0.02%	2.26%	0.01%	3.75%
Sea ice 90-95%	0.00%	1.83%	0.07%	2.22%	0.01%	3.71%
Sea ice 80-90%	0.00%	1.55%	0.01%	2.51%	0.00%	3.51%
Sea ice 60-80%	-0.14%	2.84%	-0.01%	2.79%	0.03%	3.83%
Sea ice 10-60%	0.14%	9.53%	-0.01%	3.57%	0.02%	4.91%
Sea ice 0-10%	-0.20%	4.41%	0.09%	3.82%	0.08%	5.35%

rMB: relative mean bias (%); rRMSr: relative root-mean-square residual (%)

3. Results/validation

PART 1

Land use map
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2. IGBP

AVHRR NB reflectances

Cloud mask
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BB flux
BB albedo

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Instantaneous **swath** grid

Spatial aggreg. regridding 0.25°
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Instantaneous **regular** grid

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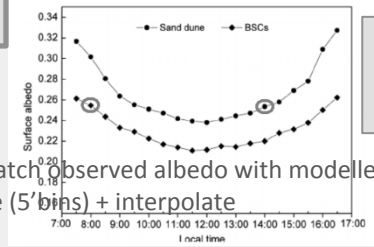


Per pixel: match observed albedo with modelled diurnal cycle (5' bins) + interpolate

Diurnal cycle modeling

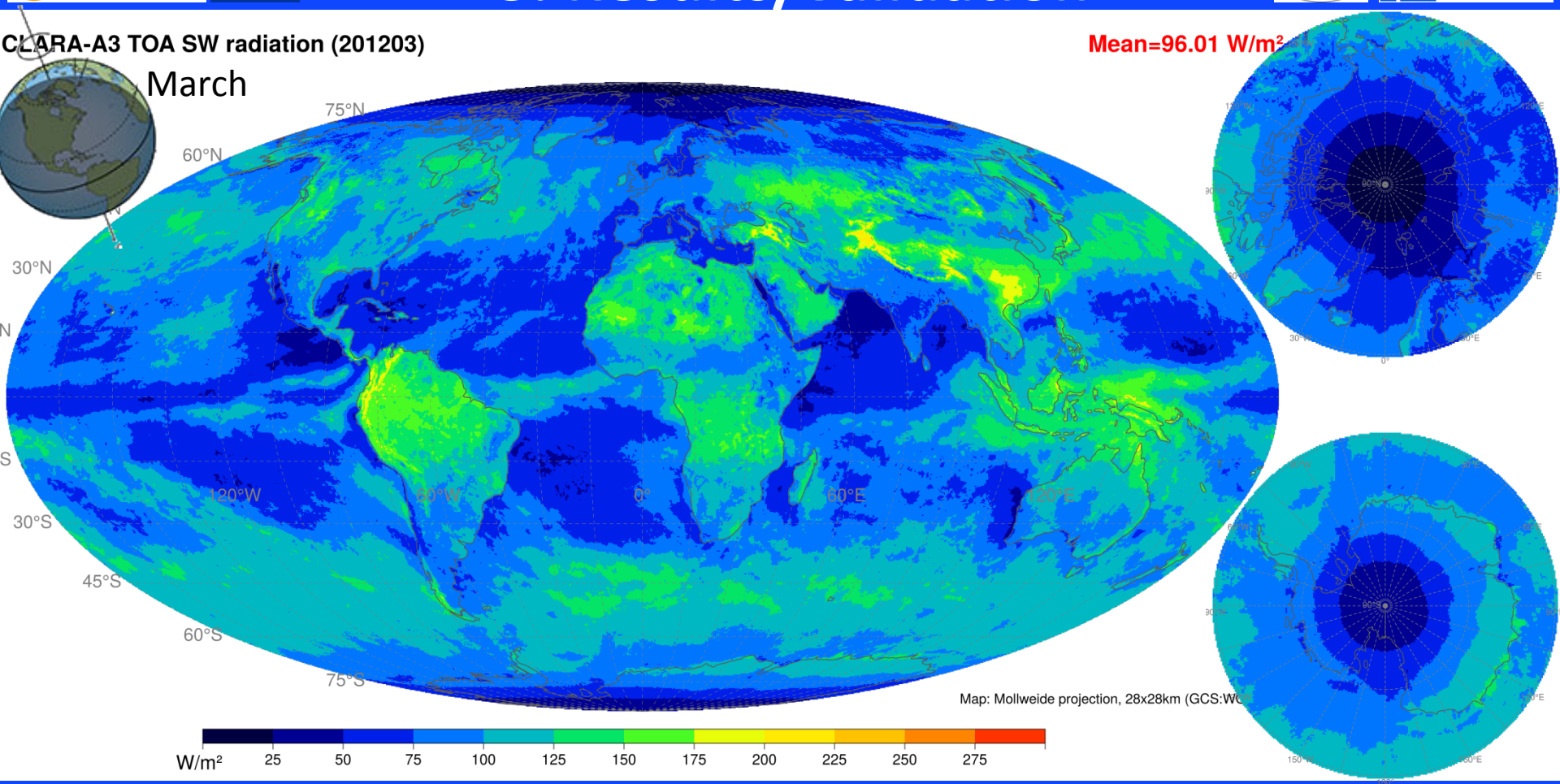
Daily mean

PART 4

Monthly mean

4 monthly means:
Mar, Jun, Sep, Dec

3. Results/validation



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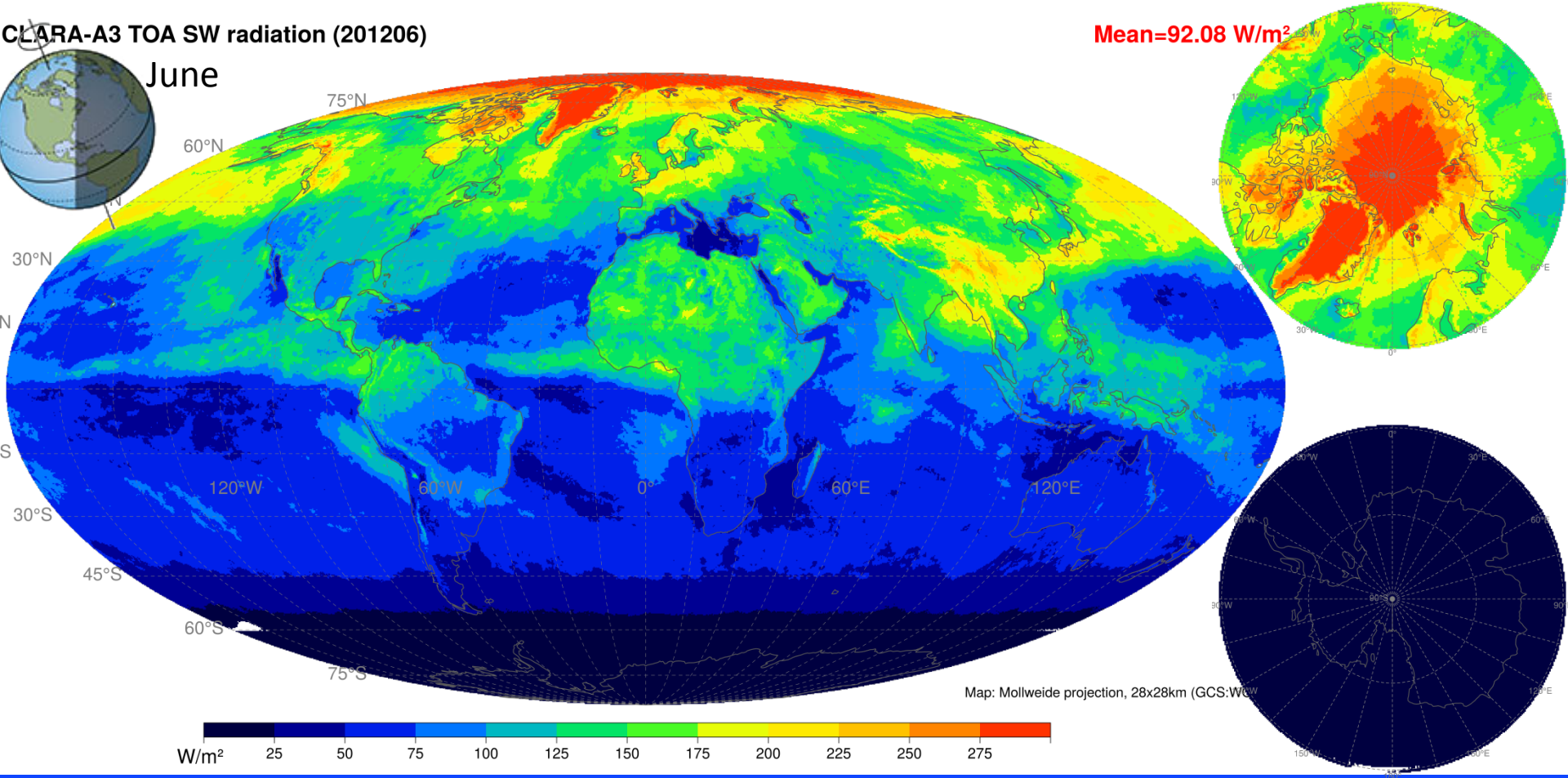

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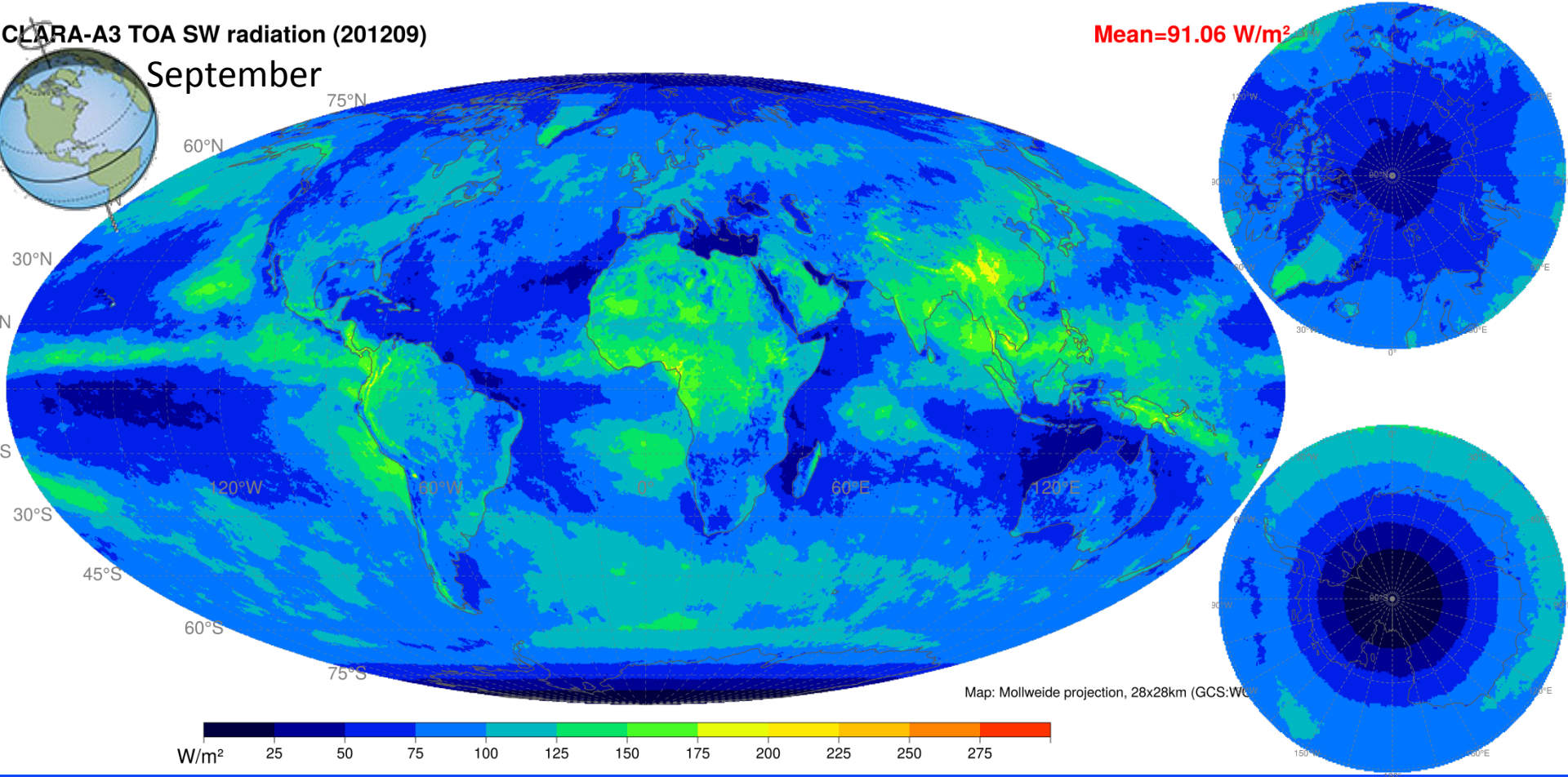

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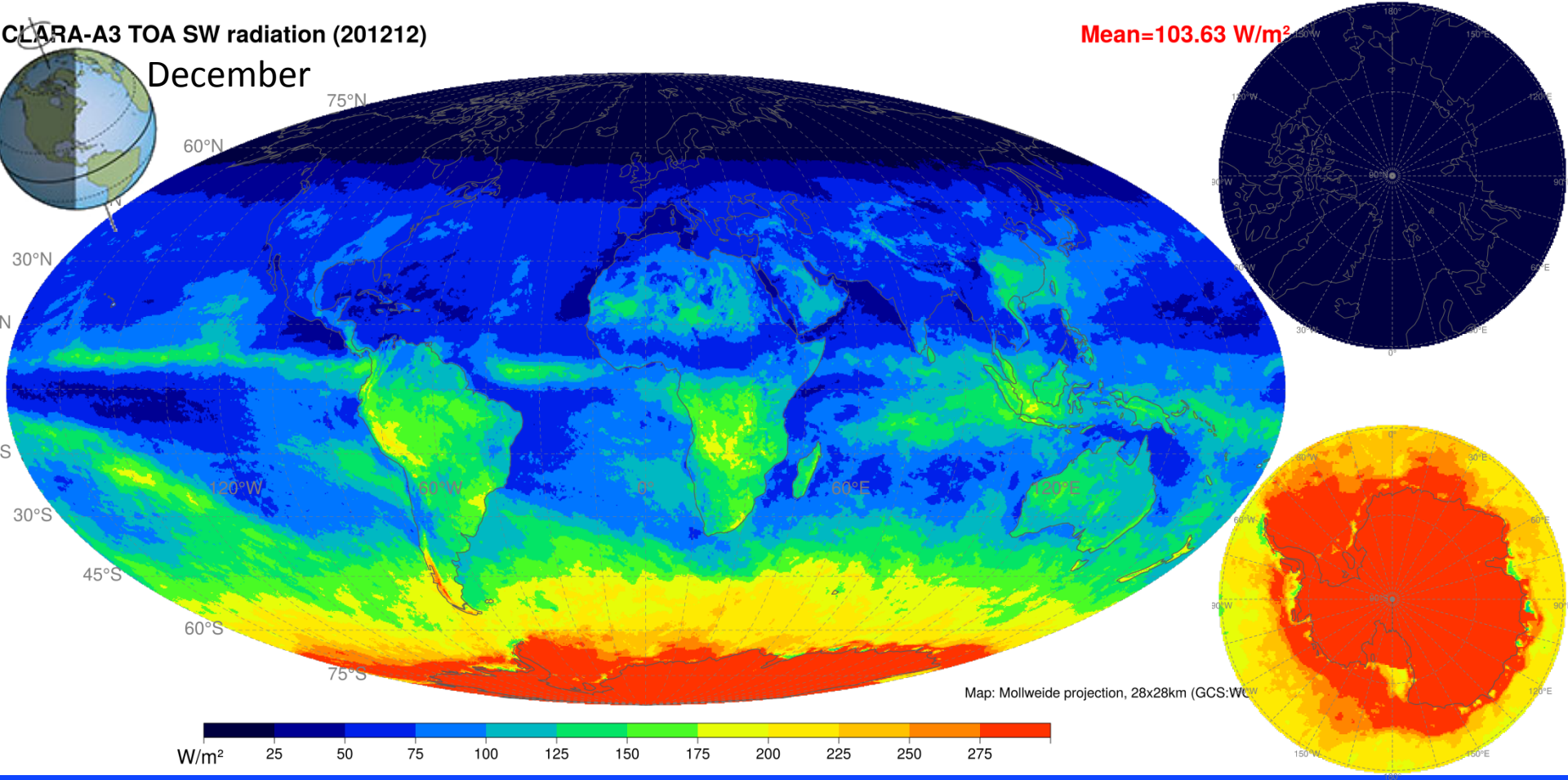

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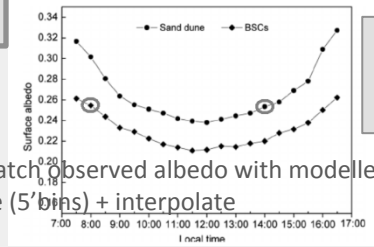

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Daily mean

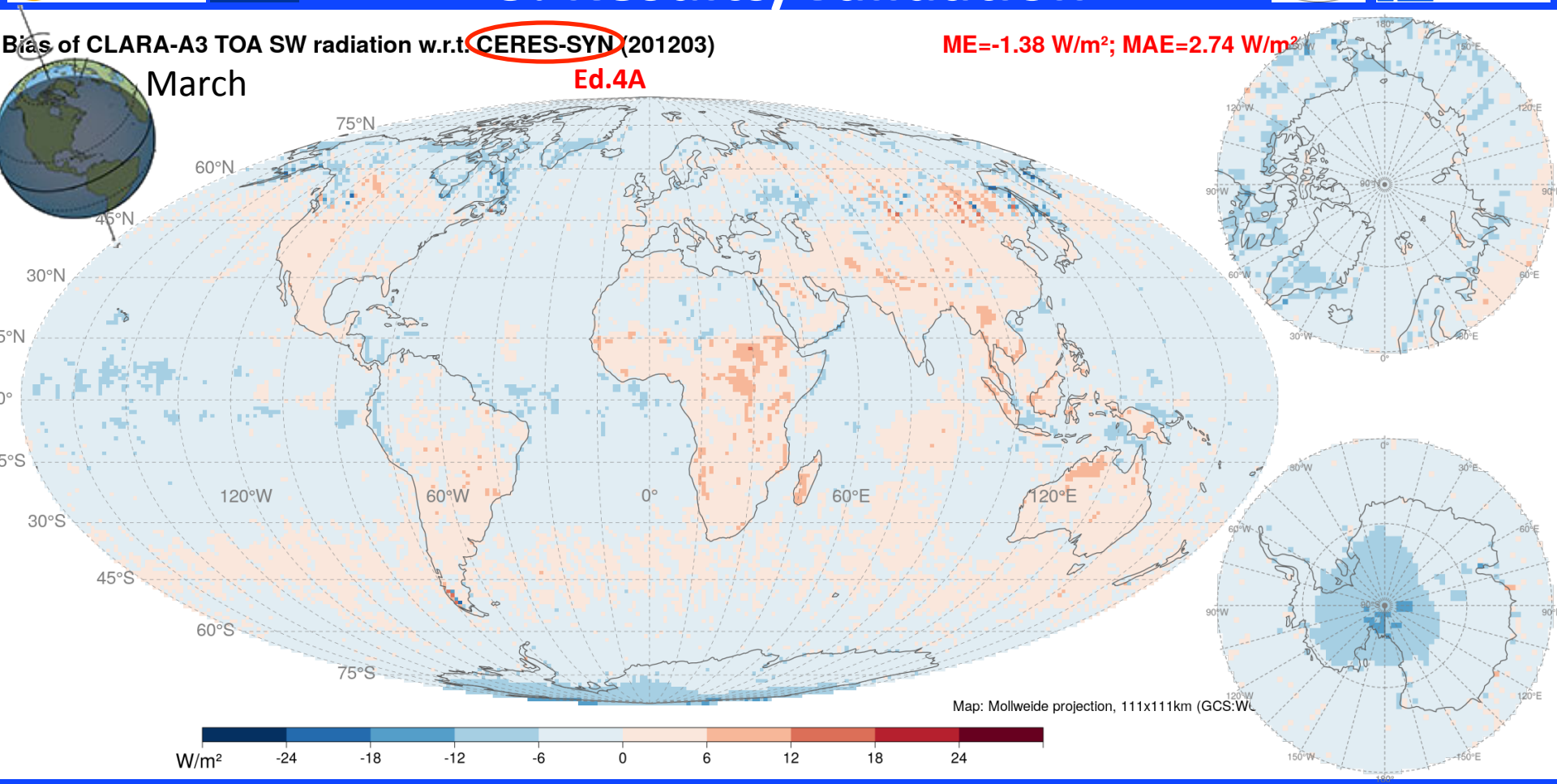
PART 4

SYN1deg-Ed4A

↕ bias ↕

Monthly mean

3. Results/validation



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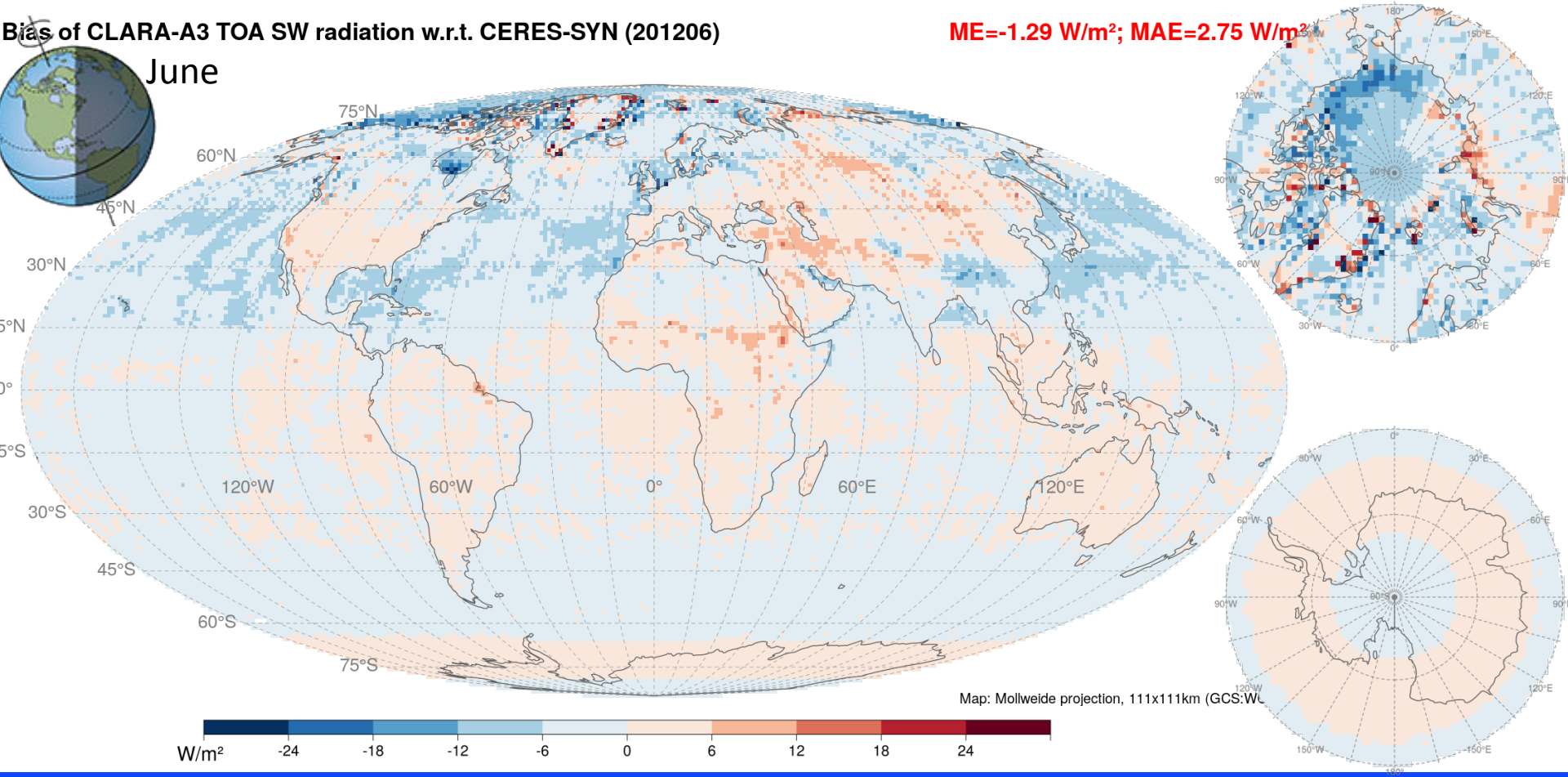

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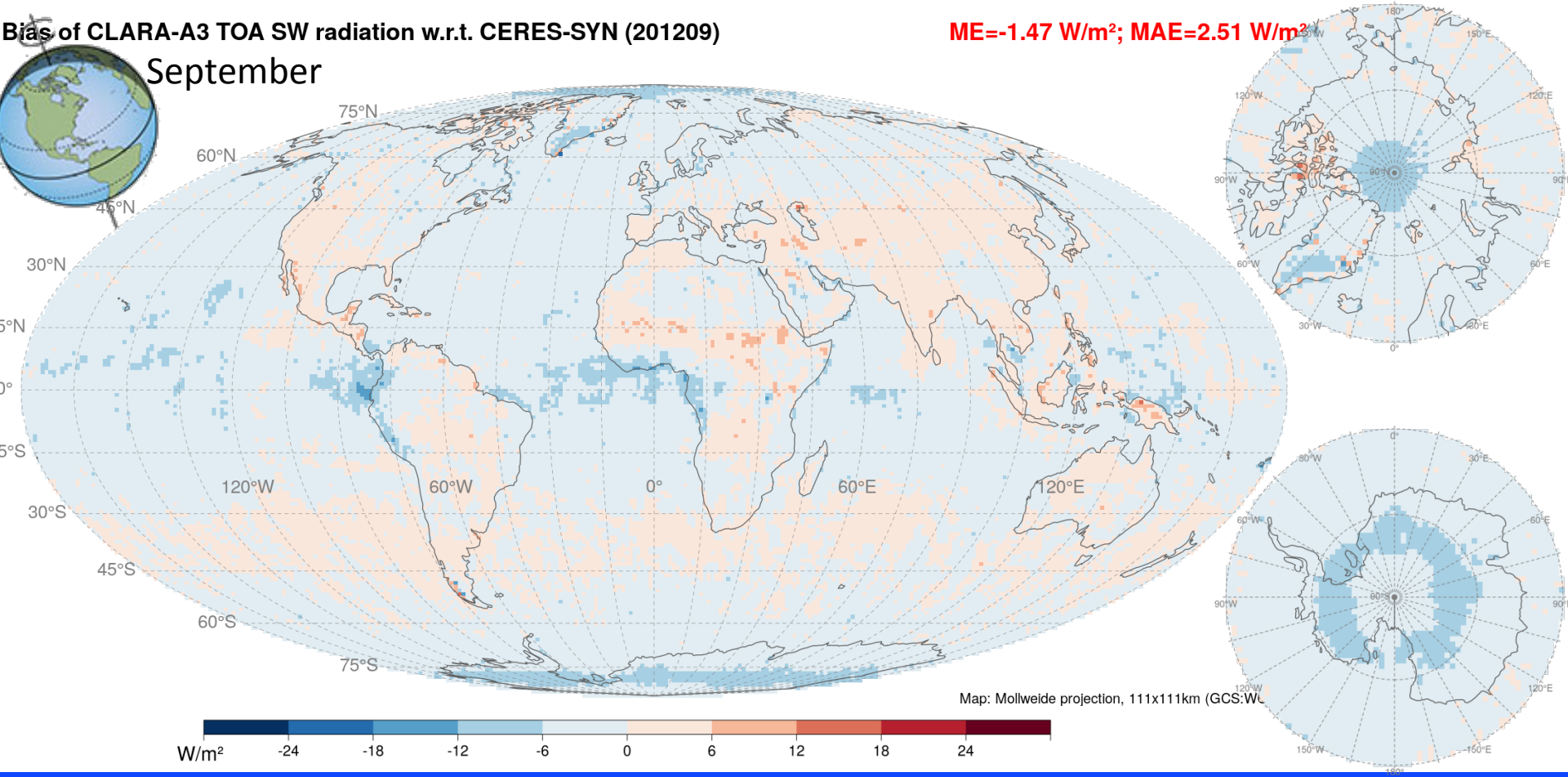

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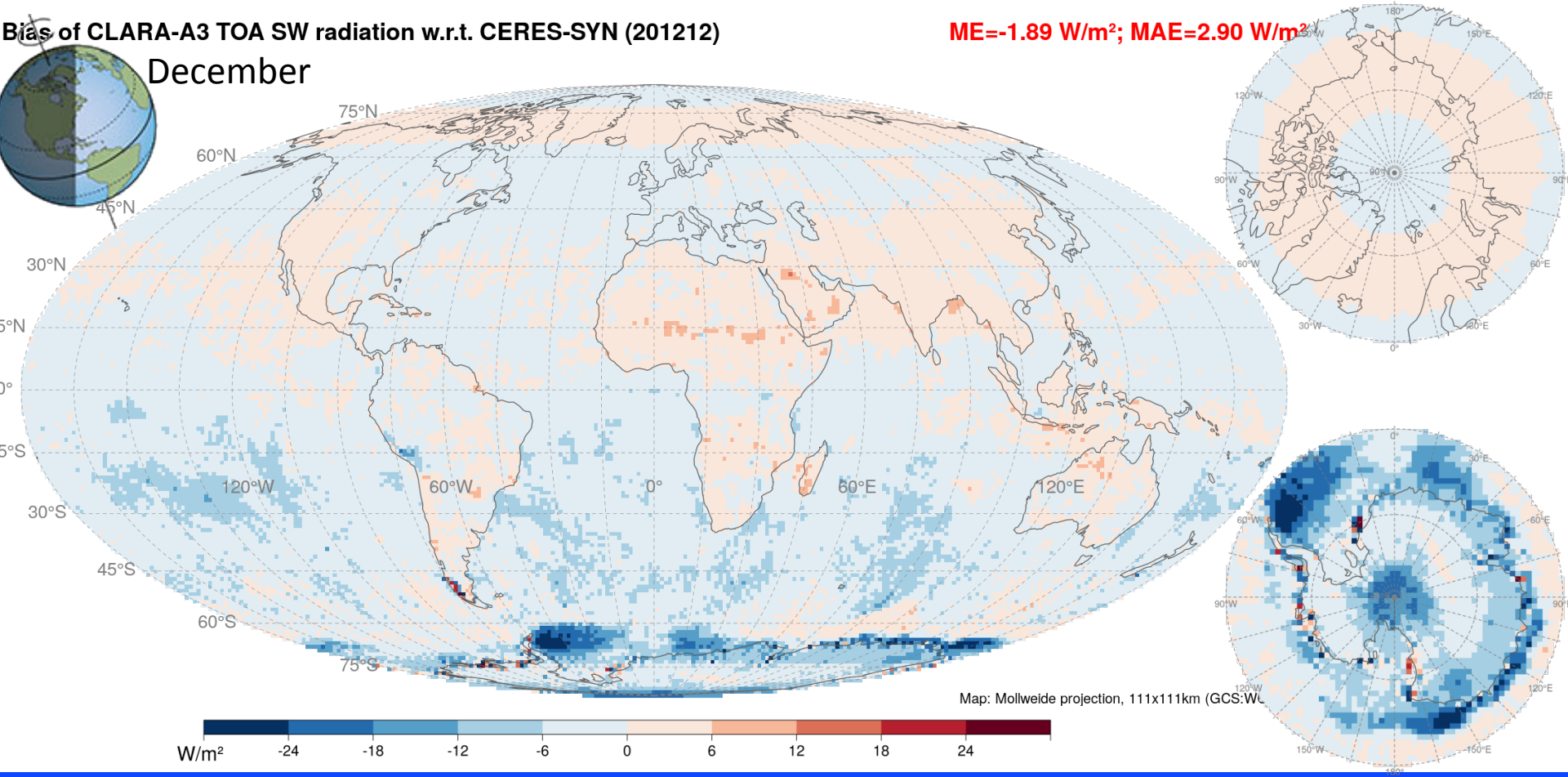


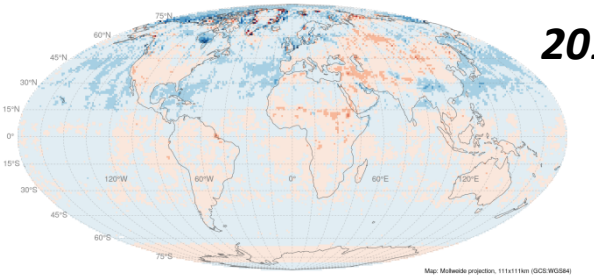
3. Results/validation

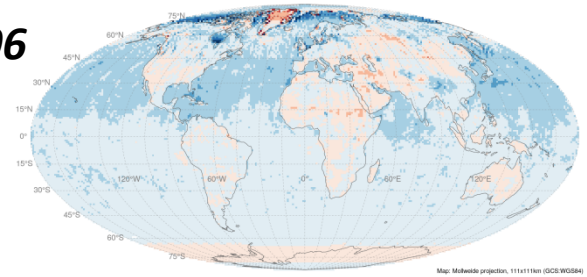
ADM: Loeb et al. (CERES-TRMM/-TERRA)

ADM: Suttles et al., 1988 (ERBE)

2012-06

-1.29 W/m²

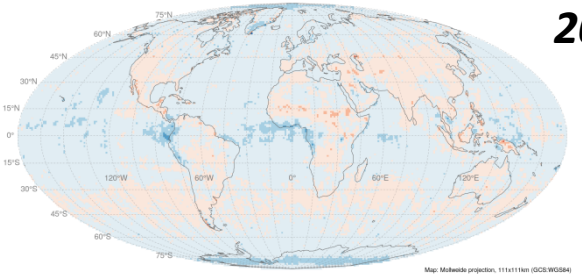


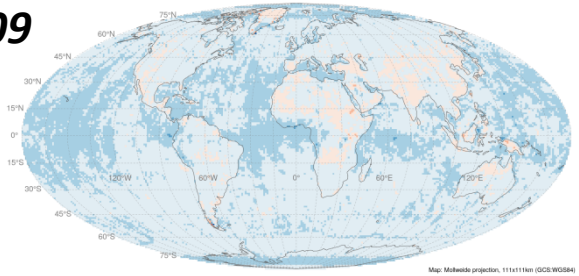


-3.86 W/m²

2012-09

-1.47 W/m²

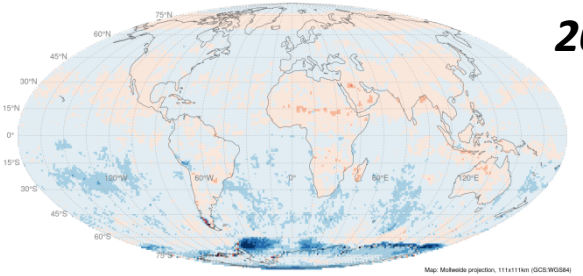


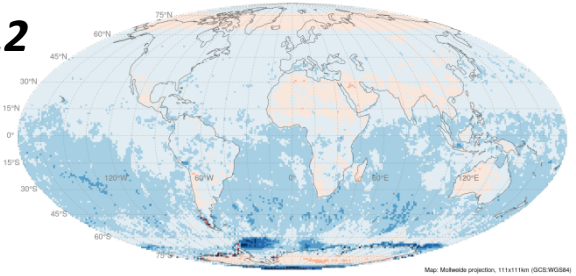


-4.29 W/m²

2012-12

-1.89 W/m²





-4.70 W/m²

3. Results/validation

PART 1

Land use map
1. USGS
2. IGBP

AVHRR NB reflectances

Cloud mask
1. Binary (classic)
2. Probabilistic

NB-to-BB
1. Hucek & Jacobowitz, 1995 (ERBE)
2. Regression AVHRR-CERES *(NOAA-Aqua) using SSF Aqua-FM3 Ed4A*

BB reflectance
BB radiance

ADM's
1. Suttles et al., 1988 (ERBE)
2. Loeb et al., 2003,2005 (CERES-TRMM, + **CERES-TERRA for snow/ice**) **Ed.-2B**

BB flux
BB albedo

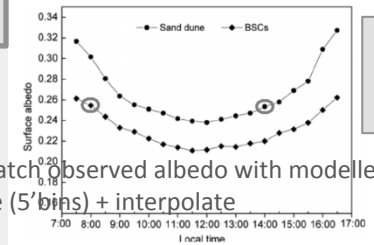
PART 2

Instantaneous **swath** grid

Spatial aggreg. regridding 0.25°
1. Simple/fast: reproject pixel centre
2. Complex: reproject pixel area

Instantaneous **regular** grid

PART 3



Per pixel: match observed albedo with modelled diurnal cycle (5' bins) + interpolate

Diurnal cycle modeling

Daily mean

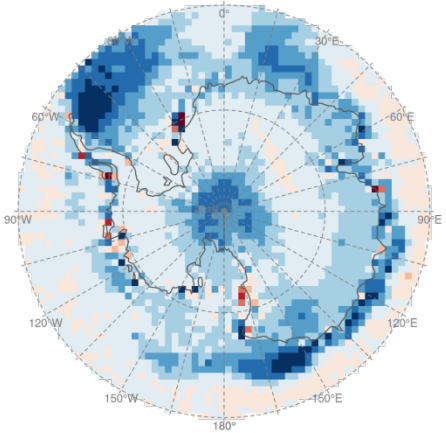
PART 4

SYN1deg-Ed4A

↕ bias ↕

Monthly mean

Bias 12/2012:



EUMETSAT CM SAF

CCLRC - DFBO - DIFA - GKSS - Hadley Centre
GERB
Imperial College - RMIB - University of Leicester

Royal Meteorological Institute Belgium
RMI

Thanks for your attention!

<tom.akkermans@meteo.be>

Extra slides

Sample size of nb-to-bb matched observations (per scene type)

Table 1. Overview of surface types, corresponding IGBP categories, and number of matched shortwave NTB pairs for clear, overcast, and allsky conditions; period: 1/7/2011-30/6/2012 (NOAA-19).

Surface type	IGBP category	Nr.(clear)	Nr.(overcast)	Nr.(all)
Ocean	17	18091	146138	337625
Forests	1,2,3,4,5	2199	5235	20655
Savannas	8,9	4015	2643	15627
Grass/crop	6,10,11,12,13,14	5098	5888	27959
Dark deserts	7,18	13280	2960	32806
Bright deserts	16	40627	2538	74829
Perm. snow/ice	15	26285	15442	72252
Fresh snow	19	16883	28327	155349
Sea ice 100%		7490	10449	38176
Sea ice 95-99%		17117	31740	108993
Sea ice 90-95%		4161	16191	42719
Sea ice 80-90%		11923	28925	87424
Sea ice 60-80%		3624	26614	68811
Sea ice 10-60%		1798	150492	255814
Sea ice 0-10%		1534	23309	42766

Extra slides

What if we calculated biases with EBAF instead of SYN?

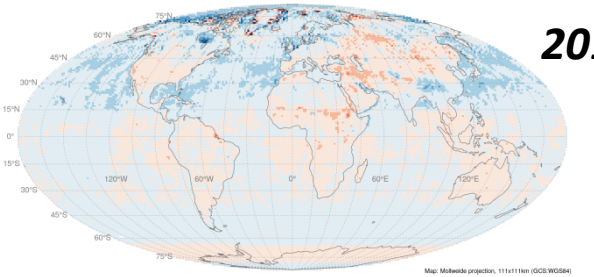
BIAS WITH CERES-SYN

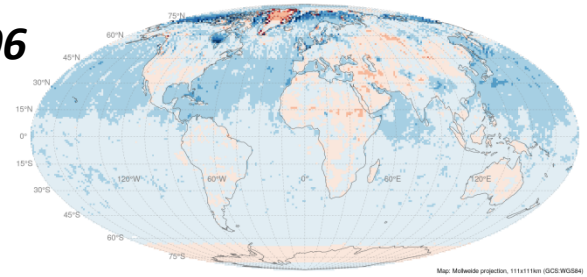
ADM: Loeb et al. (CERES-TRMM/-TERRA)

ADM: Suttles et al., 1988 (ERBE)

2012-06

-1.29 W/m²

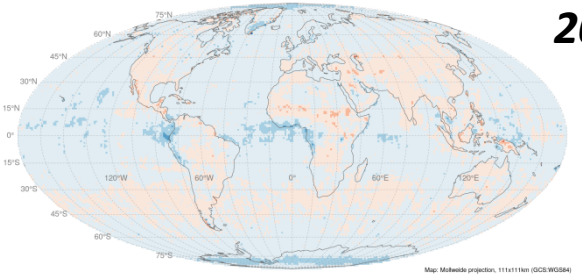


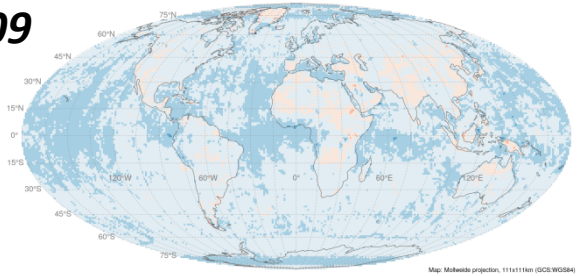


-3.86 W/m²

2012-09

-1.47 W/m²

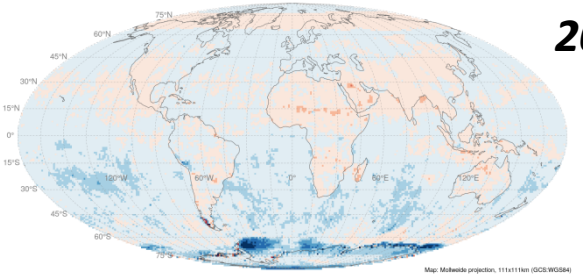


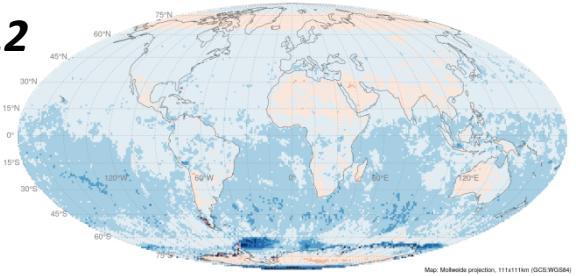


-4.29 W/m²

2012-12

-1.89 W/m²





-4.70 W/m²

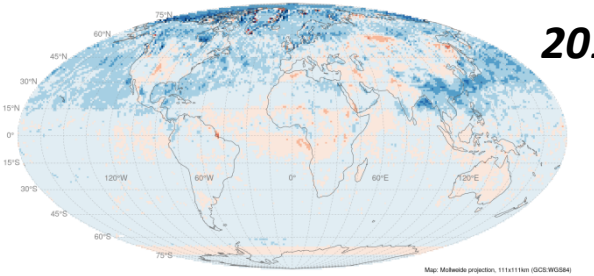
BIAS WITH CERES-EBAF

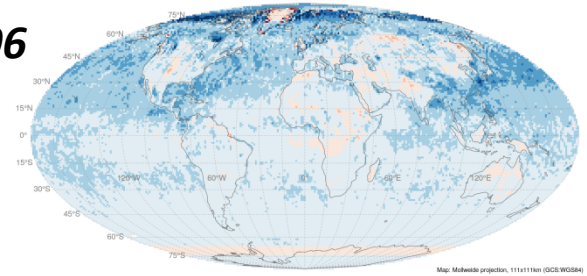
ADM: Loeb et al. (CERES-TRMM/-TERRA)

ADM: Suttles et al., 1988 (ERBE)

2012-06

-2.89 W/m²

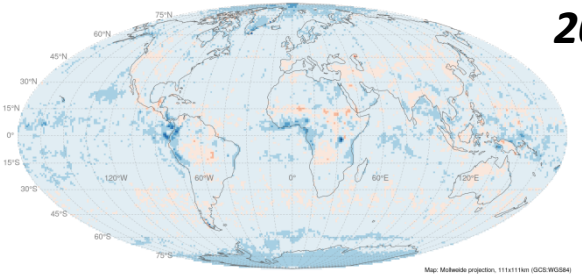


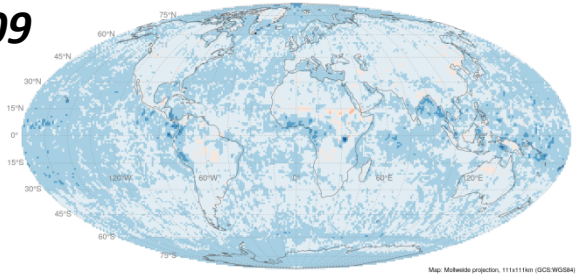


-5.56 W/m²

2012-09

-3.12 W/m²

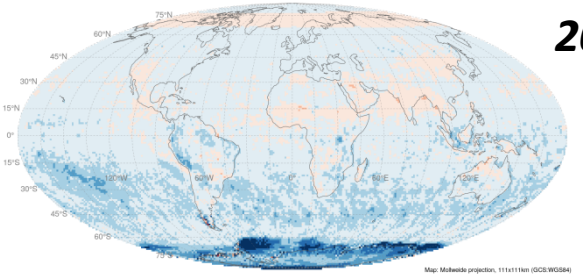


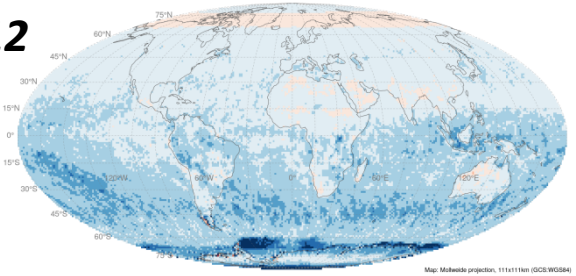


-5.94 W/m²

2012-12

-3.70 W/m²



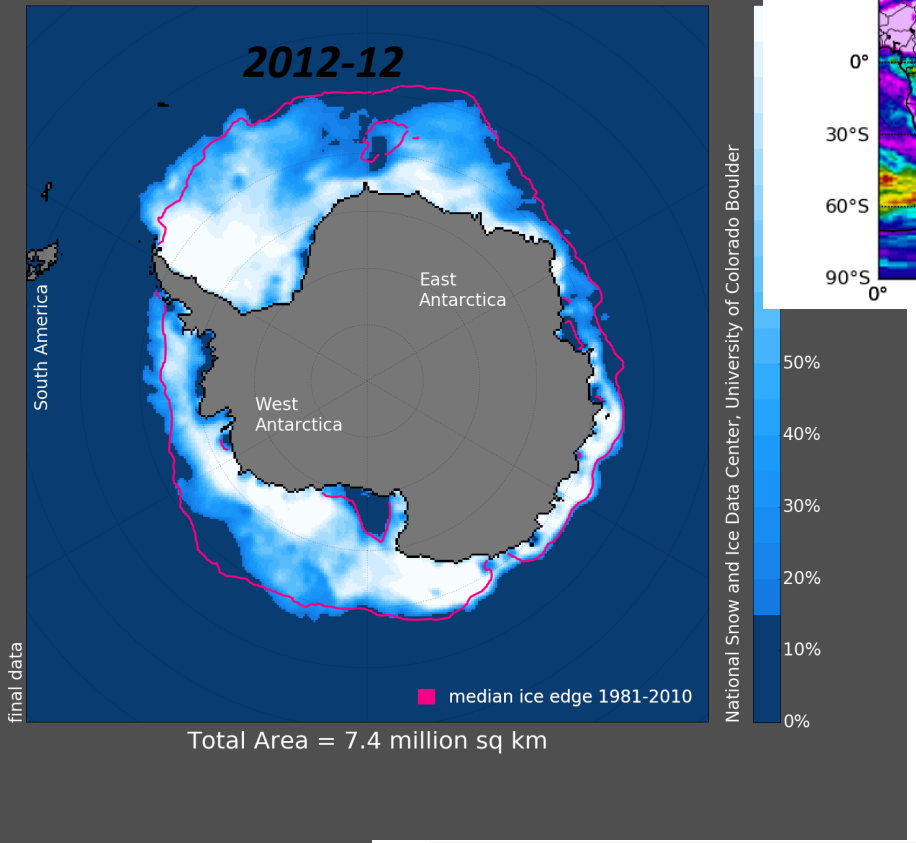


-6.51 W/m²

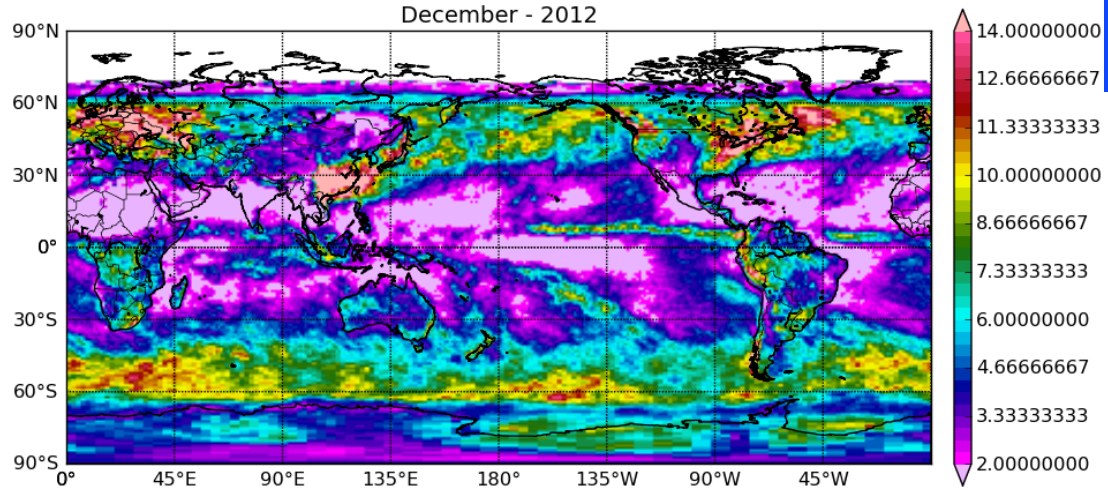
Extra slides

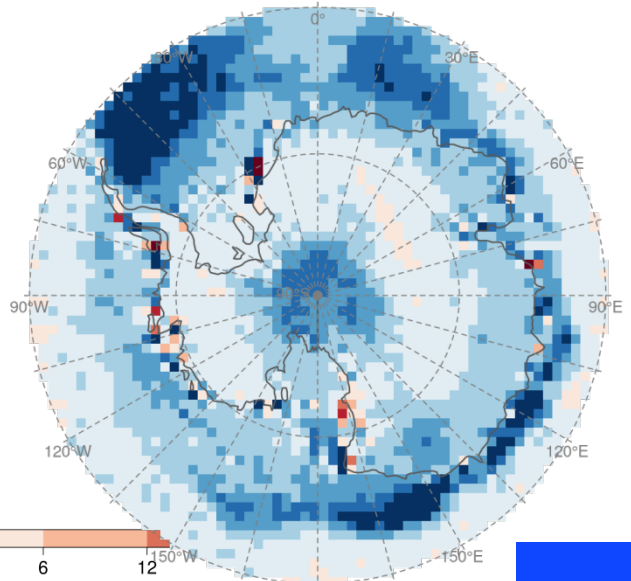
What would cause the bias related to overcast seaice?

Sea Ice Concentration, Dec 2012



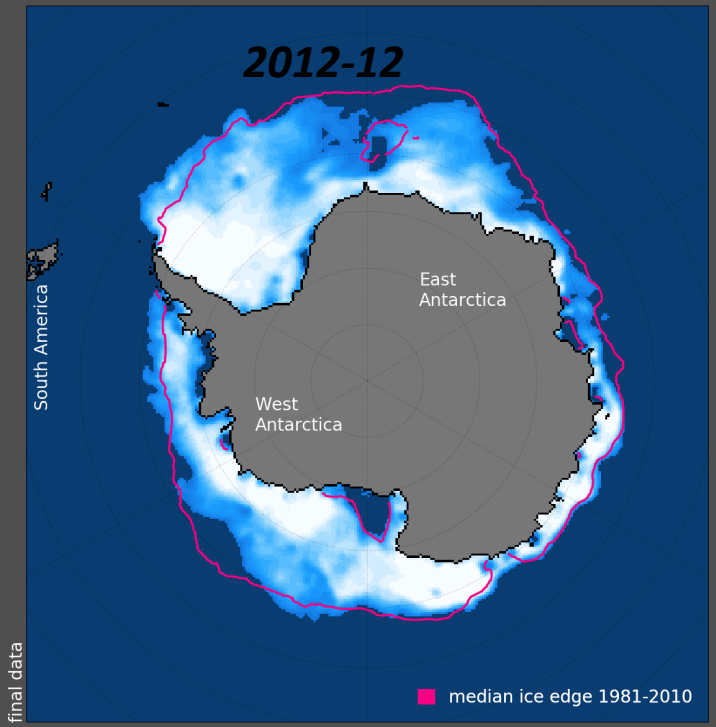
Total Area = 7.4 million sq km



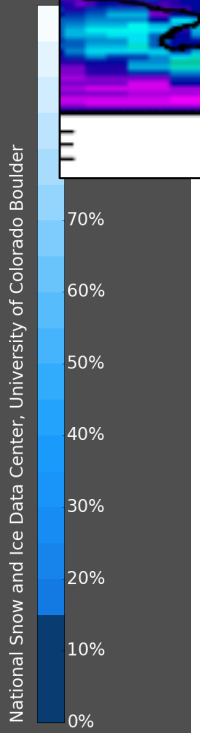


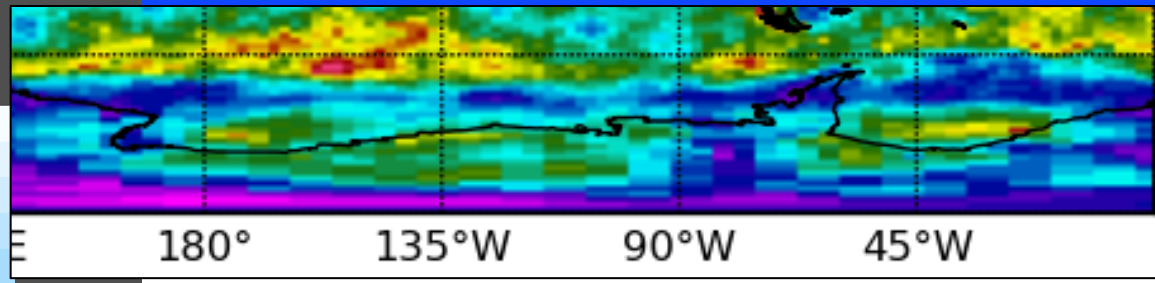
2012-12

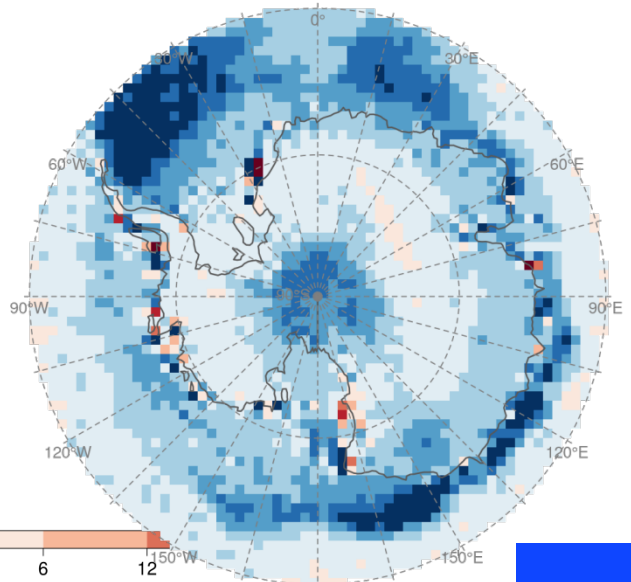
Sea Ice Concentration, Dec 2012



Total Area = 7.4 million sq km

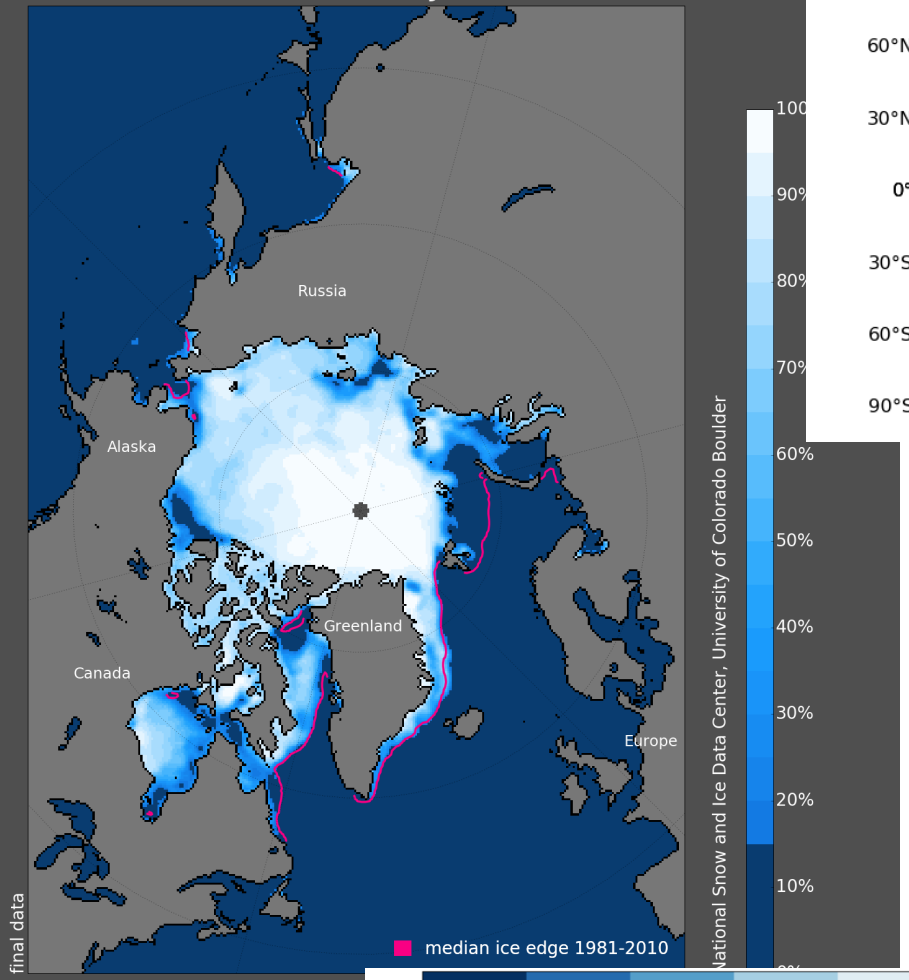




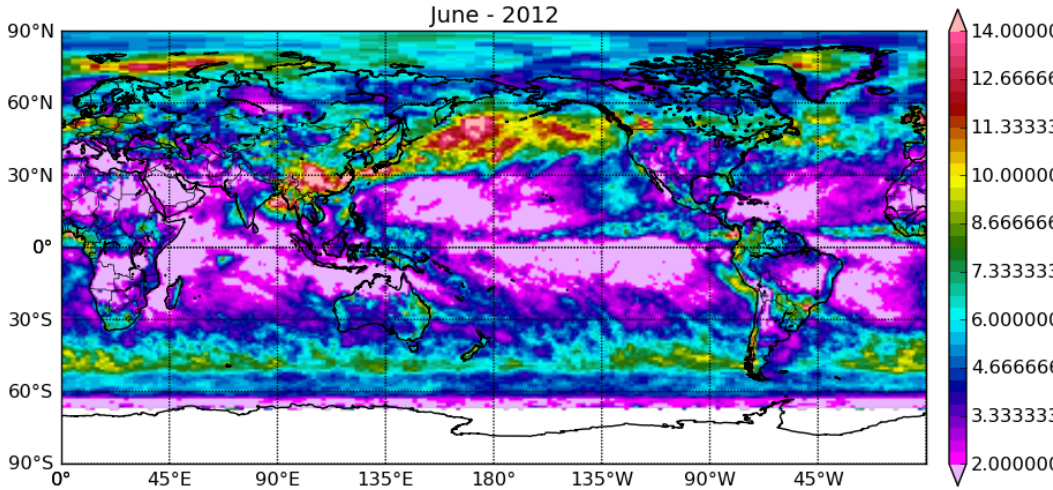


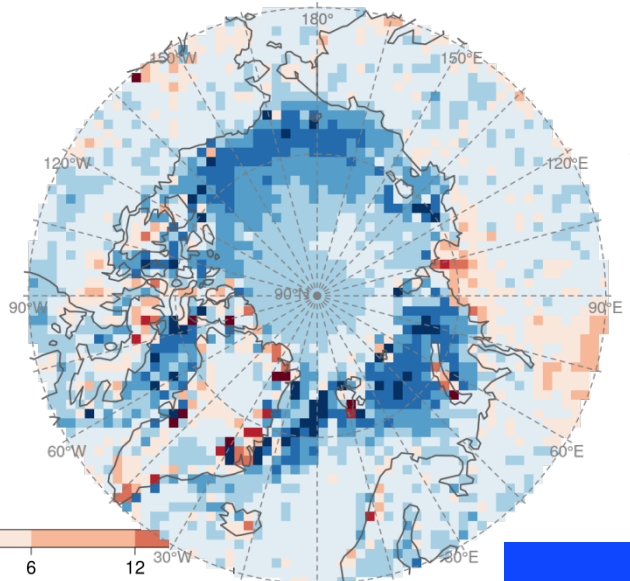
2012-12

Sea Ice Concentration, Jun 2012

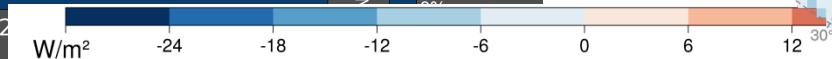


Total Area = 8.2





2012-06



Extra slides

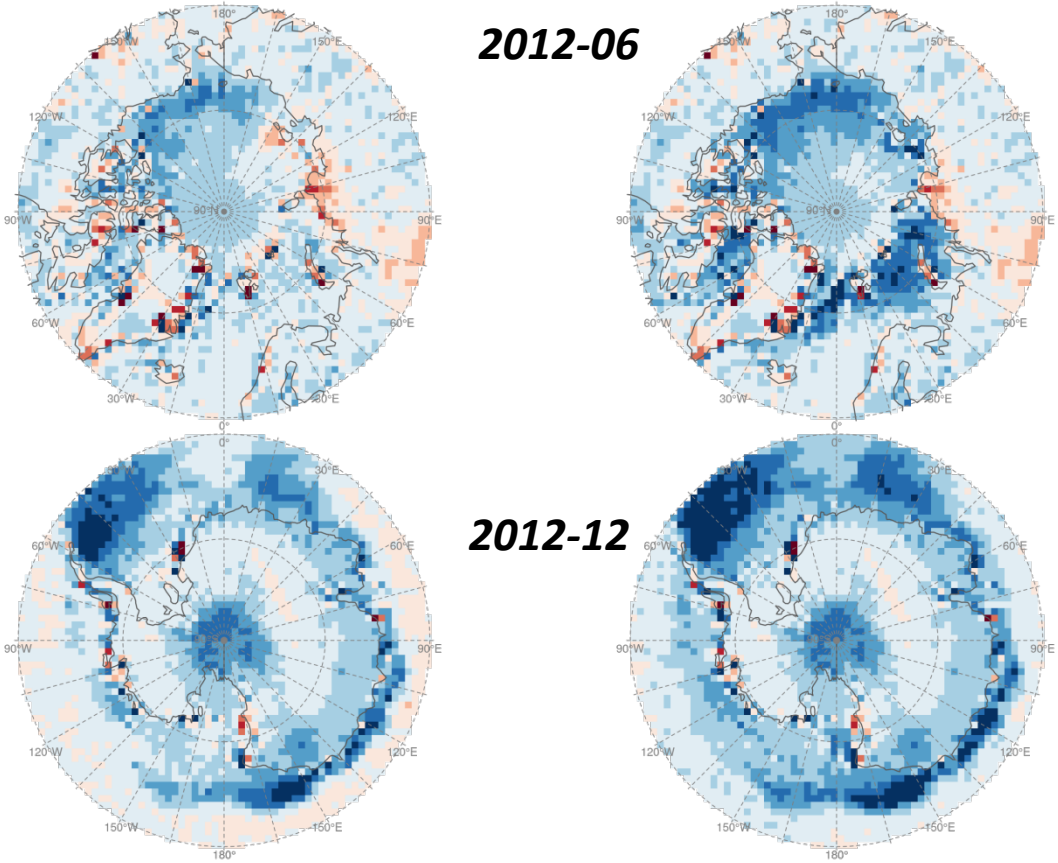
What if we applied original ADM's for overcast seaice from Terra?

(instead of replacing them by weighted mean from ocean and permanent snow ADM's)

Overcast seaice ADM:

Weighted mean overcast ocean and perm.snow

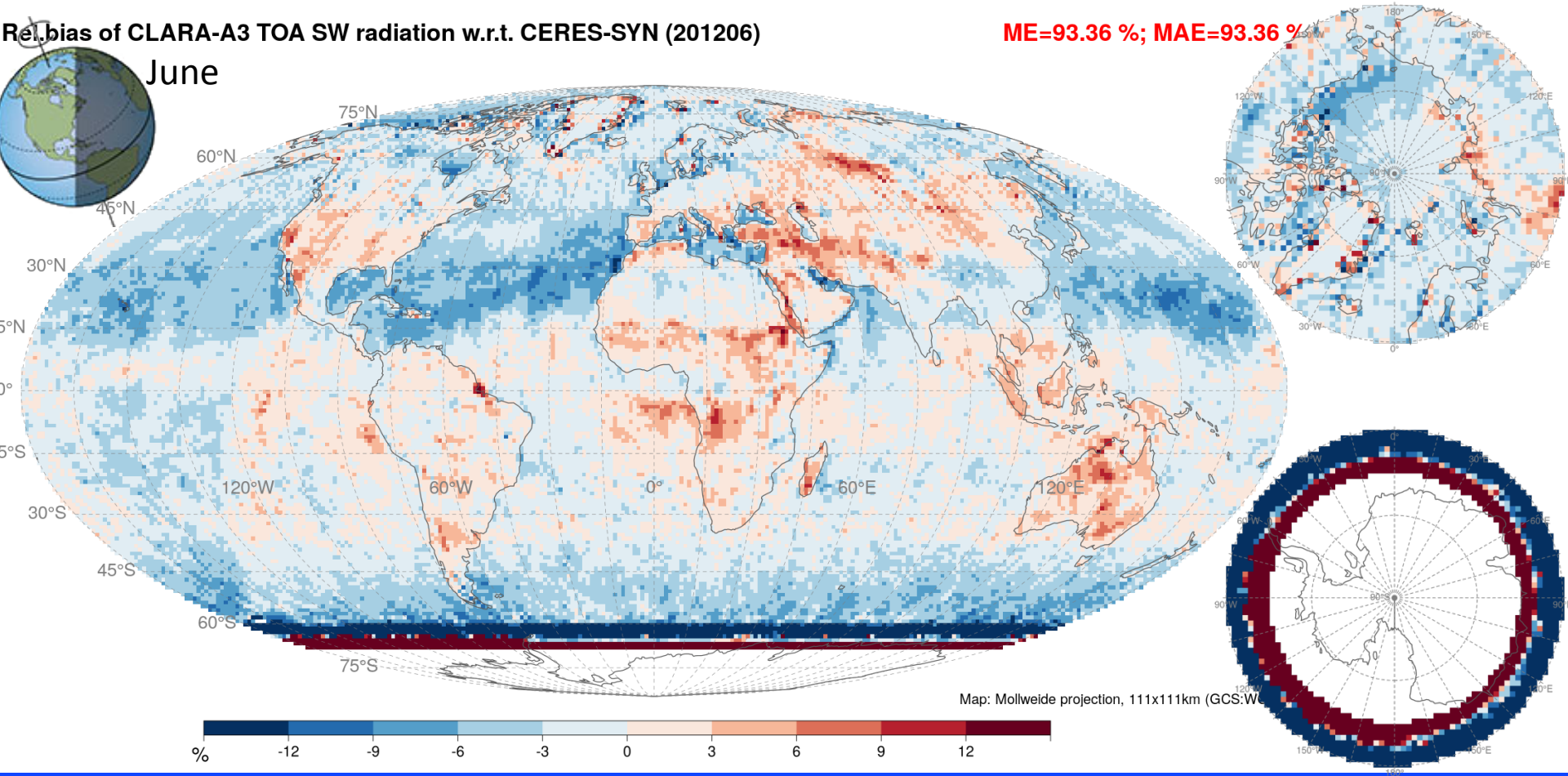
Original Terra ADM's overcast seaice (tau<10, tau>10)



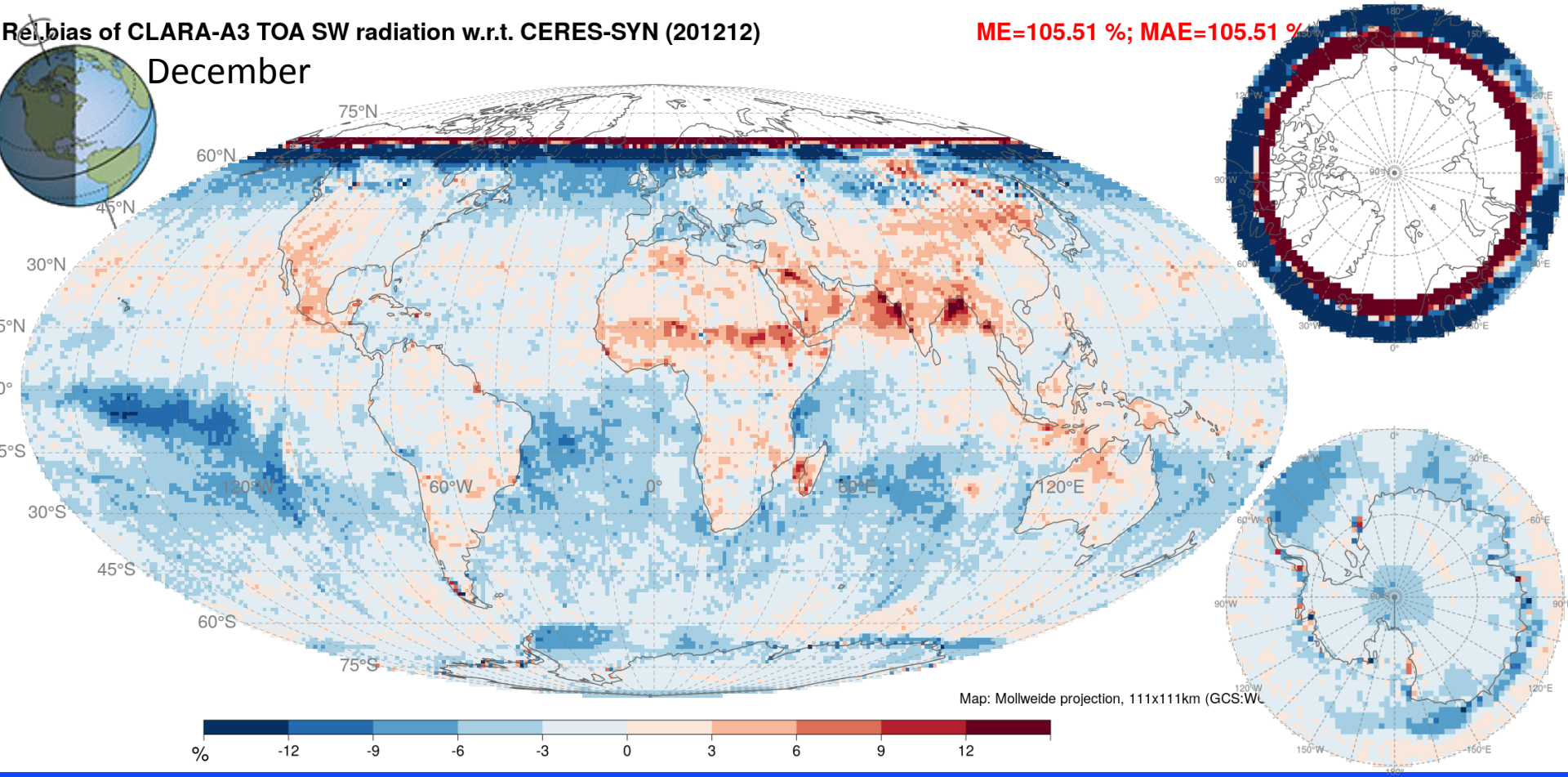
Extra slides

What if we calculate **relative** biases (instead of absolute)?

Extra slides



Extra slides

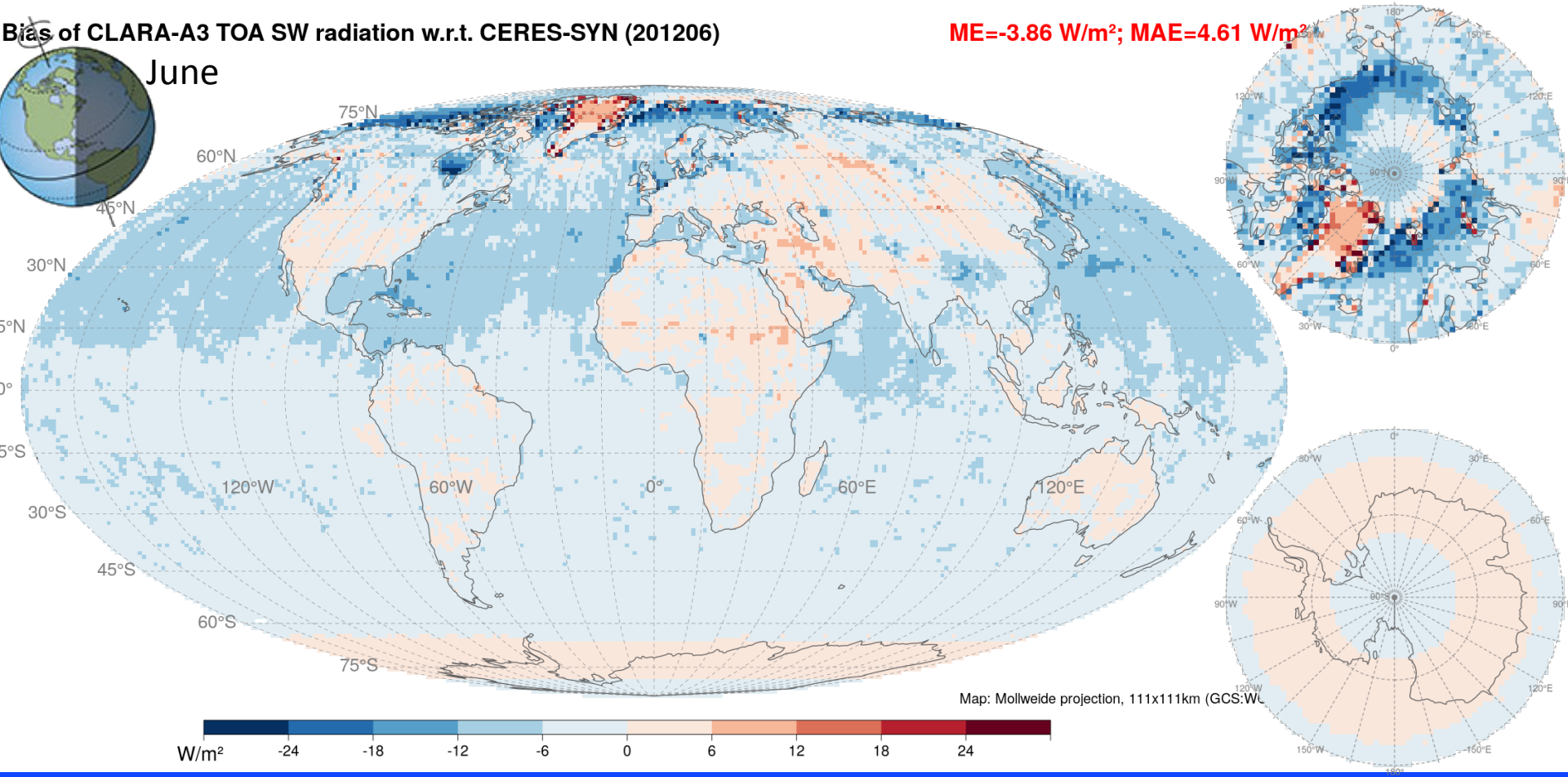


Extra slides

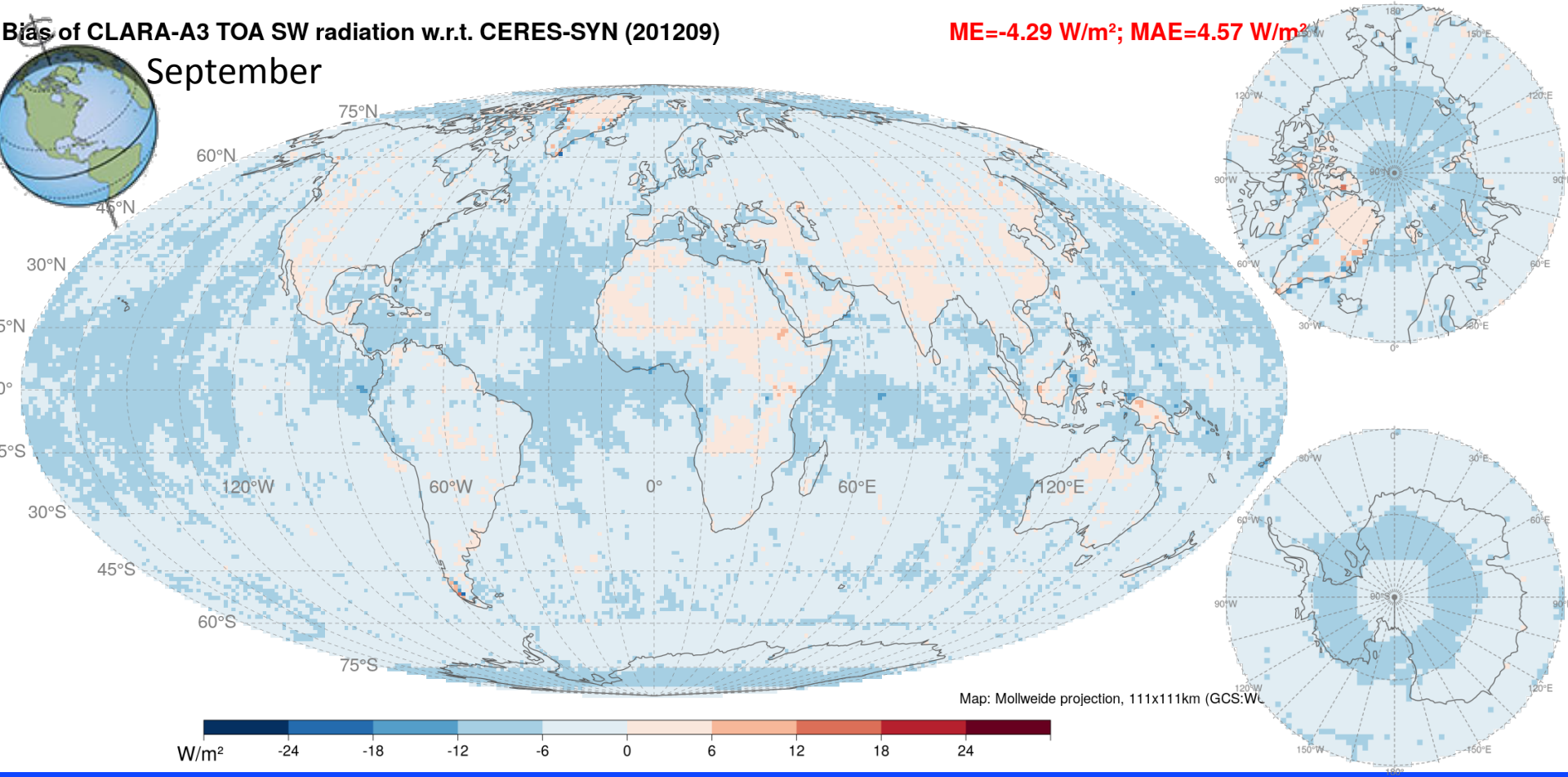
Bias with CERES-SYN using ADM's from Suttles et al., 1988

(instead of ADM's from Loeb et al.)

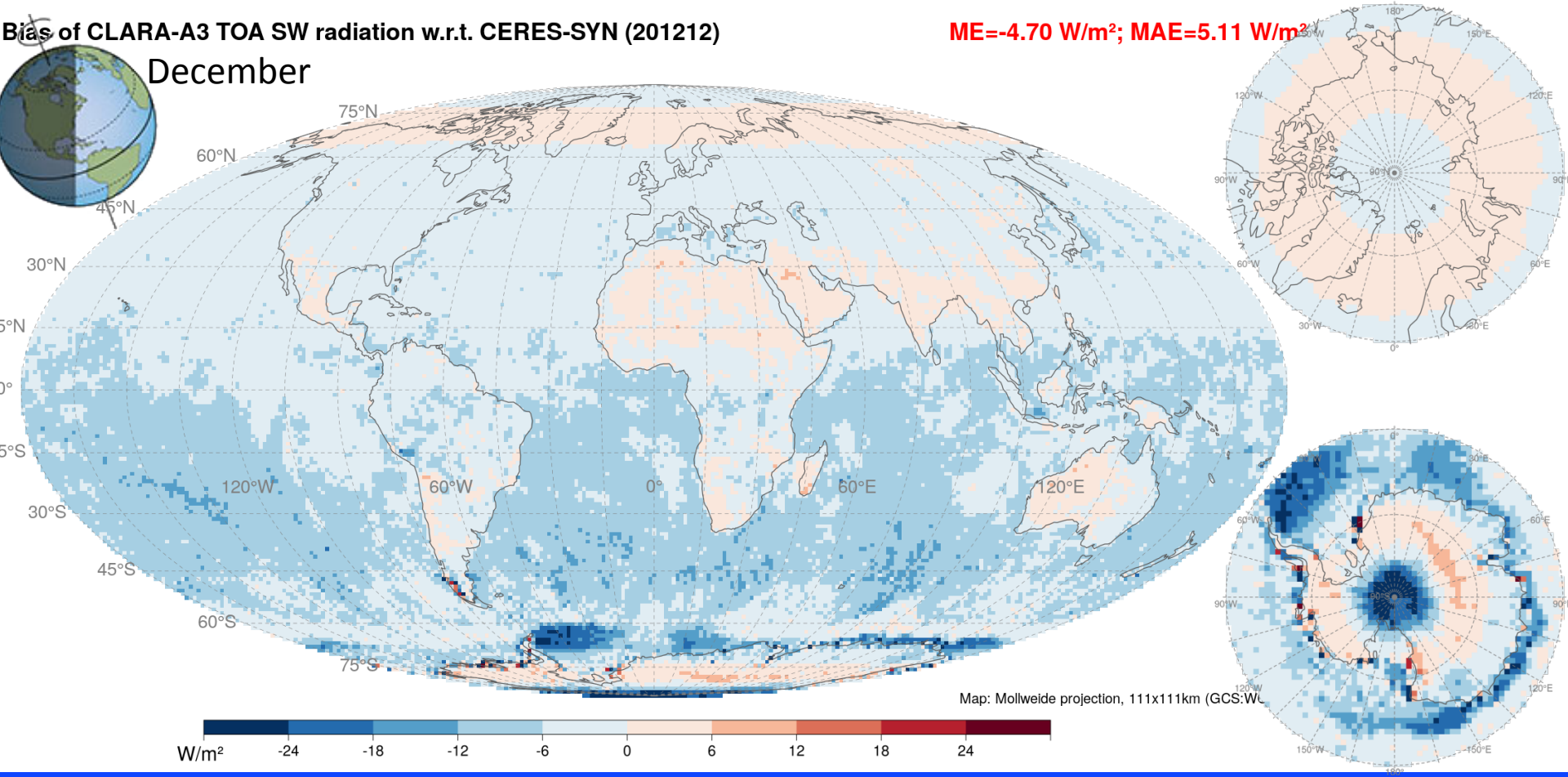
3. Results/validation



3. Results/validation

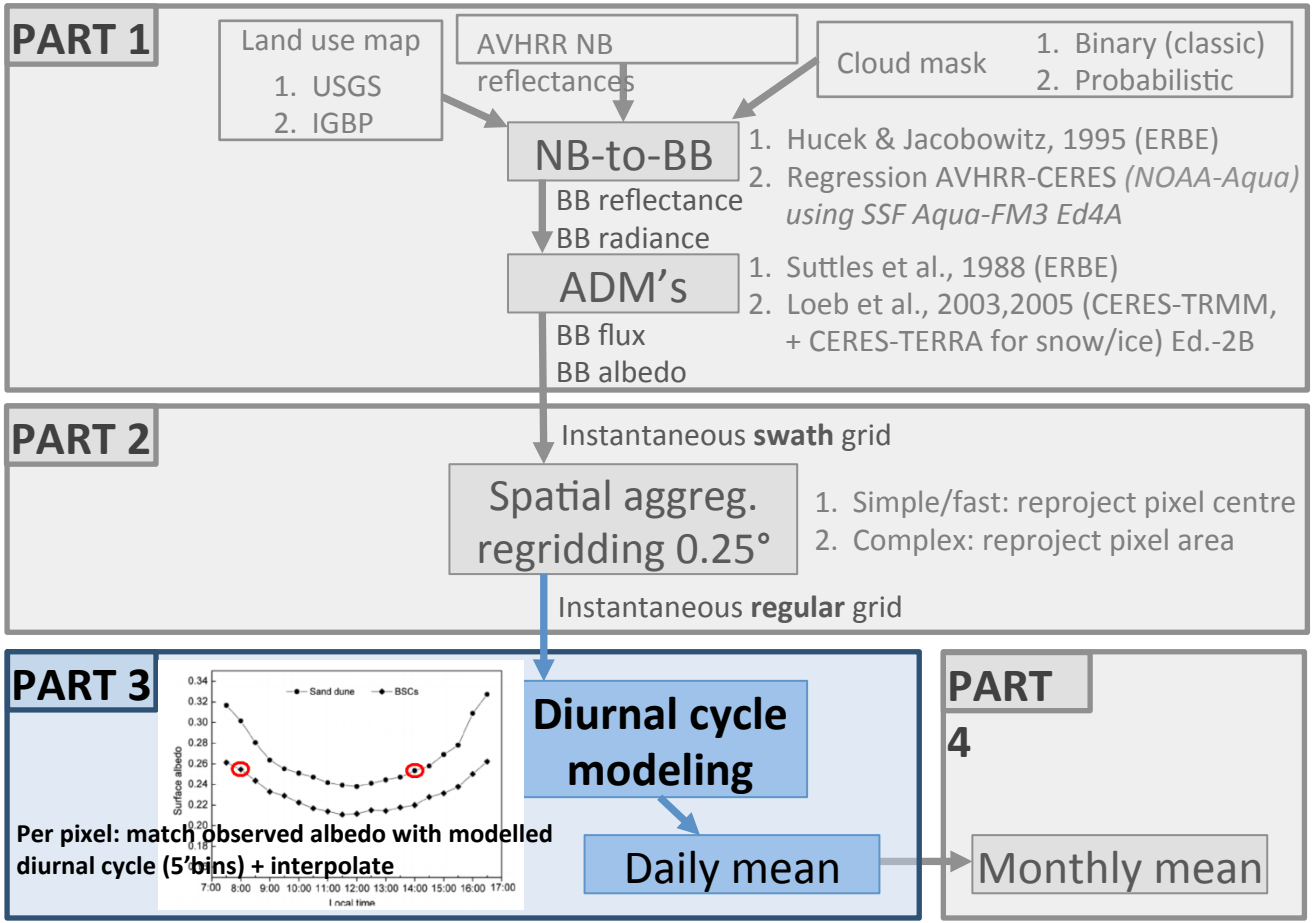


3. Results/validation

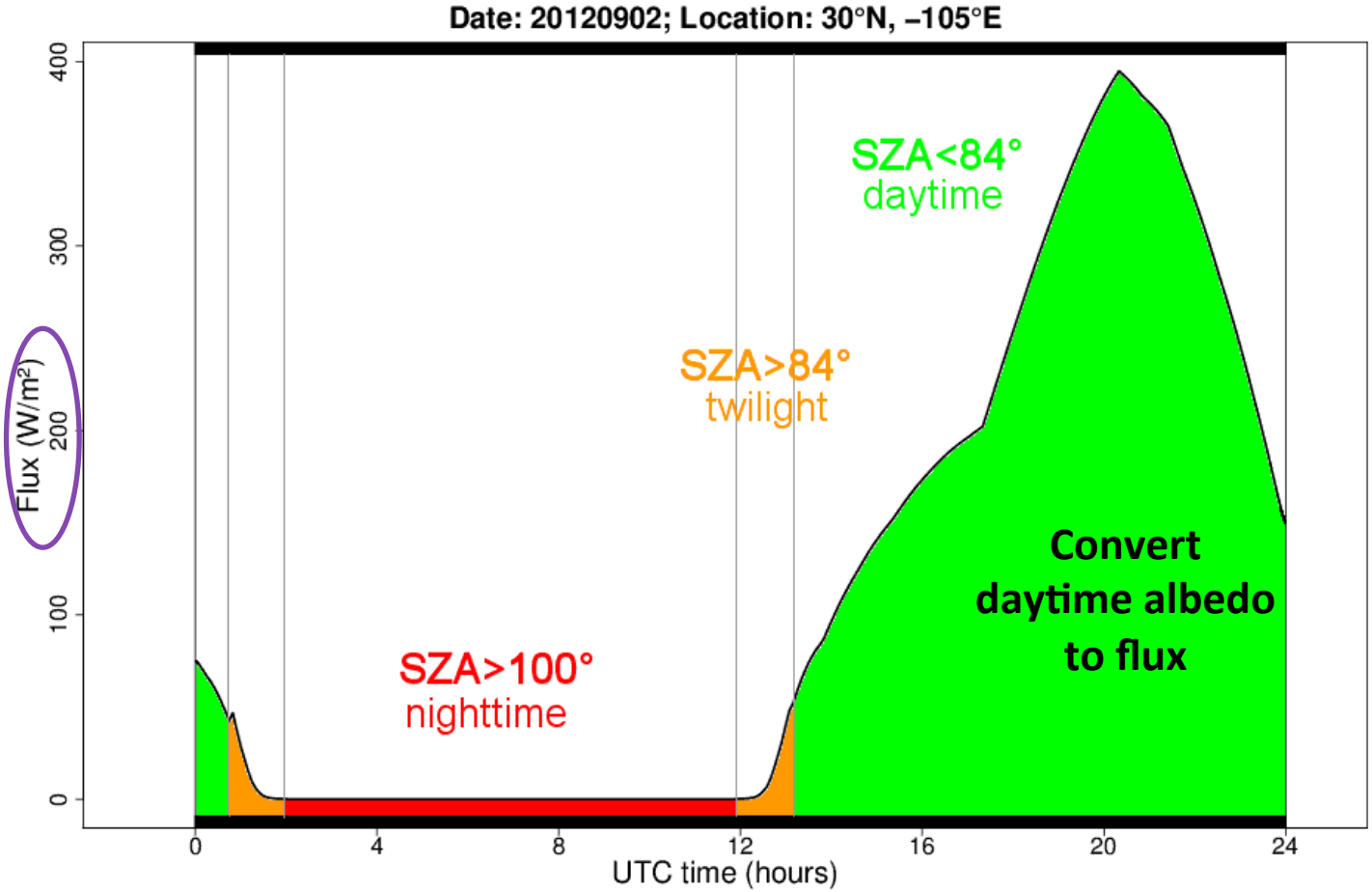


Diurnal cycle modeling

Extra slides



Diurnal cycle modeling:

- Based on Young et al., 1998
- cfr. CO-method in TISA (Doelling et al.,2013)

Extra slides