global aerosol

and their radiative effects

Stefan Kinne

overview

- atmospheric aerosol
- aerosol optical properties and observations
- global distributions (MACv3 climatology)
- deduction of (pre-defined) components
- aerosol radiative effects … also by components
- direct climate impacts (extra aerosol presence since 1850)
- indirect climate impacts (via modified clouds)
- outlook

atmospheric aerosol

- different sources, lifetimes of a few days in the troposphere
- high variability in space and time

atmospheric optical properties

- **how much ?** via visible attenuation → **AOD** at 550nm
- **how absorbing ?** via scatt. potential SSA → **AAOD** (=AOD *[1-SSA])
- **what size ?** via sub-/super-um size-modes → **AODf**ine **AODc**oarse

- optical observations:
  - satellite interpretations (passive & active)
  - ground-monitoring (AERONET, MAN, LIDAR)
  - in-situ (poor statistics)

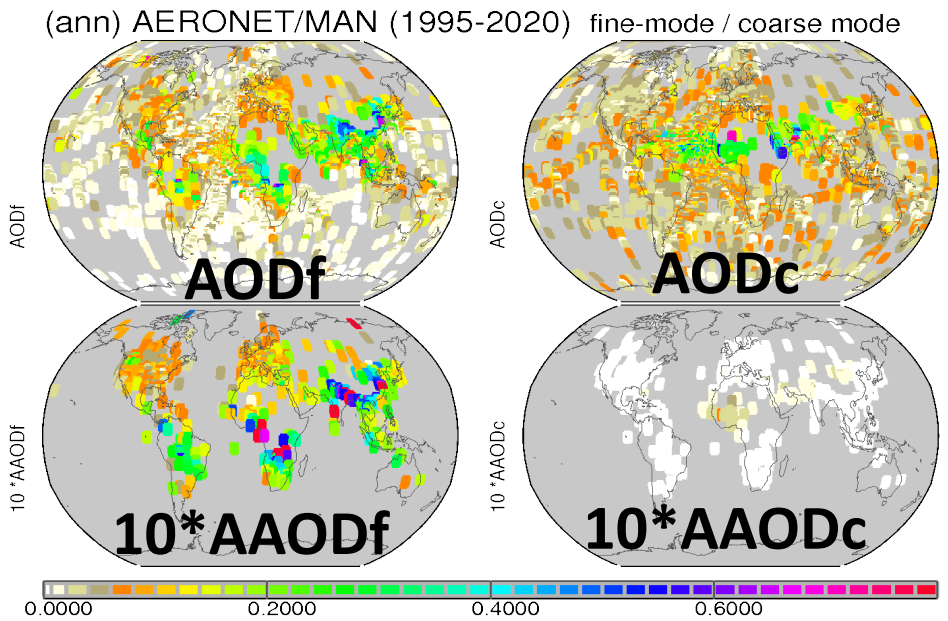
- modeled interpretations
  - emission data processing and transport

AeroSAT

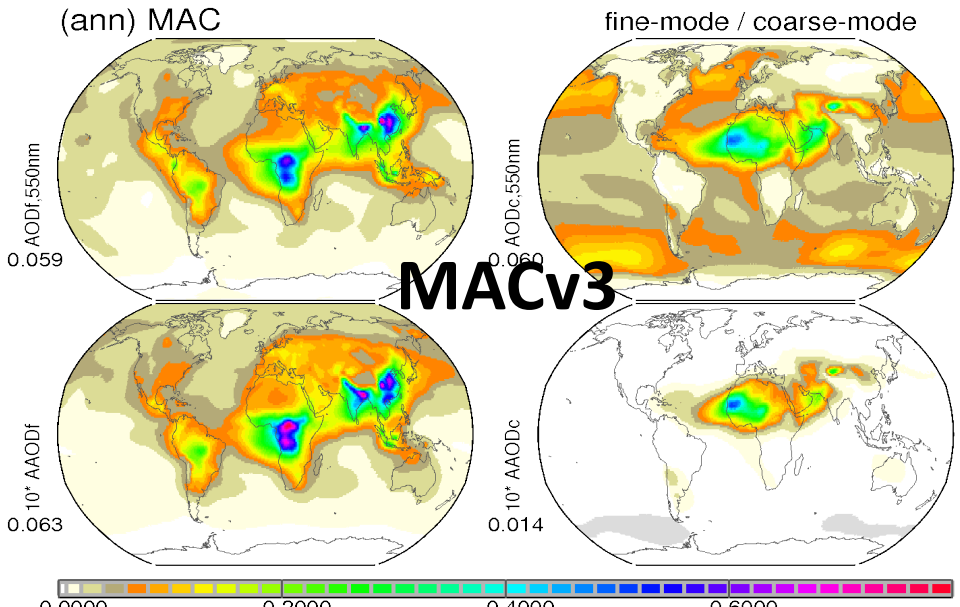
AeroCom

global distributions

- **combine** observations (*of photometry*)
  AODfine, **AODc**oarse **(global)**
  AAODfine, **AAODc**oarse **(land only)**
- **expand** monthly statistics with patterns from global modeling →
- **distribute AOD** on components
  BC/OCmix, **OM**, **SU** (reff), **SS**, **DU** (reff)
- **apply** component properties to define spectral properties (→ rad. effects)
  AOD (λ), **SSA** (λ), **ASY** (λ)



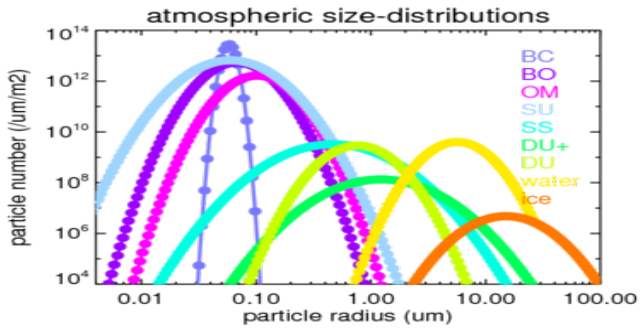
annual average maps



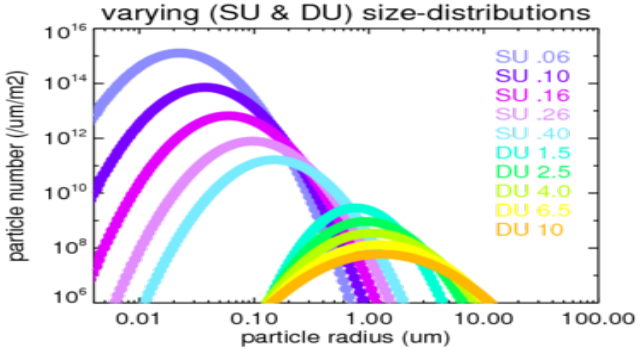
spectral properties
of pre-defined aero components

size-distributions

of components

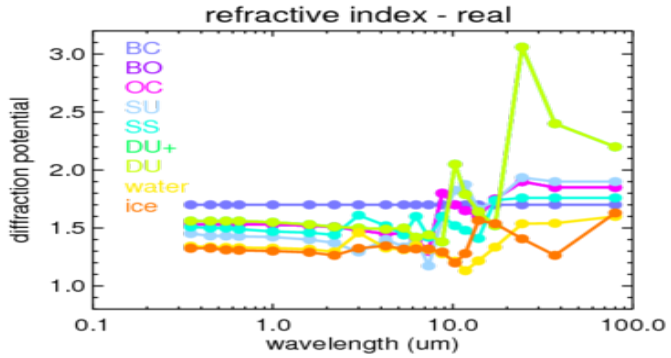


for DU and SU

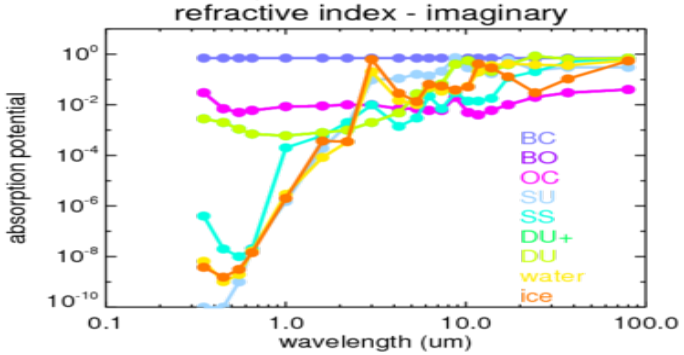


refractive indices

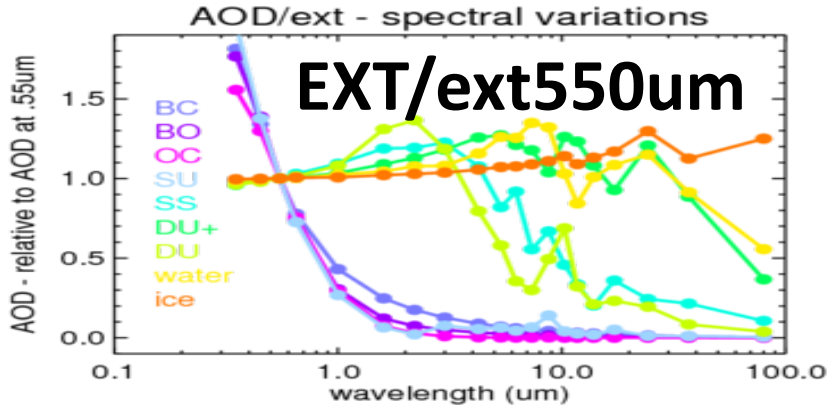
real part

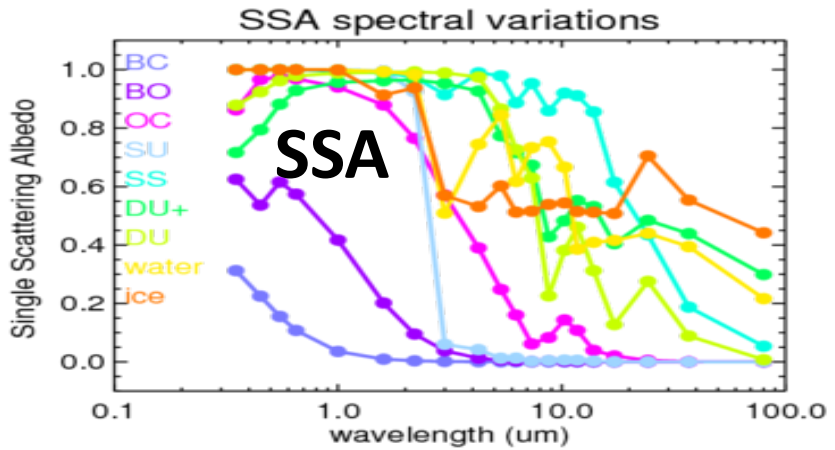


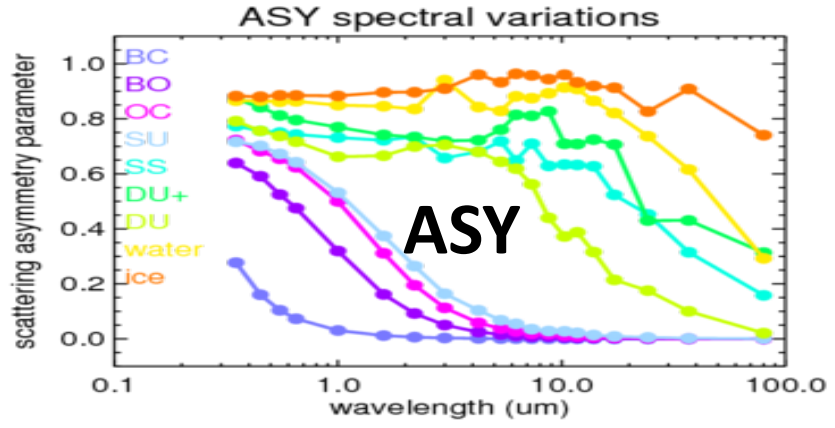
imaginary part



BC
BO
OC
SU
SS
DU+
DU
water
ice



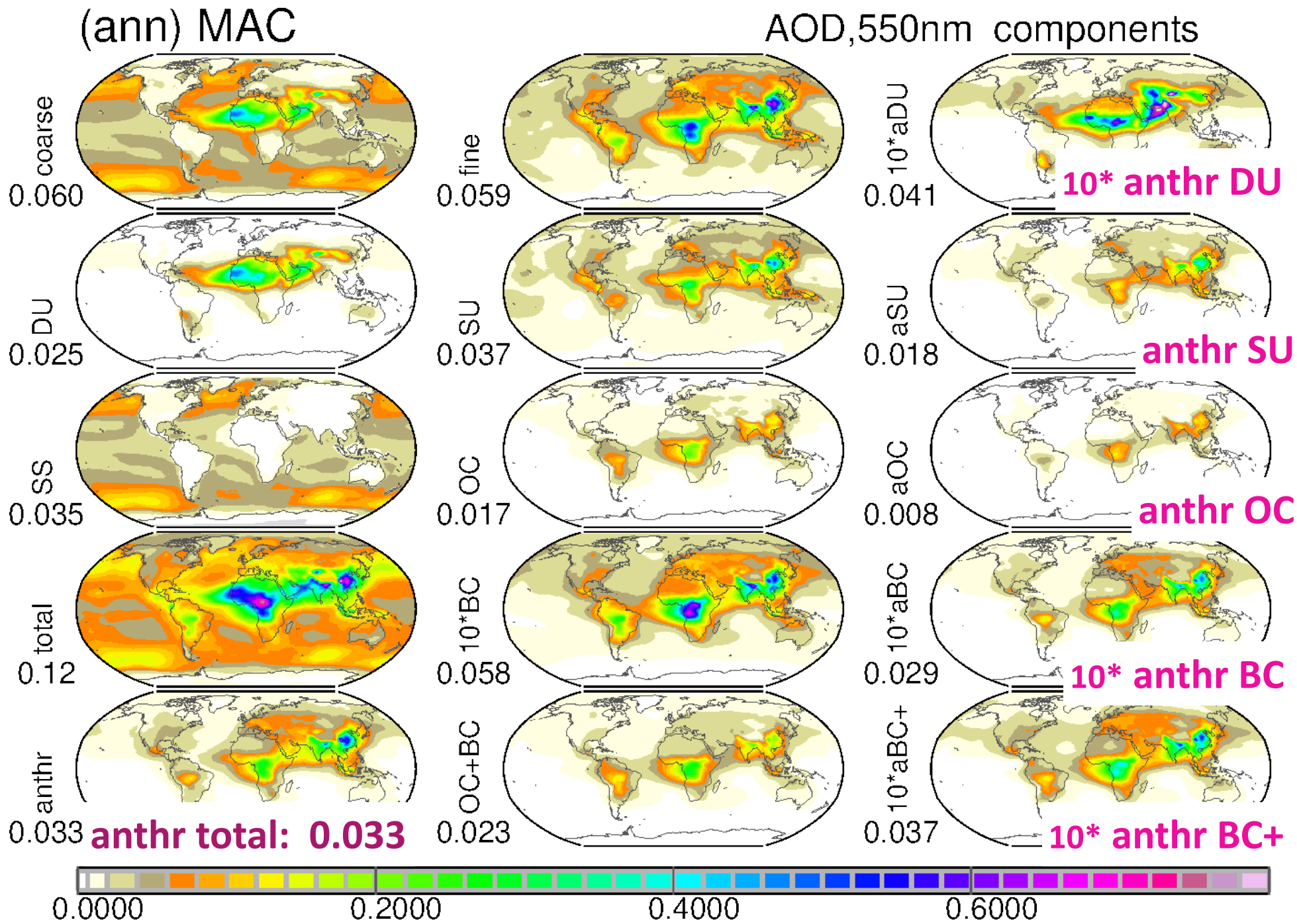




AOD (550nm) split

- total .12
  - coarse .06
    - dust **DU**
    - seasalt **SS**
  - fine .06
    - sulfate **SU**
    - org matter **OC**
    - BCcore/OC mix **BO**

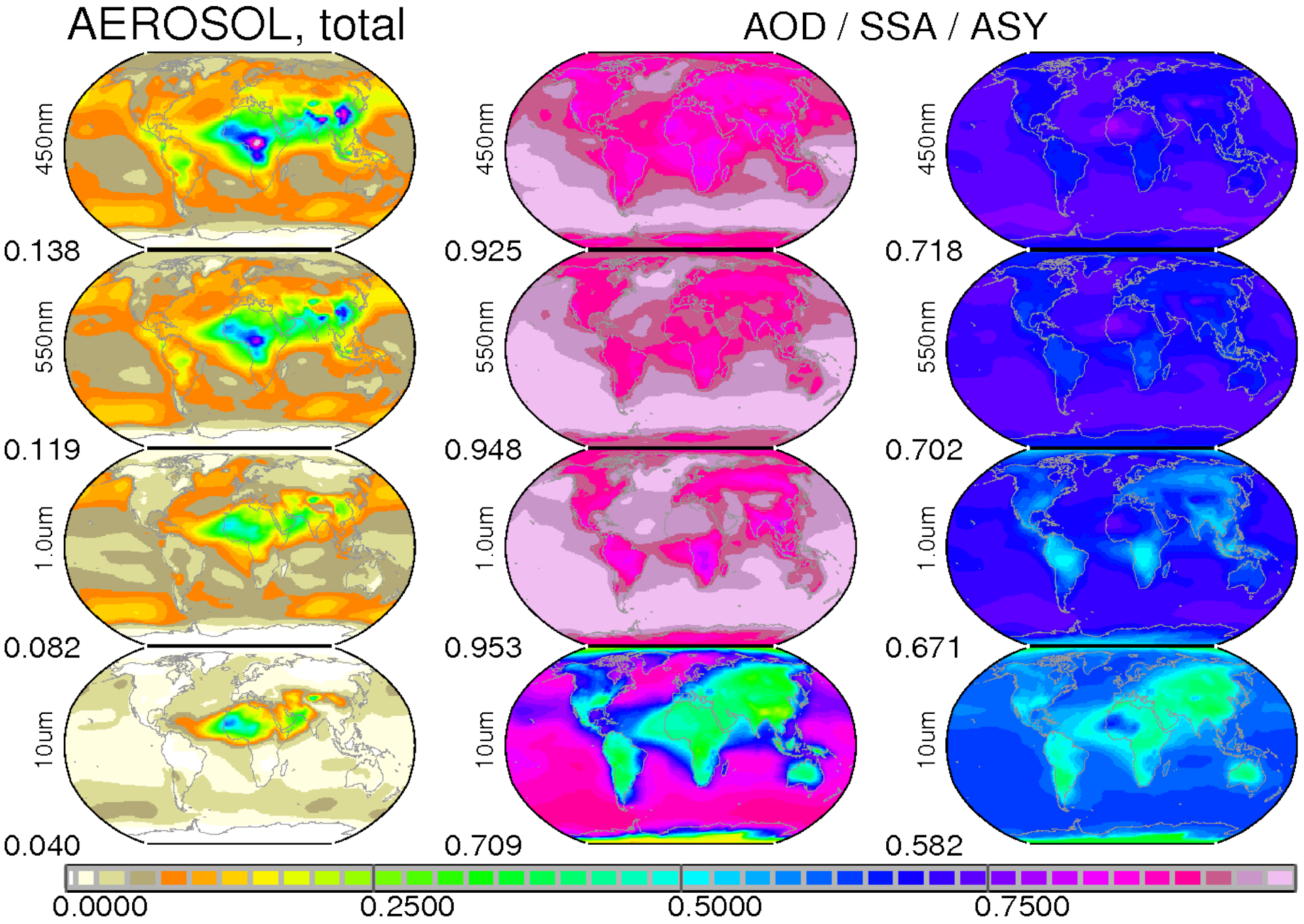
annual maps



aerosol
single
scattering
properties

- **AOD**
- **SSA**
- **ASY**

here at
- **.45um**
- **.55um**
- **1.0um**
- **10.um**



MAC for you ? … if you like

- available via ftp download

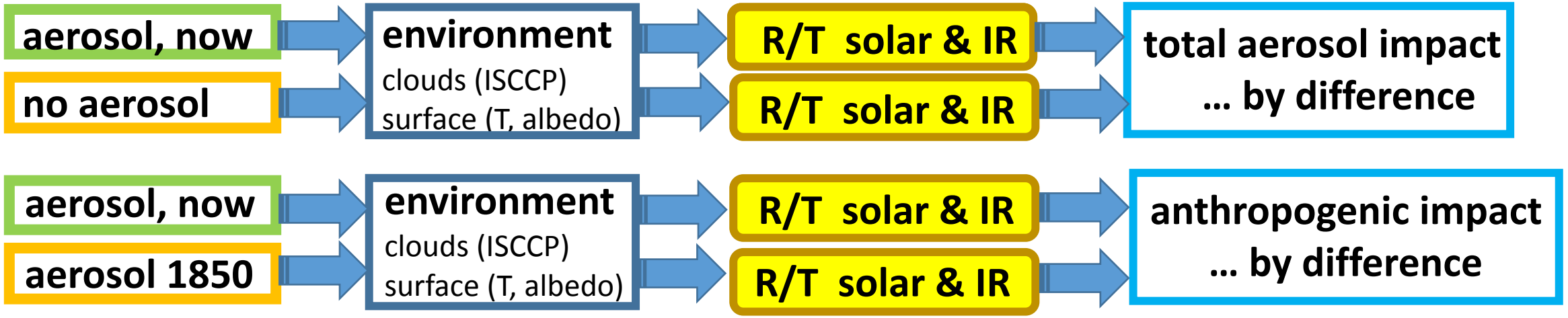
ftp-projects.mpimet.mpg.de/aerocom/climatology/MACv3_2022

- /550nm_20bands MACv3, 20 bands (gen), 550nm details
- /altitude altitude distr. (fine-, coarse-mode, total)
- /ant_time anthrop AOD (1850-2100) / fac to ant2015
- /total_30bands MACv3, 30 RRTM bands (gen + 2001-2022)
- /total_31bands MACv3, 31 SRB bands (gen + 2001-2022)
- /predef_types at different (20, 30, 31) spectral resolutions

… finally by multiplying MODIS AODf and AODc anomalies …

MACv3 data are offered for specific years of the 2001 - 2020 time-period

radiative transfer application



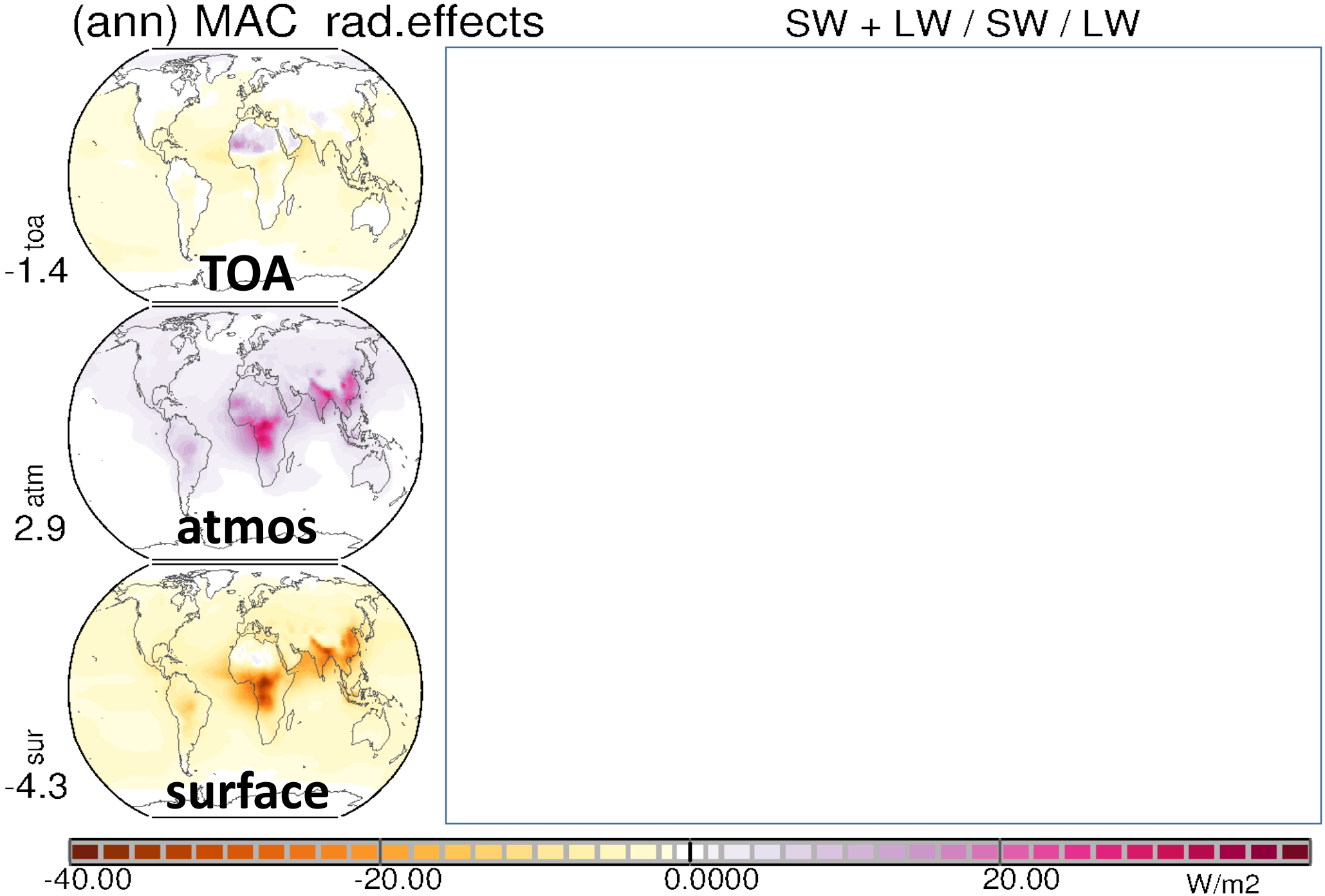
radiative broadband flux differences:

- *Top Of Atmosphere* ***… impact on climate***
- ***atmosphere*** *(solar heating)* ***… impact on dynamics***
- ***surface*** ***… impact on surface processes***

total

added
presence
impact

annual averages



cooling

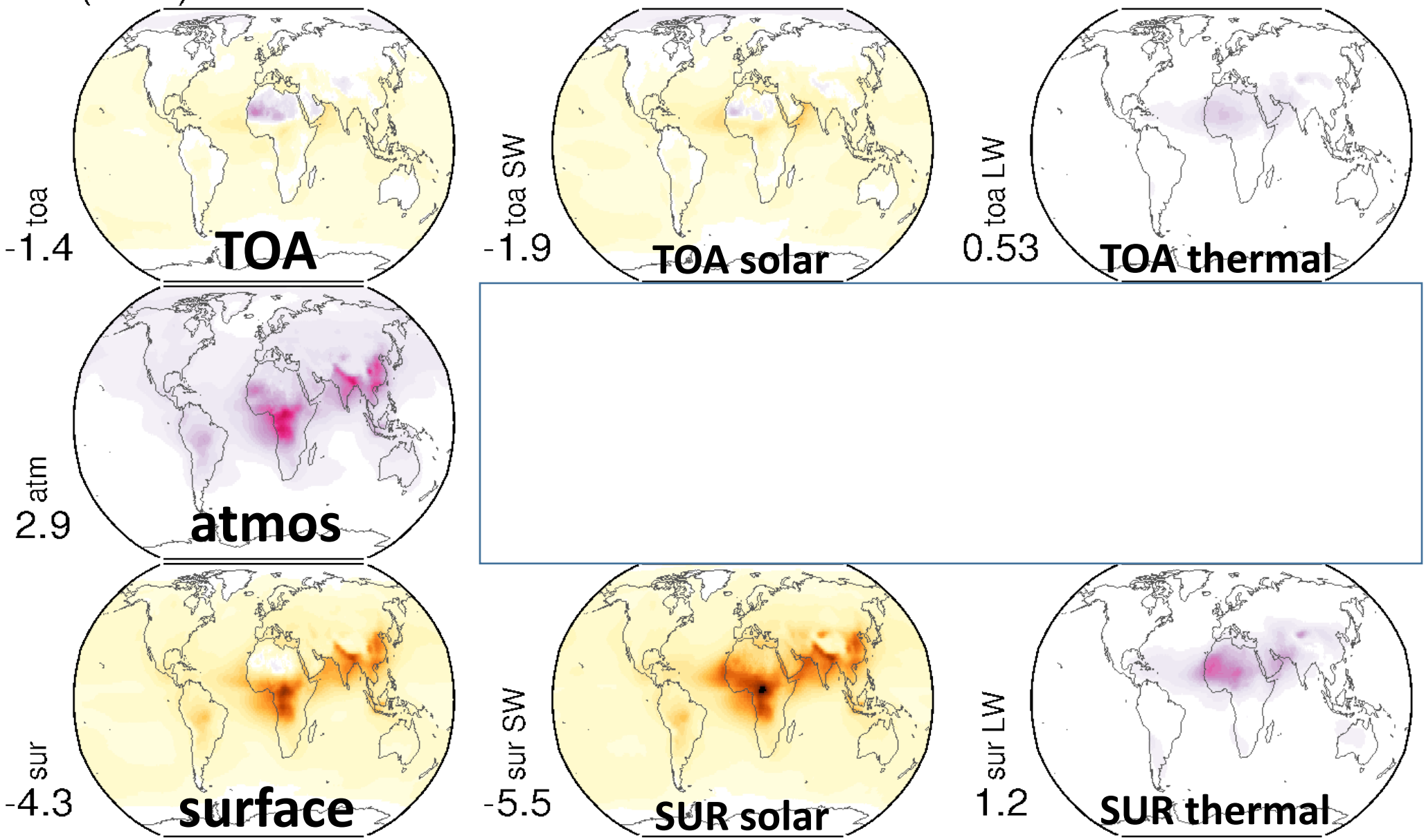
warming

total

added presence **impact**

(ann) MAC rad.effects

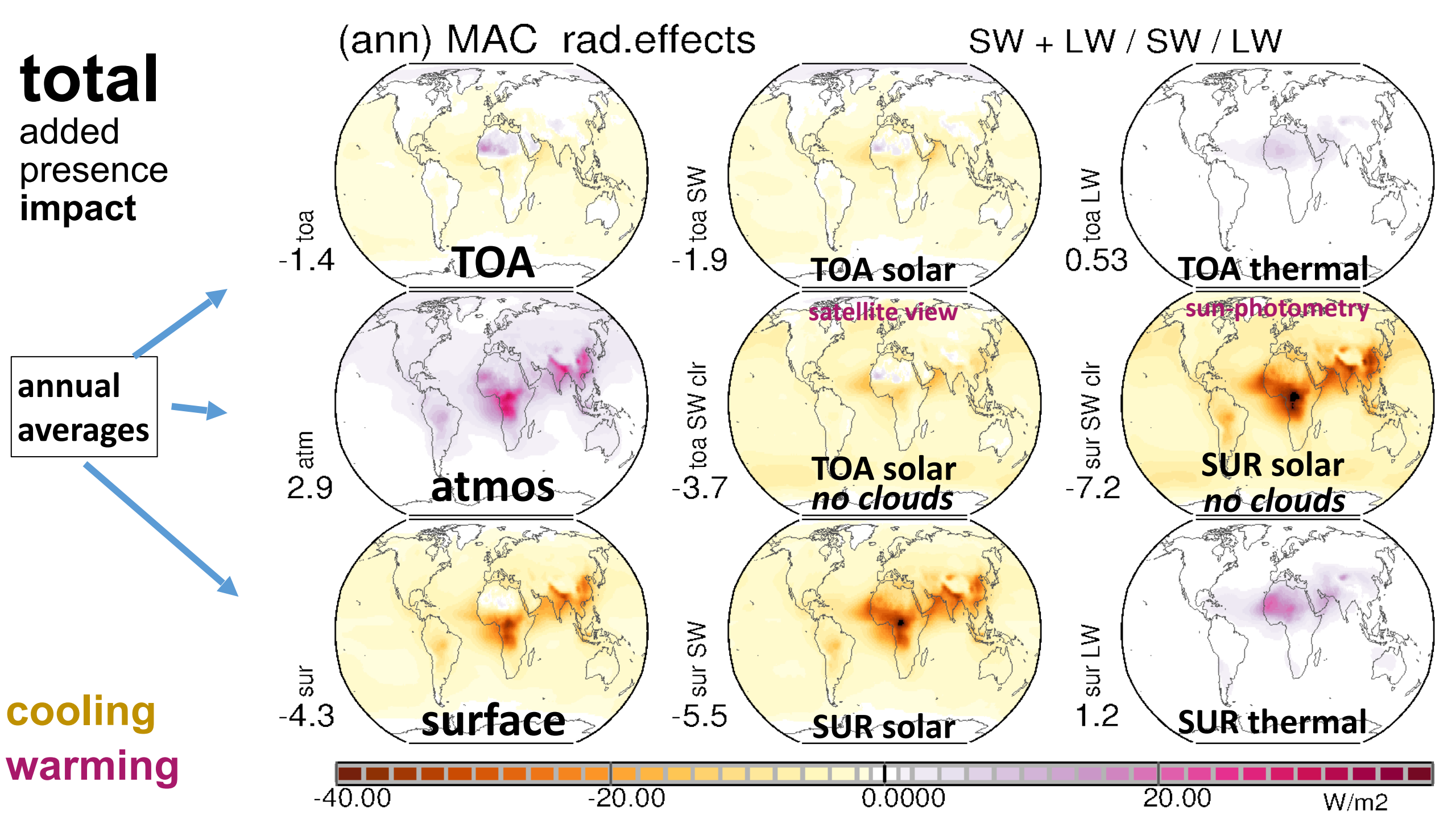
SW + LW / SW / LW



annual averages

cooling

warming


total
added
presence
impact
annual
averages
cooling
warming
(ann) MAC rad.effects
SW + LW / SW / LW
toa
-1.4
TOA
toa SW
-1.9
TOA solar
toa LW
0.53
TOA thermal
satellite view
sun-photometry
atm
2.9
atmos
toa SW clr
-3.7
TOA solar
no clouds
sur SW clr
-7.2
SUR solar
no clouds
sur
-4.3
surface
sur SW
-5.5
SUR solar
sur LW
1.2
SUR thermal
-40.00
-20.00
0.0000
20.00
W/m2

total

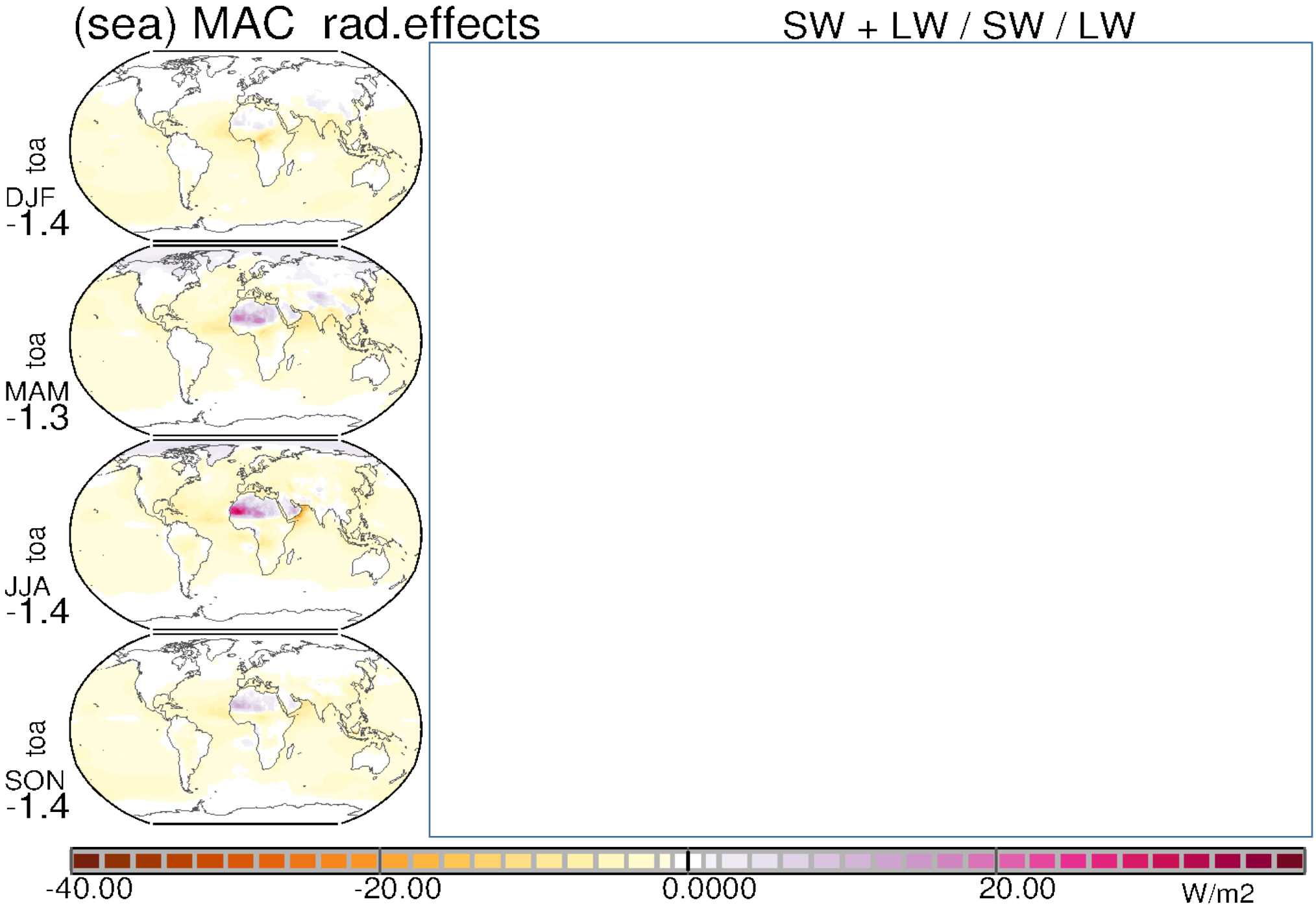
added
presence
impact

seasonal variations

- **winter**
- **spring**
- **summer**
- **fall**

cooling

warming



total

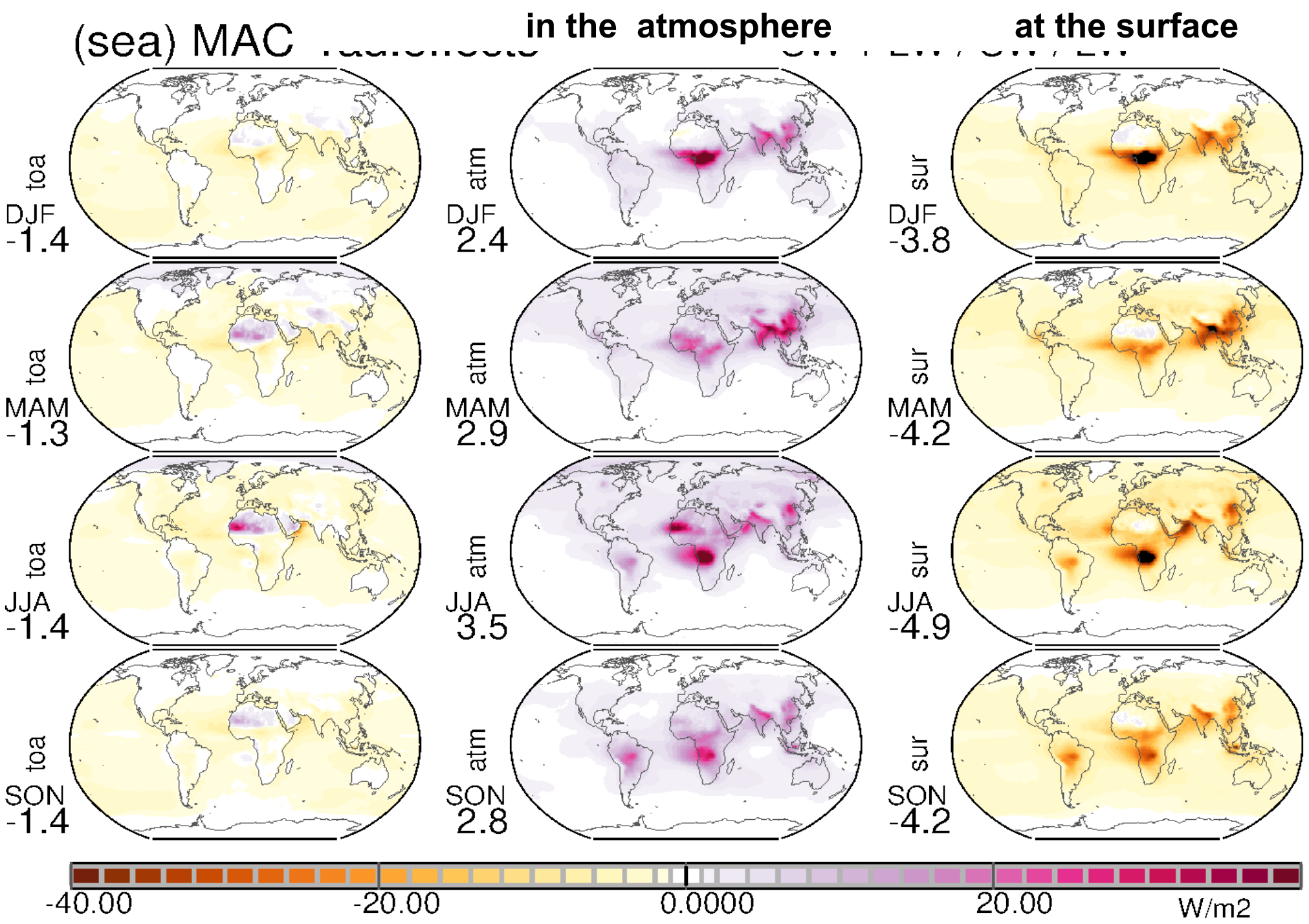
added presence **impact**

seasonal variations

- **winter**
- **spring**
- **summer**
- **fall**

cooling

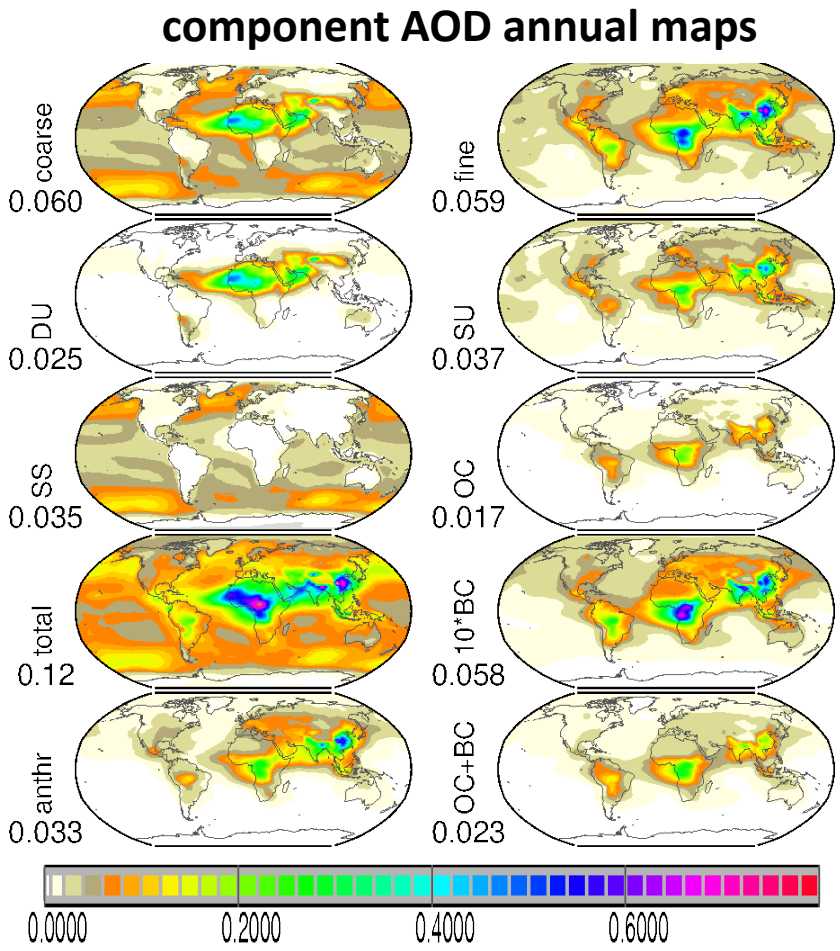
warming

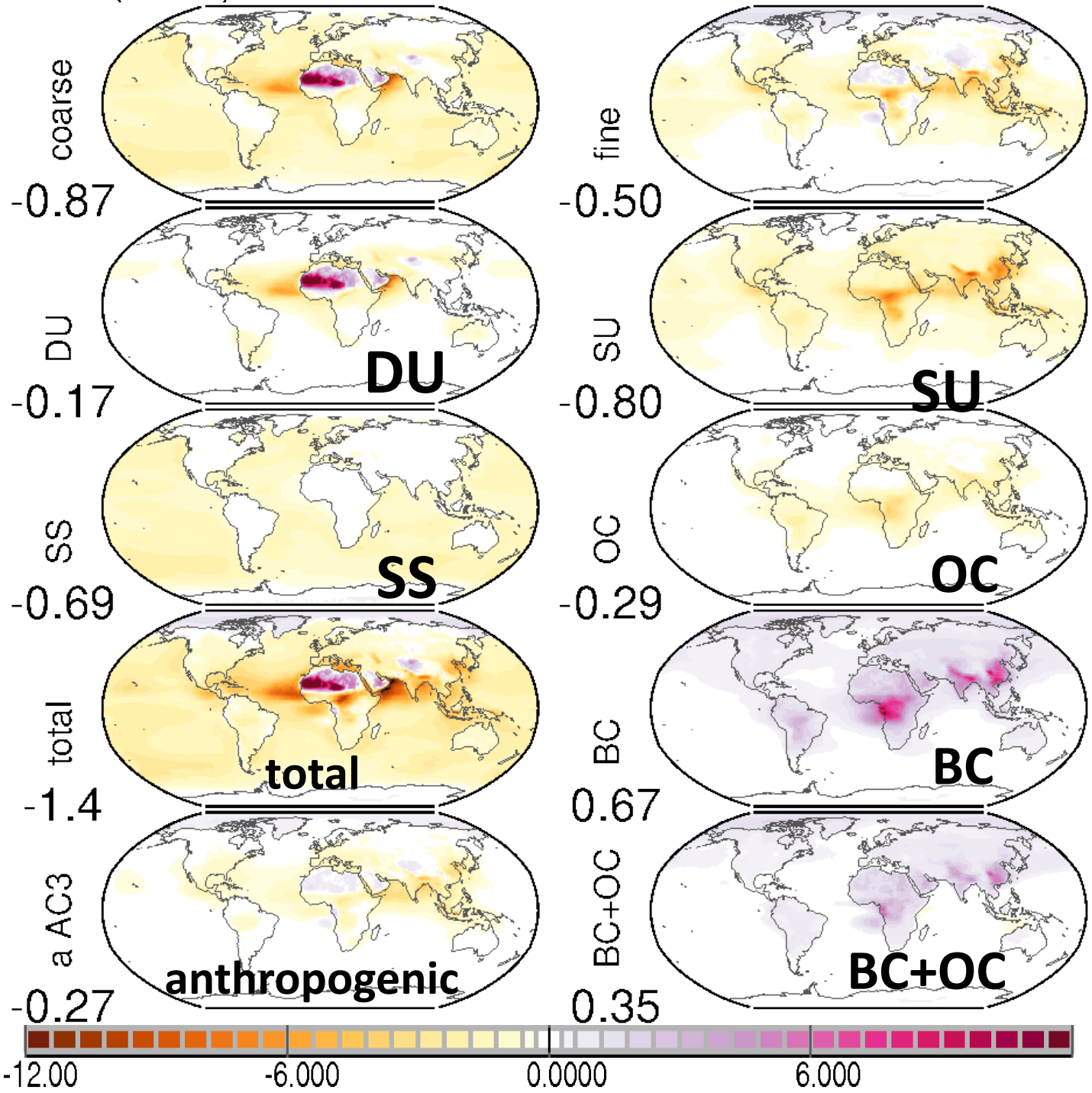


component TOA effects

cooling

warming

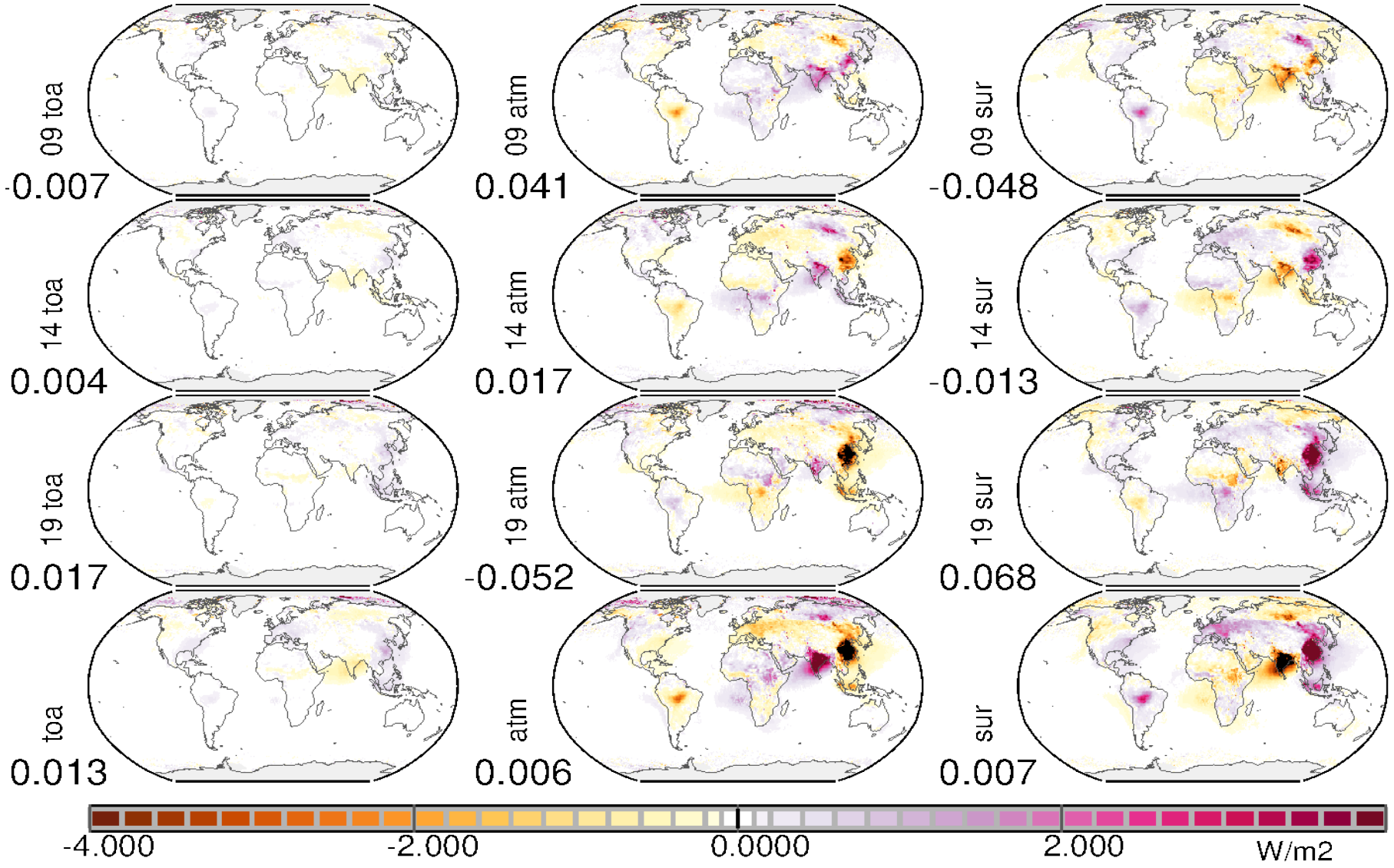




trends in aerosol radiative effects

MODIS (+MACv3)

- **2006-2012 vs 2001-2007**
- **2011-2017 vs 2007-2012**
- **2016-2022 vs 2011- 2017**
- **2016-2022 vs 2001- 2007**



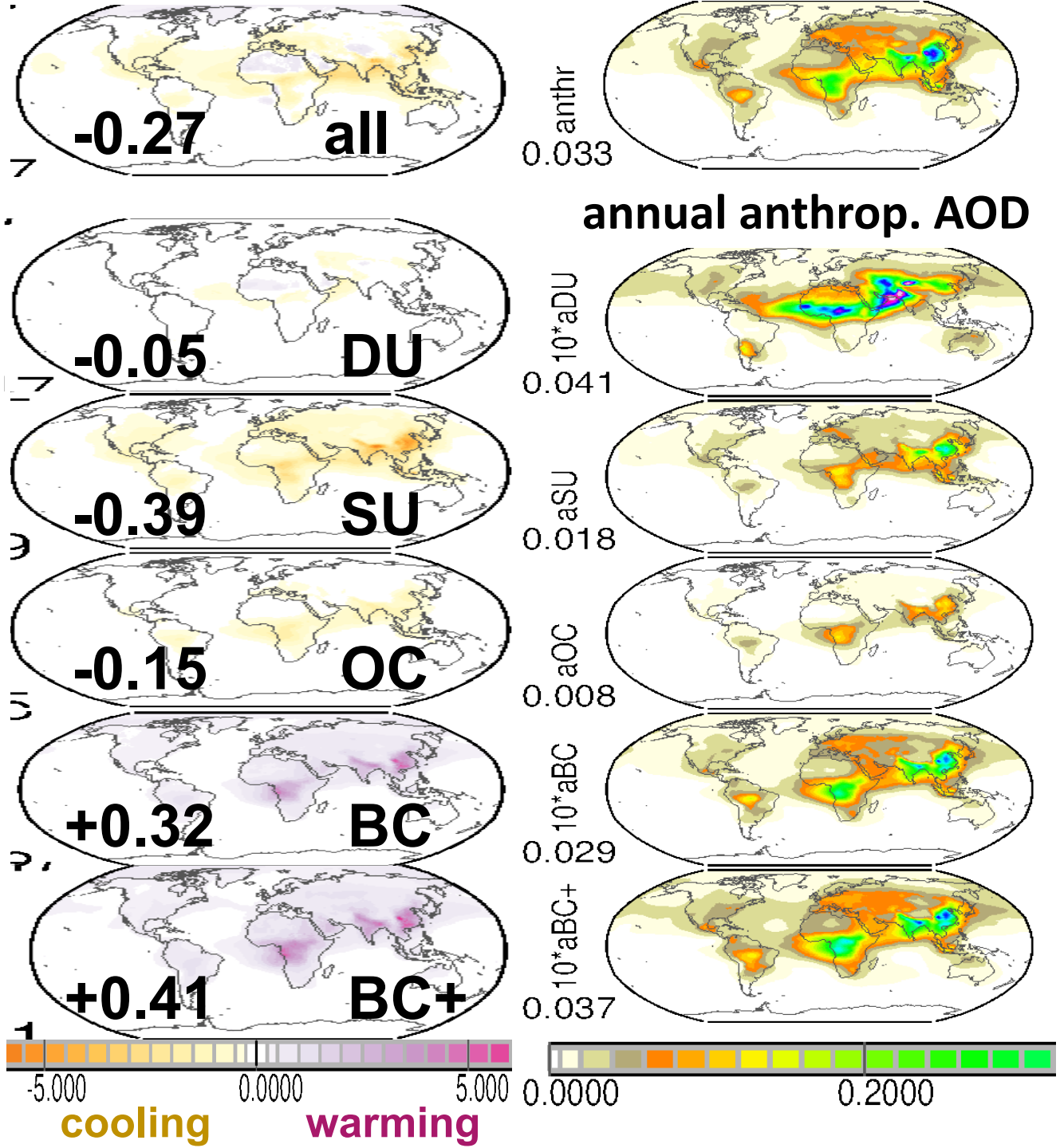
summary – aerosol radiative effects

- **small … compared to clouds**
- *overall TOA (climate) cooling*
- **globally: -1.2 W/m2** [SU -0.80, SS -0.67, OC -0.29, DU -0.17, BC +.67]
- *maximum around 2010 … now slowly declining*

- **uneven global distributions** ('hot spots' over India and E Asia)
- *stronger TOA cooling over darker surfaces (e.g. deep oceans)*
- significant TOA thermal IR warming near dust source regions
- *solar (ATM) heating by absorbing wildfire and pollution aerosol*
- SURface cooling largely proportional to aerosol loads
- *seasonality via aerosol maxima (fire, dust) and solar radiation*

radiative (climate) forcing *since 1850*

- direct (presence) forcing
  - -0.3 W/m2 details →
  - uncertainty mainly from pre-industrial definition
- indirect (via cld) forcing
  - more condensation nuclei for smaller droplets
    - faster evaporation
    - delayed precipitation
  - -0.7 W/m2 but uncertain !!

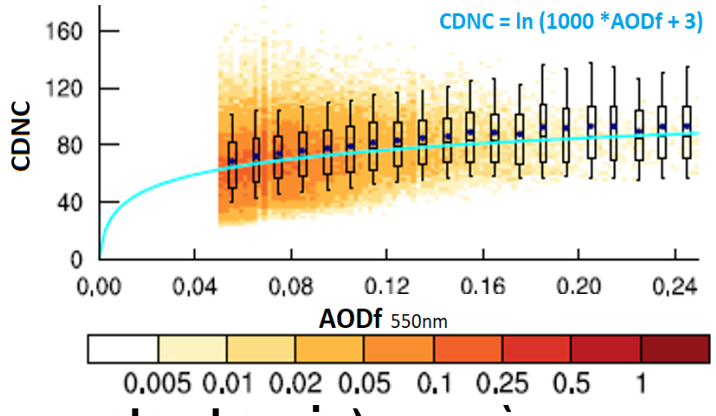


total aerosol forcing estimates -0.94 W/m2

1. indirect

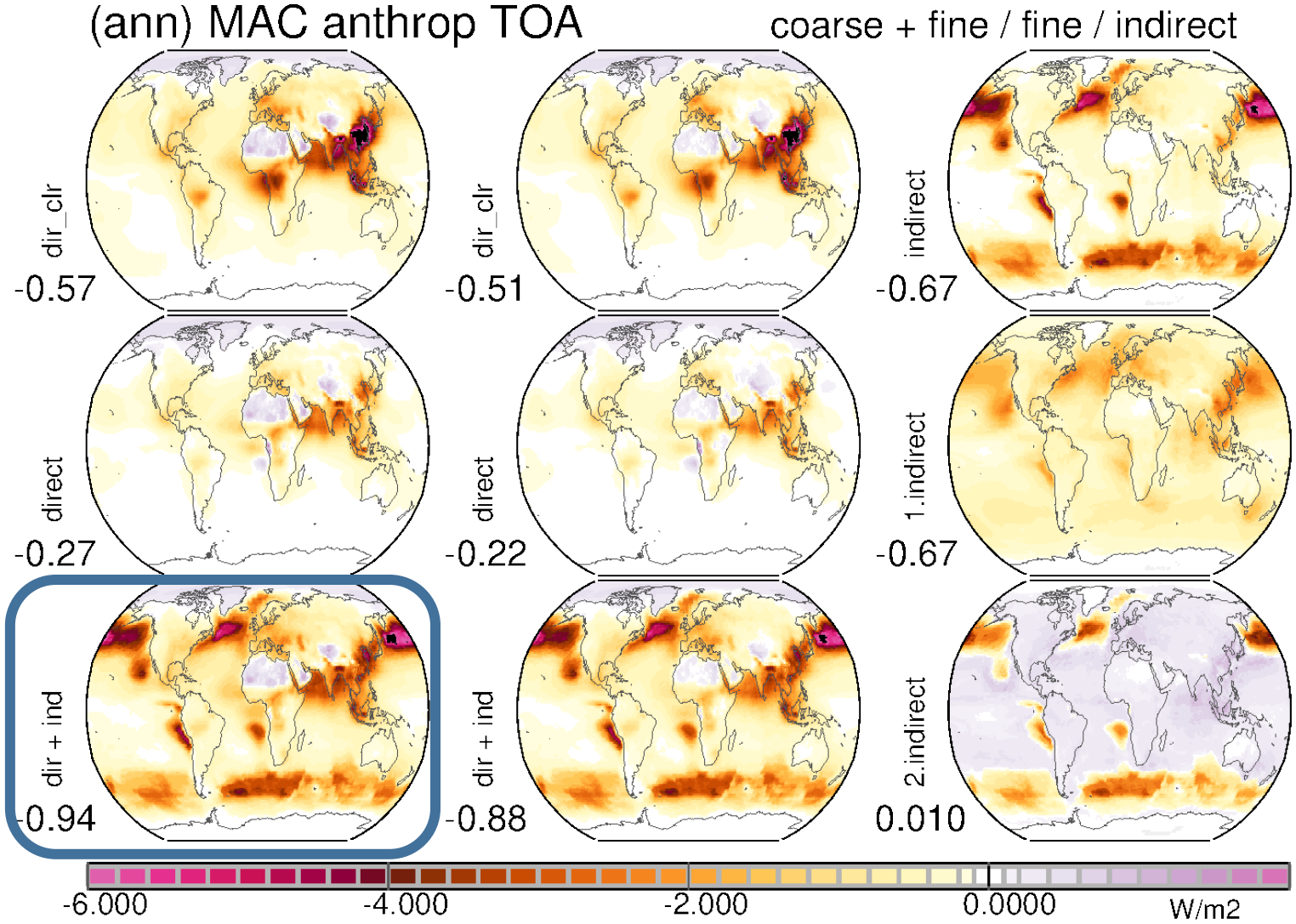
- drop size reduction via CDNC increase

MODIS data based: CDNC vs AODf



2. indirect

- cloud cover)
- extra lifetime cloud cover) (at higher



summary – aerosol (TOA) forcing

- **small … compared to total aerosol radiative effects**
- *overall TOA (climate) cooling*
- **globally: -0.27 W/m2** [SU -0.39, SS -0.00, OC -0.15, DU -0.05, BC +.32]
- *maximum around 2010 … now slowly declining*

- **uneven global distributions**
- direct uncertainty mainly by pre-industrial definition
- indirect uncertainty larger and driven by responses to 1. indirect eff
  - enhanced evaporation (when? where? … at lower cloud cover?)
  - enhanced lifetime by precip delay (when? where? …at higher cloud cover?)
  - does cloud pre-conditioning matter (lack of CDNC)

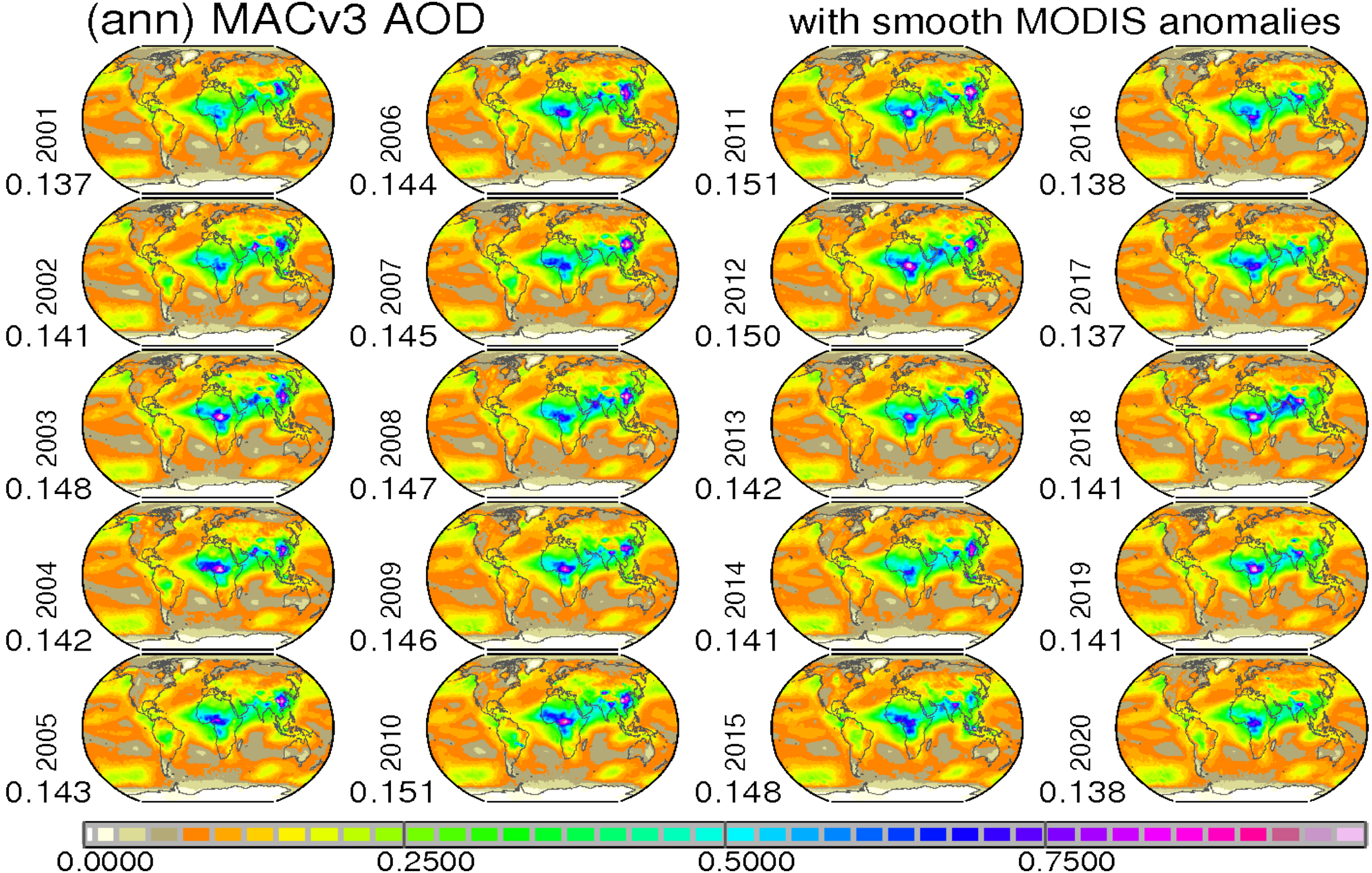
how to use photometric data ?

- most important for quantifying radiative effects
  - AODf mid-vis AOD associated with sub-micrometer sizes
  - AODc mid-vis AOD associated with super-micrometer size
  - AAODf mid-vis absorption of sub-micrometer sizes
  - AAODc mid-vis absorption of super-micrometer sizes
  - re,f useful optical info for aerosol number concentration
    - become member of AERONET for use of their inversion products

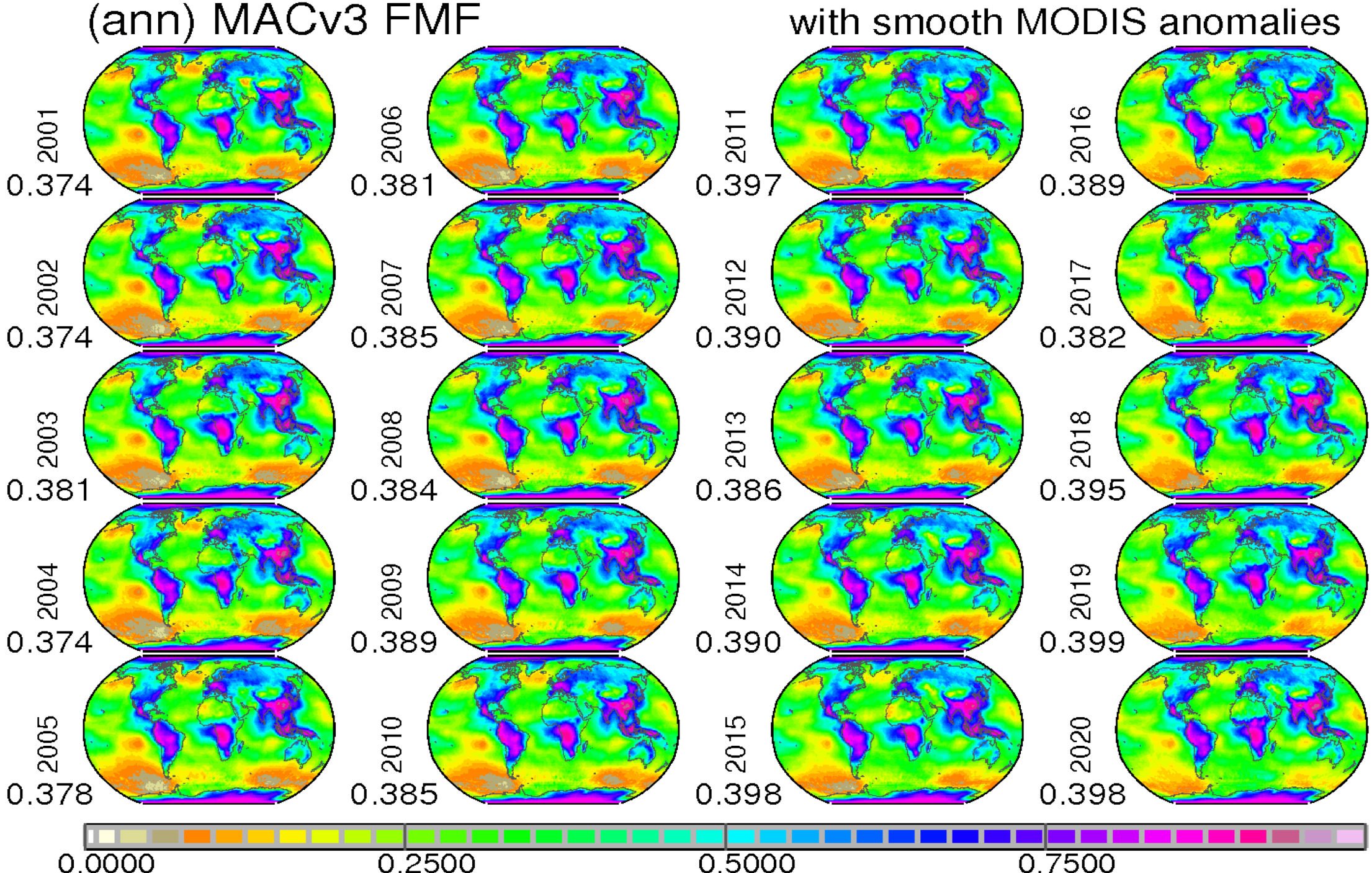
- link to satellite data and to modeling for global answers
  - regional representative ground sites (no mountains, but ships)
  - provide data at satellite overpasses for more mature retrievals
  - connect with satellite and modeling community (AeroCom, AeroSAT)

extras

MAC AOD
by year



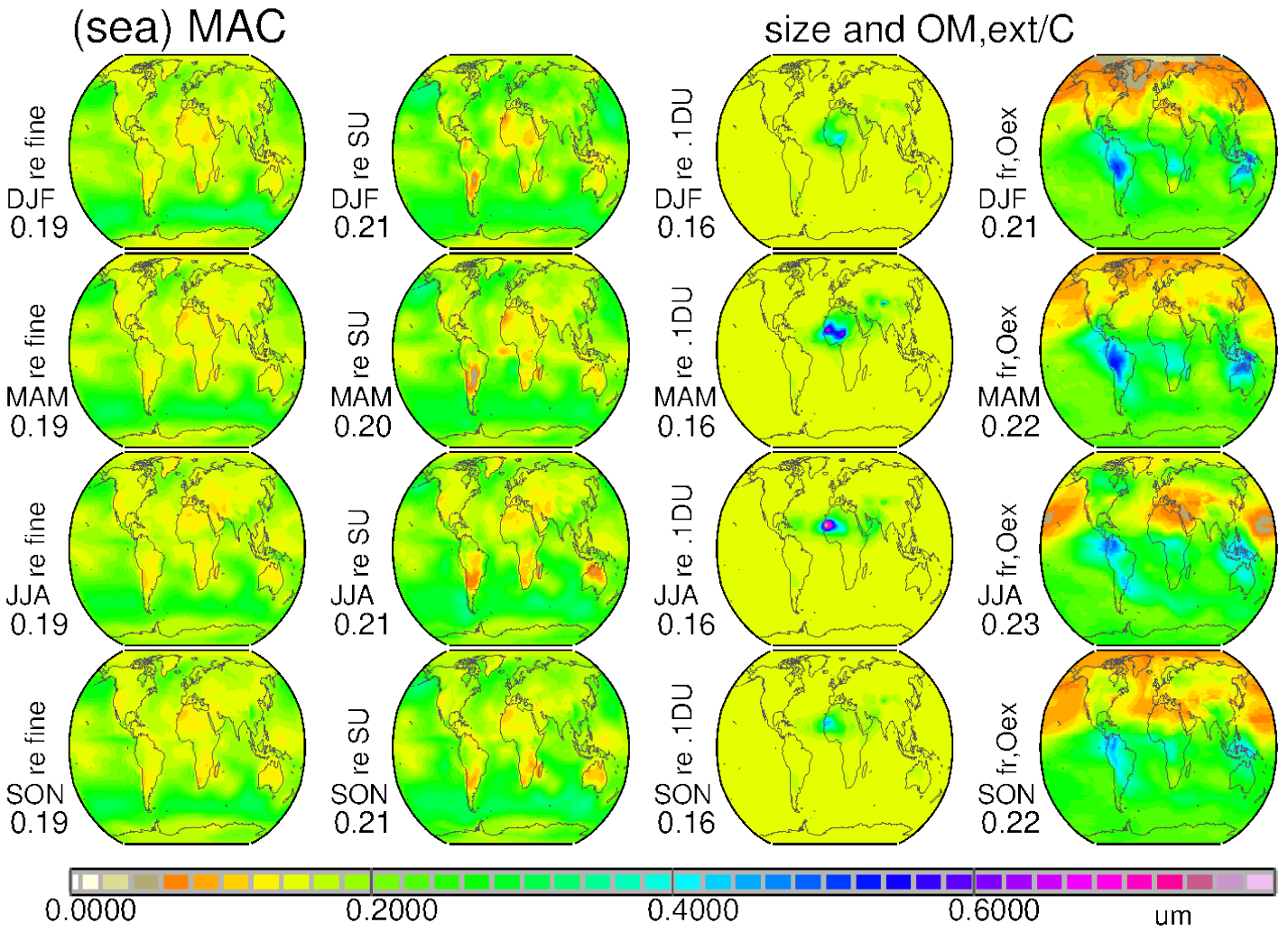
MAC FMF
by year



sizes in MAC

(effective radii of components)

- **ref**ine
  - larger fine-mode sizes over oceans
- **re,SU** (fine-mode, no abs)
  - smaller sizes over continents
- **re,DU** (*0.1 in plot)
  - larger over the Sahara
- extern OM to **C ratio**
  - smaller near pollution



assumptions for pre-defined aerosol types

FINE-MODE: <0.5um

MAC: **AODf**, **AAODf**, **REf**
OC/BC ratio from modeling
→ **BCOC**, **OC**, **SU**(r)

COARSE-MODE: >0.5um

MAC **AODc**, **AADOc**
dust AOD ~ dust size
→ **SS**, **DU** (r)

aerosol type	label	Reff	Rm	std_d	RF_R	RF_I	SSA	< OD >	N
		[um]	[um]		at 550nm wavelength				[#/m2]
soot (no use)	BC	.06	.03	1.7	1.70	.7000	.155	0.005	4.0 e+11
soot + o.shell	BO	.12	.08	1.5			.615	0.015	4.0 e+11
organic	OC	.18	.12	1.5	1.53	.0050	.975	0.022	1.8 e+11
sulfate	SU	.06	.03	1.7	1.43	.0000	.999	0.023	4.4 e+13
sulfate	SU	.10	.05	1.7	1.43	.0000	.999	0.023	4.1 e+12
sulfate	SU	.16	.08	1.7	1.43	.0000	.999	0.023	6.0 e+11
sulfate	SU	.26	.13	1.7	1.43	.0000	.999	0.023	1.2 e+11
sulfate	SU	.40	.20	1.7	1.43	.0000	.999	0.023	3.8 e+10
seasalt	SS	2.5	.75	2.0	1.50	.0000	.999	0.035	3.3 e+09
dust	DU	1.5	0.93	1.55	1.53	.0011	.962	0.025	2.7 e+09
dust	DU	2.5	1.34	1.7	1.53	.0011	.931	0.025	1.3 e+09
dust	DU	4.0	1.55	1.85	1.53	.0011	.918	0.025	7.0 e+08
dust	DU	6.5	1.98	2.00	1.53	.0011	.882	0.025	3.6 e+08
dust	DU	10	2.30	2.15	1.53	.0011	.840	0.025	2.0 e+08
cloud water	water	10	6.7	1.5	1.33	.0000	.999	10.0	2.5 e+10
cloud ice	Ice	40	20	1.7	1.31	.0000	.999	0.5	1.1 e+08

radiative effects over time

MODIS (+MACv3)

- 2001 -2007
- 2006 -2012
- 2011 -2017
- 2016 -2022