aerosol direct radiative forcing

on the disagreement of estimates from global modelling and observation-based techniques

Stefan Kinne
MPI-Meteorology, GER

Michael Schulz
LSCE-CNRS, FRA

Background

- anthropogenic climate change (since pre-industrialization)
  - at ToA
    - greenhouse gases: + 2.5 +/-0.20 W/m2
    - aerosol direct effect: - (0.0 to 0.7) W/m2 !
    - aerosol indirect effs: - (0.5 to 1.3) W/m2

⇨ aer. direct eff. uncertainty is surprisingly large

- modeling
  - IPCC (2001): - 0.43 W/m2
  - IPCC (2006): - 0.20 +/-0.20 W/m2 (+BC, -SU, mixing)
- remote sensing tied techniques
  - several studies - 0.55 +/-0.20 W/m2

questions - approach

- questions
  - can we explain the discrepancy between data-tied and global model results for aerosol forcing
    - standard deviations do NOT overlap !
  - why is new IPCC aerosol climate cooling so weak ?
- approach
  - conduct radiative transfer simulations with the best available for essential input (aerosol, environment)
  - explore impact of uncertainty in sensitivity studies
  - compare global fields among different approaches

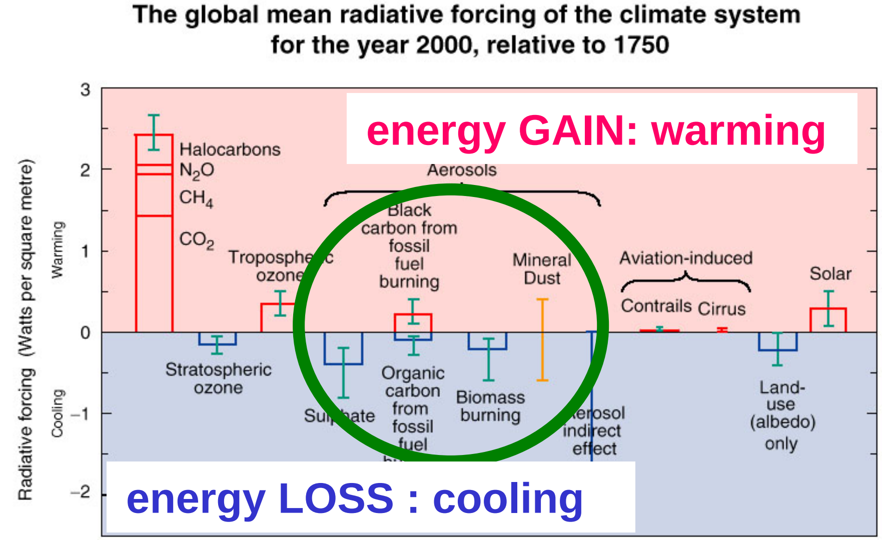
direct ToA forcing ingredients

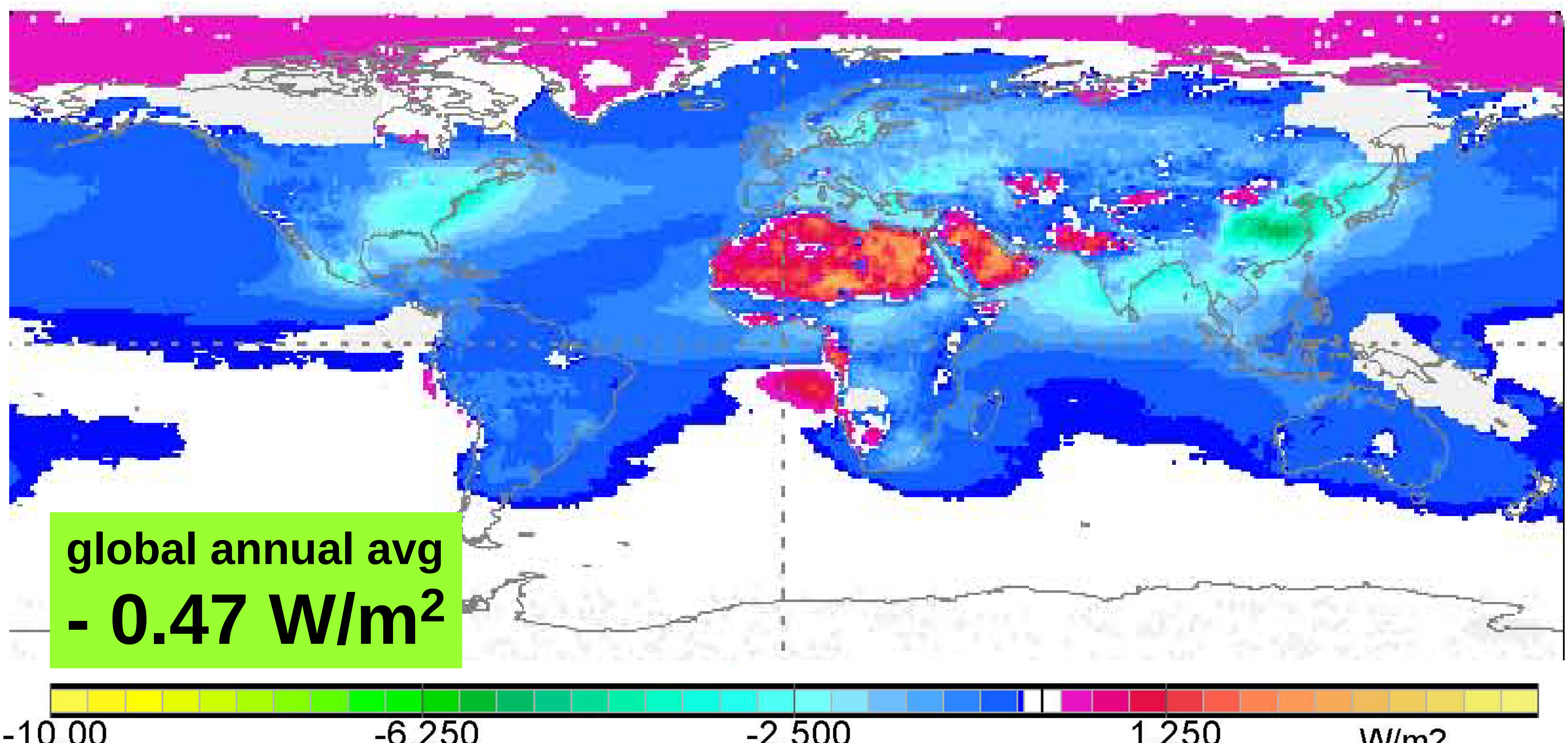
…with many opposing influences: inconsistencies cause uncertainty!

- **aerosol properties**
  - aot (aerosol amount) — *with more aot: stronger impact*
  - ssa (aero absorption) — *with more absorption: less negative*
  - g (aerosol size) — *with smaller scatterers: stronger im.*
- **environmental properties**
  - available sun light — *with more insolation: stronger im.*
  - solar surface albedo — *with higher albedo: less negative*
  - cloud co-location — *with cloud above: reduced impact*
  - rel. altitude to clouds — *with clouds below: less negative*
  - sun-elevation — *scattering: max impact at mid angle*
  - temp. (sur. /profile) — *secondary effect for natural aerosol*
  - anthropogenic fraction — **estimates from modeling needed !**

the estimate

for **direct aerosol forcing**
at the top of atmosphere (ToA)
with clouds (all-sky conditions)
for anthropogenic aerosol





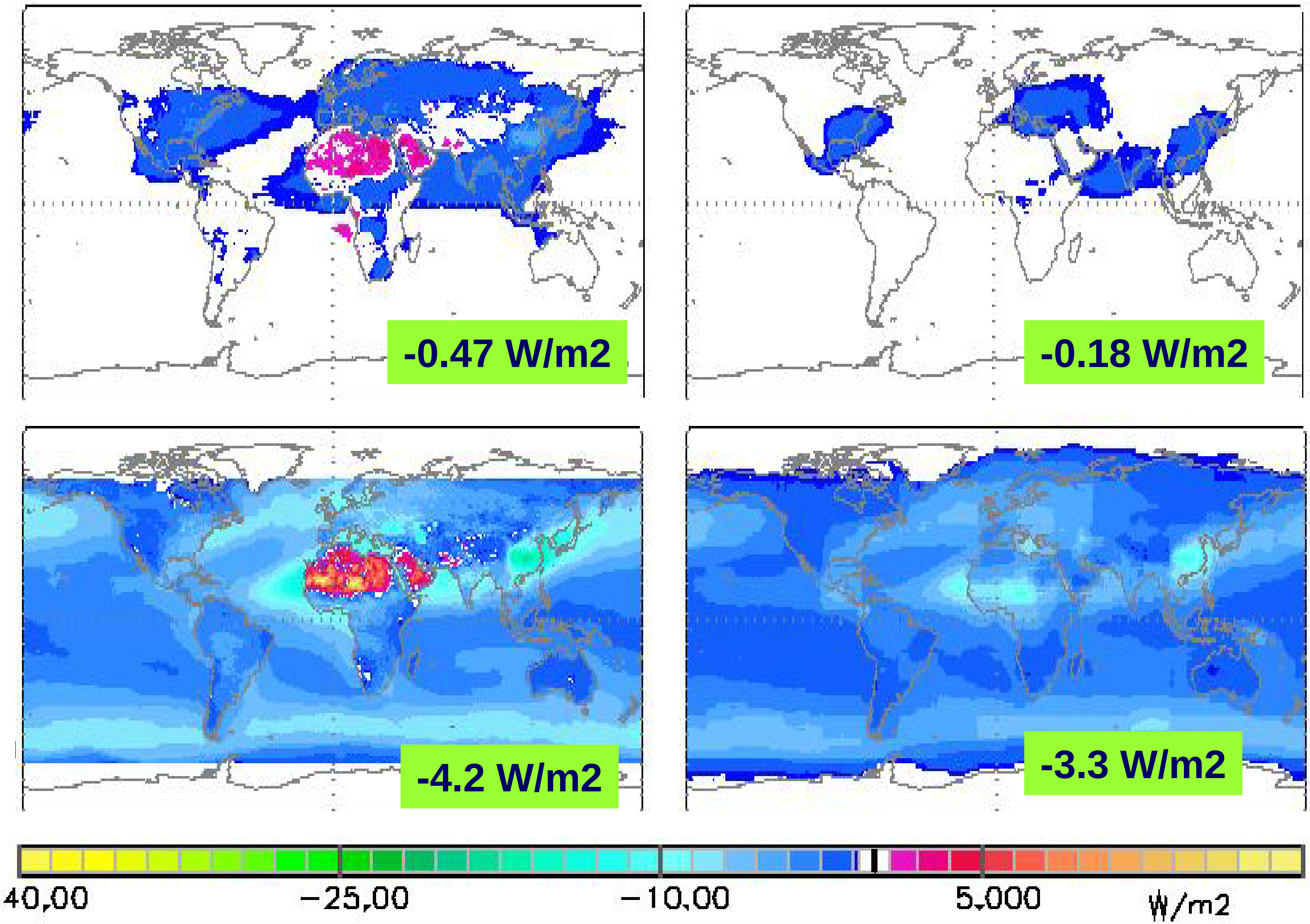
global annual avg
- 0.47 W/m^2

F,ToA - climatology vs AeroCom

climatology | **AeroCom**

all-sky ToA antrop solar

clr-sky ToA all aero. solar



sensitivity studies

- question
  - how is the (off-line) direct aerosol forcing affected by uncertainty to essential input properties?
- approach
  - reduce spatial resolution *(from 1x1 to 10x20)*
  - repeat simulations with specific modifications
  - compare essential input field
    - anthropogenic (and total) aot
    - solar surface albedo
  - compare regional and AeroCom model specific
    - ocean (60N-60S) vs global

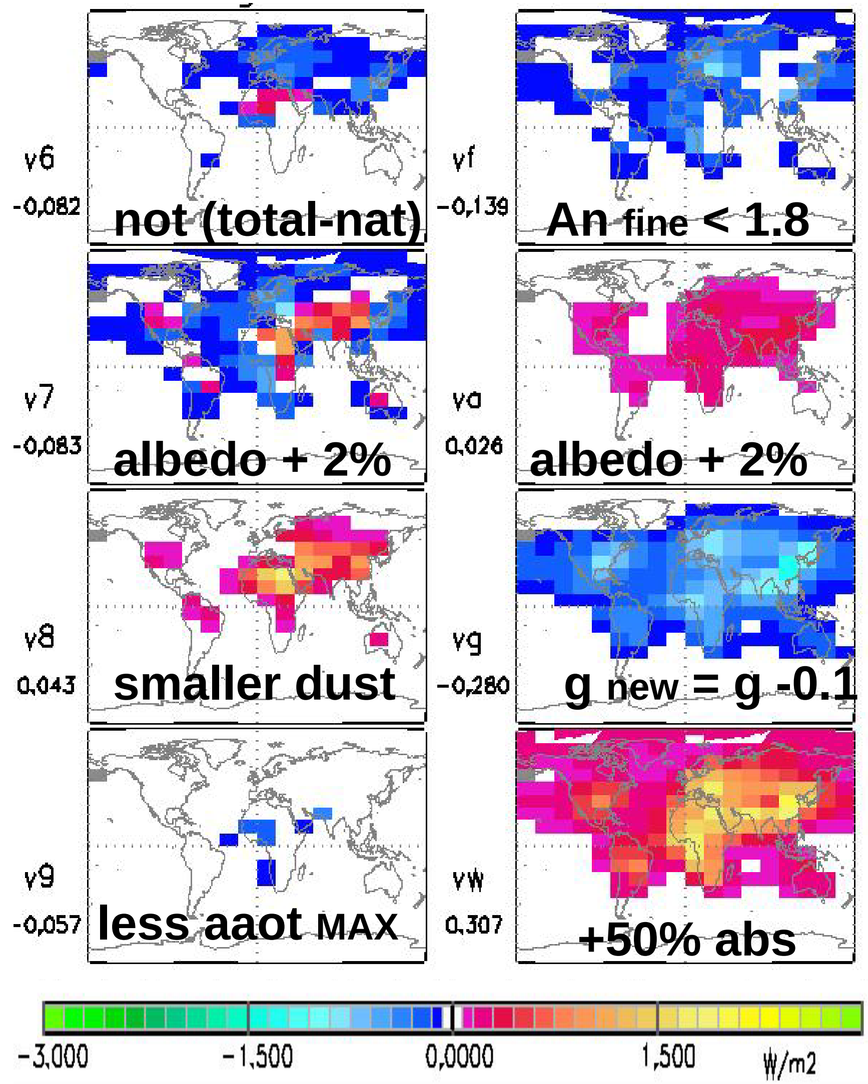
sensitivies *- to ToA ant all-sky forcing*

***+ 0.3W/m2 needed** (red/yel)*

- **most expected changes to input and assumptions increase cooling *(blue)***
- **explanation examples**
  - **50% more abs can do it**
    (but abs is already larger than AC)
  - **0.15 larger ‘g’**
    (unlikely to all aerosol)
  - **5% larger surf albedo?**
    (already too large over desert)

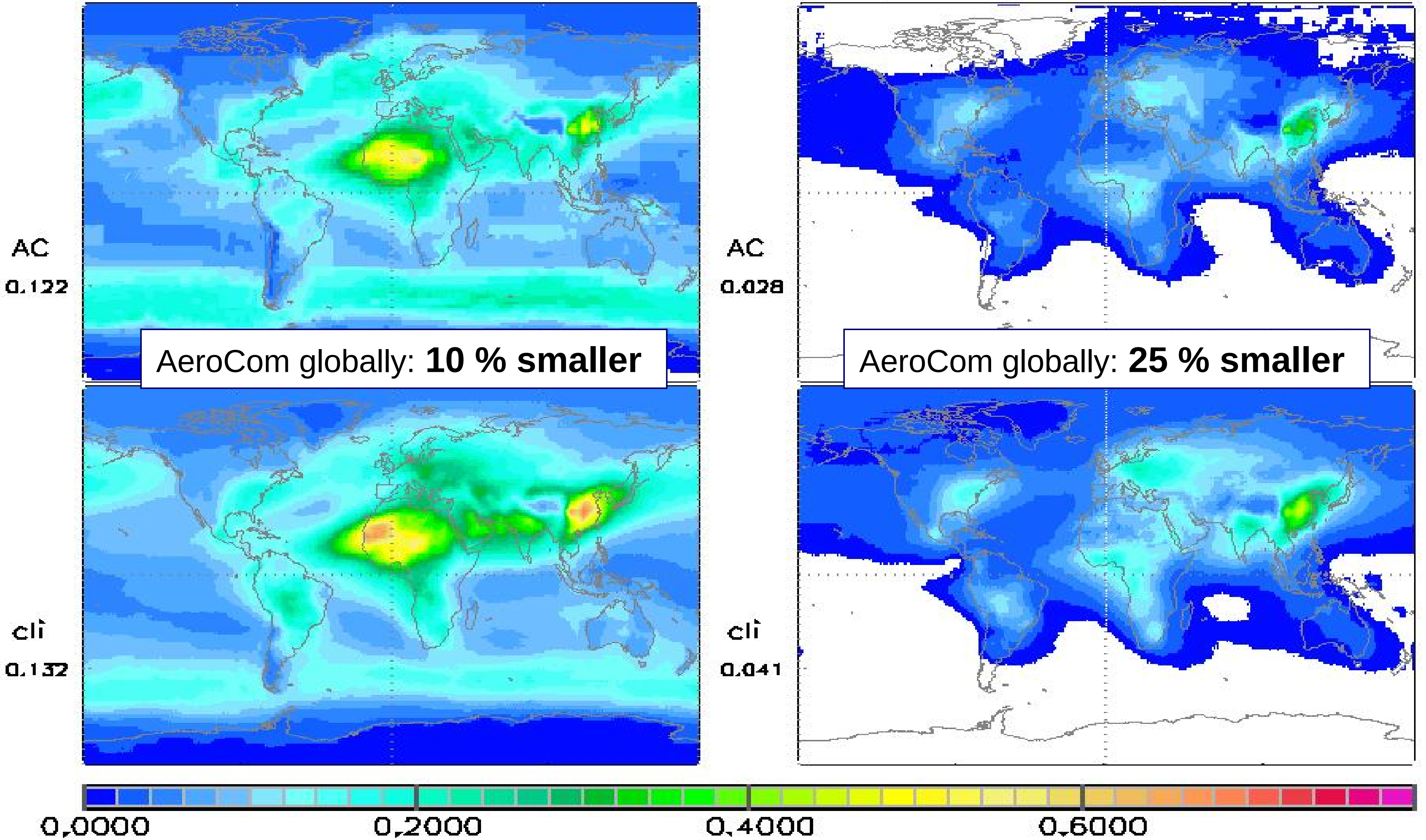
⇨ **no satisfying explanation**

forcing-difference to reference



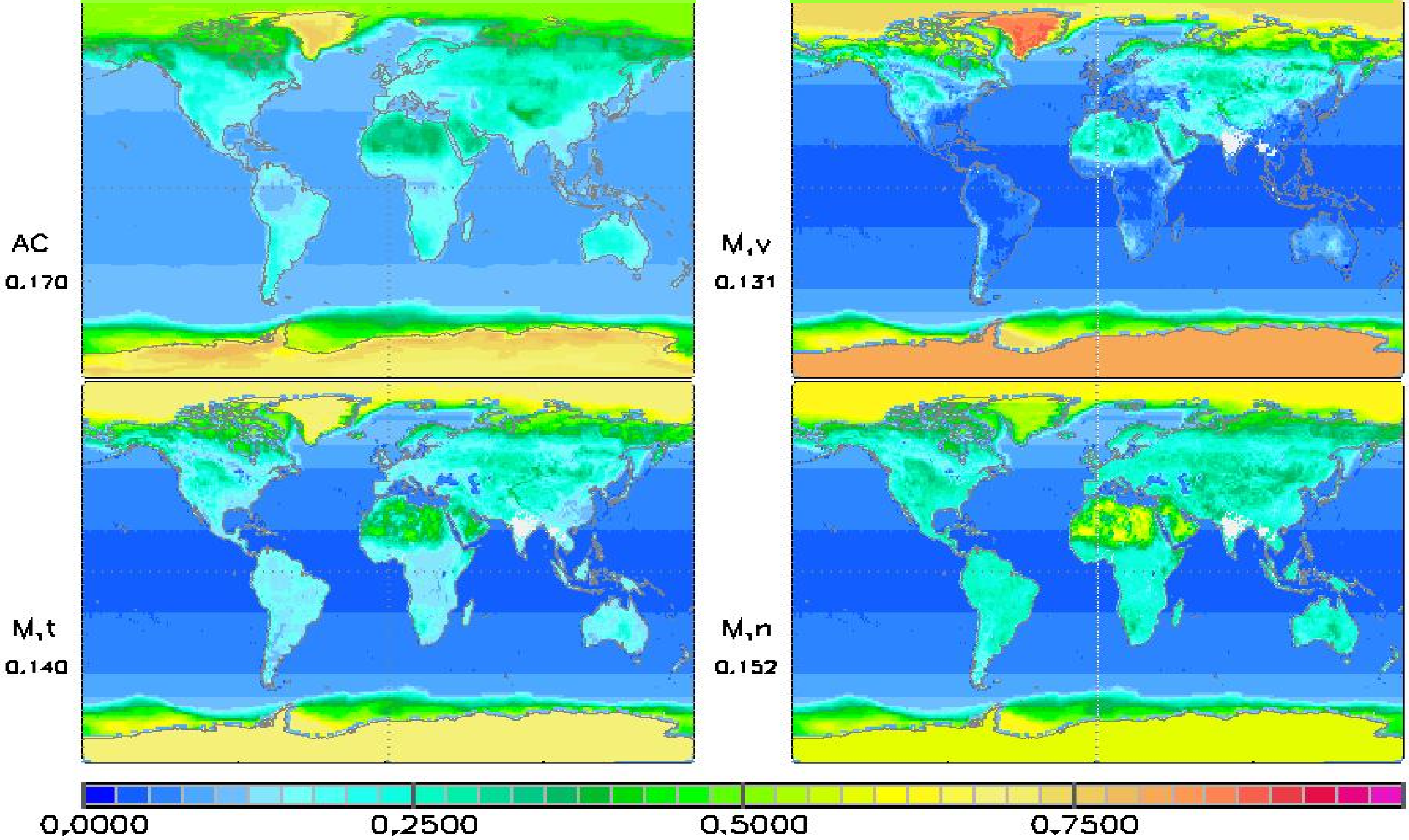
AOT – AeroCom (AC) vs. climatology (cli)

total (natural+anthropogenic) | **anthropogenic** (total-natural)



albedo – AeroCom (AC) vs. climatology (M)

total solar (visible and near-IR) | **separated** (visible and near-IR)



climatology vs AeroCom

	global	average	ocean	60N-60S
	clima	*ACom*	*clima*	*ACom*
surf.albedo	.141	.176	.060	.102
tot aot	.131	.124	.119	.123
ant aot	.040	.030	.025	.023
F toa clr tot	- 4.2	- 3.3	- 4.7	- 3.7
F toa clr ant	- 1.0	- 0.8	- 0.95	- 0.58
F toa all ant	- .47	- 0.18	- 0.65	- 0.22
FE toa clr tot	- 38	- 32	- 47	- 36
FE toa clr ant	- 31	- 22	- 39	- 24
FE toa all ant	- 16		- 21	

the reasons

in AeroCom

- total aot is lower by 10% [check]
- anthropogenic aot is lower by 25% ! [check]
- surface albedo is 3% larger [check]
- cloud-effect on forcing is stronger [check]
- aerosol absorption is weaker [oh no!]

AeroCom is an average with some black sheeps

- MPI, Sprintars, ULAQ : too much absorption !

comparison *– ToA clear-sky, anthr.*

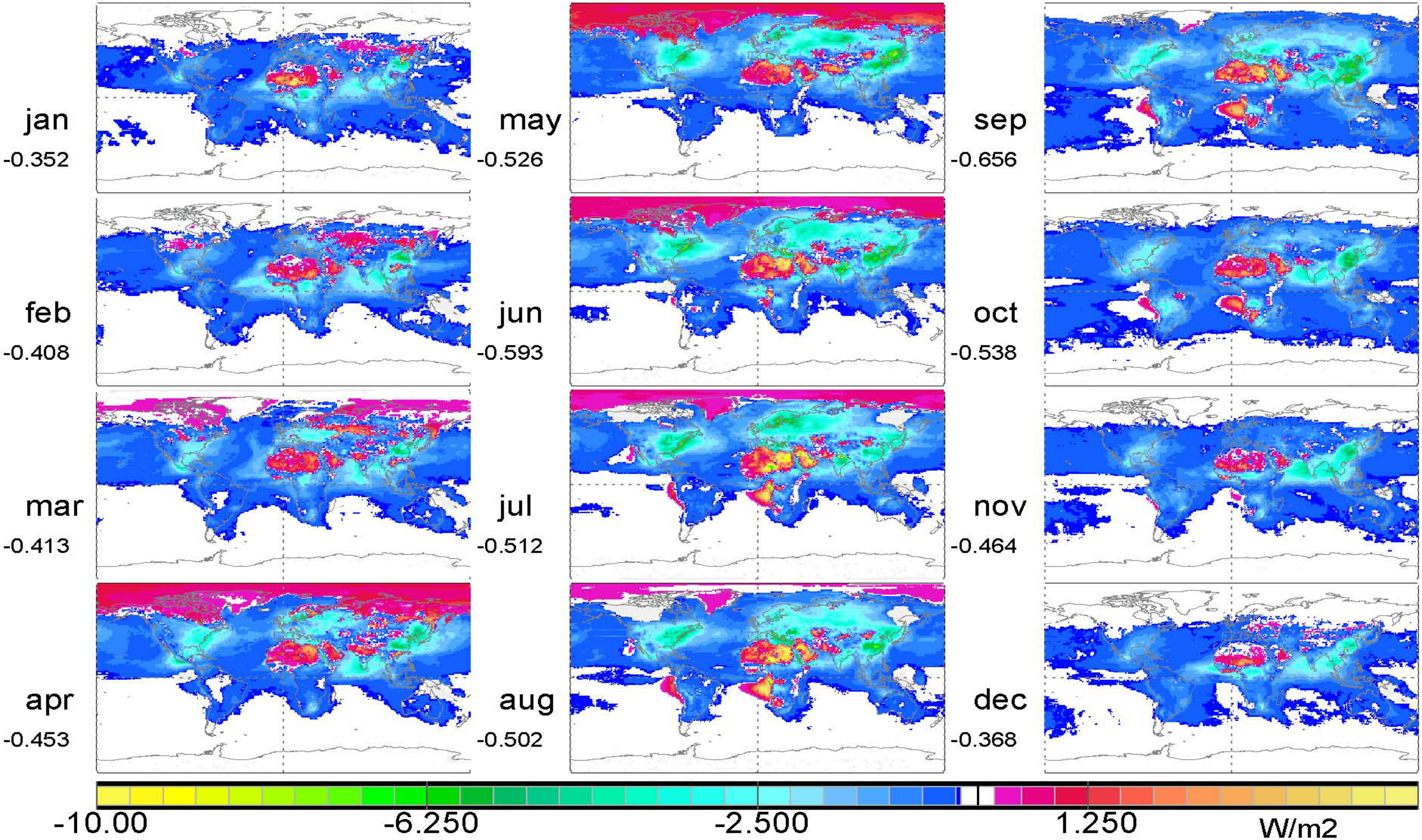
		ocean			land	
	aot	F,toa	FE,t	aot	F,toa	FE,t
U.Mich	.024	- 0.68	- 28	.058	-1.33	- 23
U.Oslo C	.021	- 0.69	- 34	.055	-1.64	- 30
U. Lille	.033	- 0.67	- 20	.088	-1.47	- 17
LSCE	.026	- 0.89	- 34	.063	-1.35	- 21
MPI	.038	- 0.49	- 13	.073	-0.75	- 10
GISS	.013	- 0.33	- 26	.026	-0.42	- 16
U.Kyusho	.030	- 0.32	- 11	.078	-0.63	- 8
AC avg.	*.026*	*- 0.58*	*- 24*	*.063*	*-1.09*	*- 18*
Yu (2005)	.031	- 1.10	- 37	.088	-1.80	- 20
Kinne	*.025*	*- 0.95*	*- 38*	*.075*	*-1.10*	*- 15*

conclusions

- Aerosol forcing is modulated not only be aerosol properties but also the environment
  - are solar surface albedos properly characterized?
  - are clouds treated in a consistent way?
- first time submitted results often contain errors
  - the AeroCom forcing average needs corrections
- correct aerosol absorption matters in rad forcing
  - small cooling results from (too?) strong absorption
- the IPCC 4AR AeroCom recommened aerosol cooling of (- 0.2) W/m2 seems too weak
  - more detailed invidual model investigations needed

extras

direct forcing - on a monthly basis



strongest cooling in summer over industrial regions of the Northern Hemisphere

other aerosol rad. forcings

Forcing W/m^2	sol,ir clear-sky	sol,ir all - sky	solar clear-sky	solar all - sky
ToA	- 3.5	- 1.7	- 4.3	- 2.2
surf.	- 6.8	- 5.1	- 8.6	- 6.3
ToA, an	- 1.0	- 0.5	- 1.0	- 0.5
surf, an	- 2.9	- 2.3	- 2.9	- 2.3

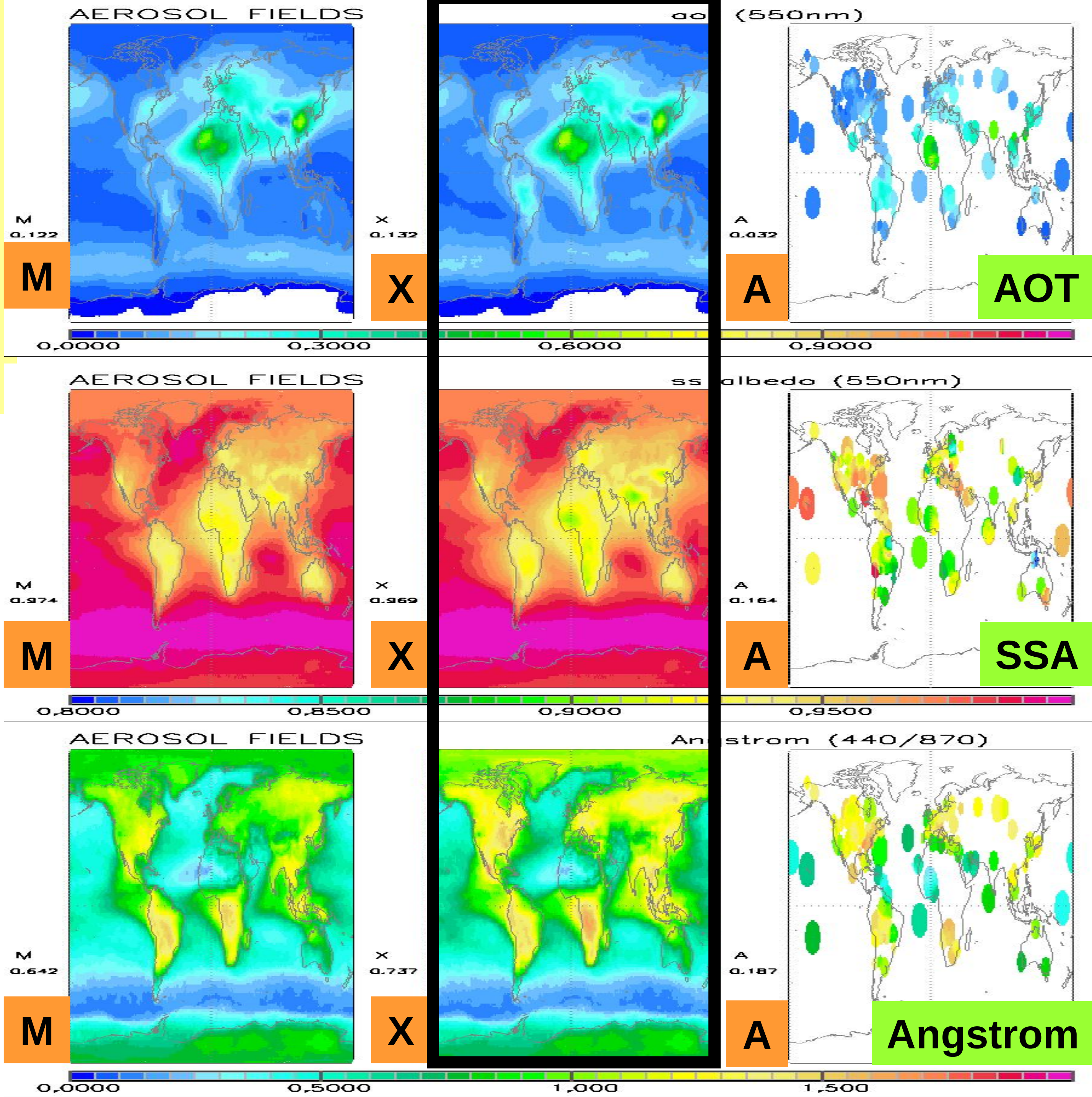
- **location**
  - ToA, surf, atm *(=ToA-surf)*
- **environment**
  - all-sky, clear-sky
- **spectral range**
  - solar, infrared, both

- **on a globally avg basis:**
  - at clr-skies: F,surf ~ 2 * F,ToA (⇨ F,atm ~ F,ToA)
  - at all-skies: F,surf ~ 3 * F,ToA (⇨ F,atm ~ 2*F,ToA)
  - solar eff. dominate IR effects: 9:1 at ToA, 4:1 at surf
  - cloud eff. (all-sky *minus* clr-sky): F,ToA is ~ halved

best ***aerosol properties***

AeroCom median + AERONET

- **M**
  AeroCom model median
- **X**
  merged product
- **A**
  AERONET (enlarged)

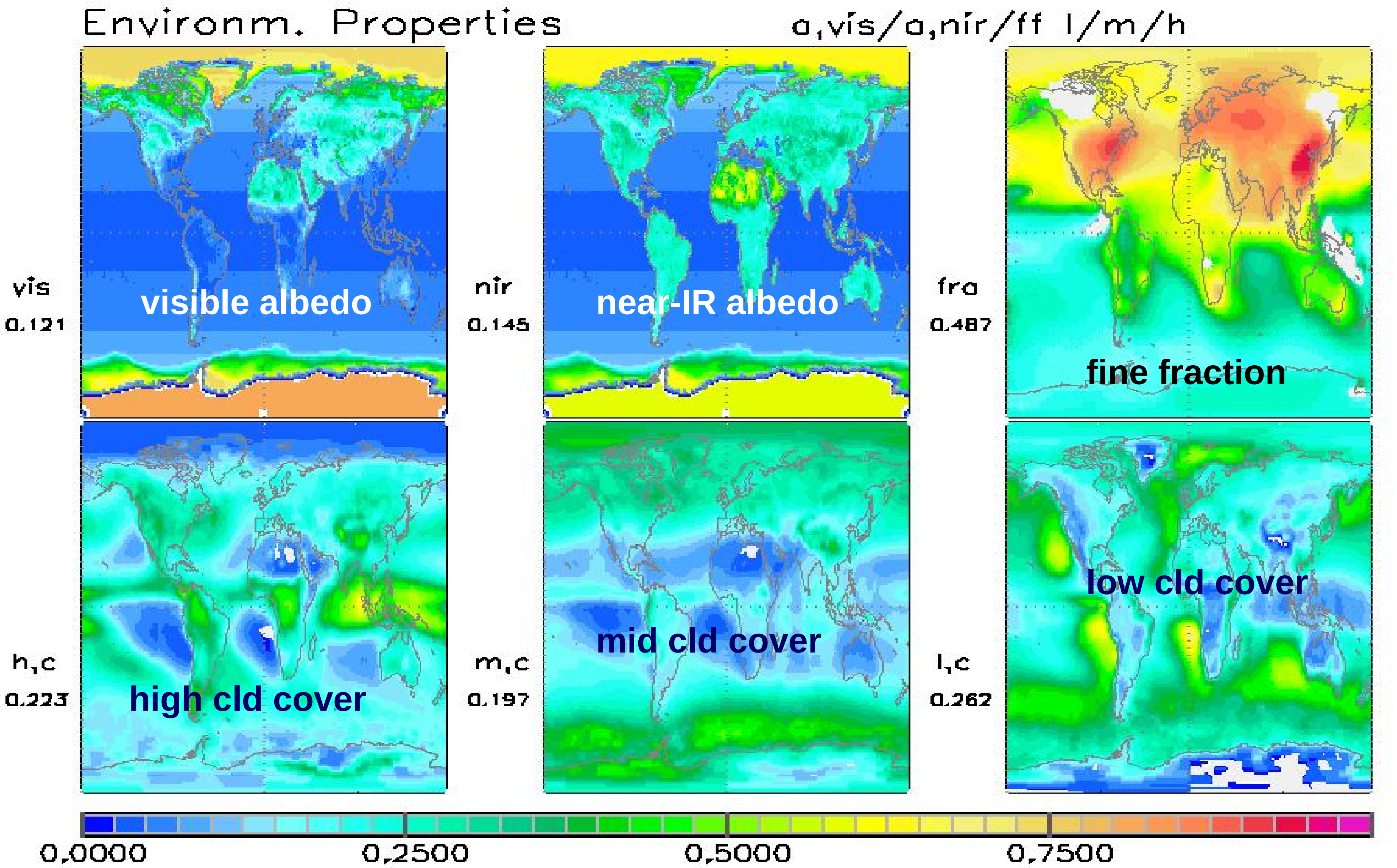


background to these data (2)

- adopt (required) environmental data
  - solar surface albedo — MODIS (VIS and near-IR)
  - anthrop fraction: — global modeling (Aerocom)
  - aerosol altitude: — global modeling (Aerocom)
  - tropospheric clouds: — ISCCP (high, mid, low, OT)
- perform rad. transfer simulations ⇨ rad. forcing
  - 2-stream radiative transfer (8 solar, 12 IR bands)
  - aerosol impact from calculation pairs (with-without)
  - solar calculations at 9 sun-angles for daily avg.
  - all-sky calculations based on 8 permutations (h/m/l)

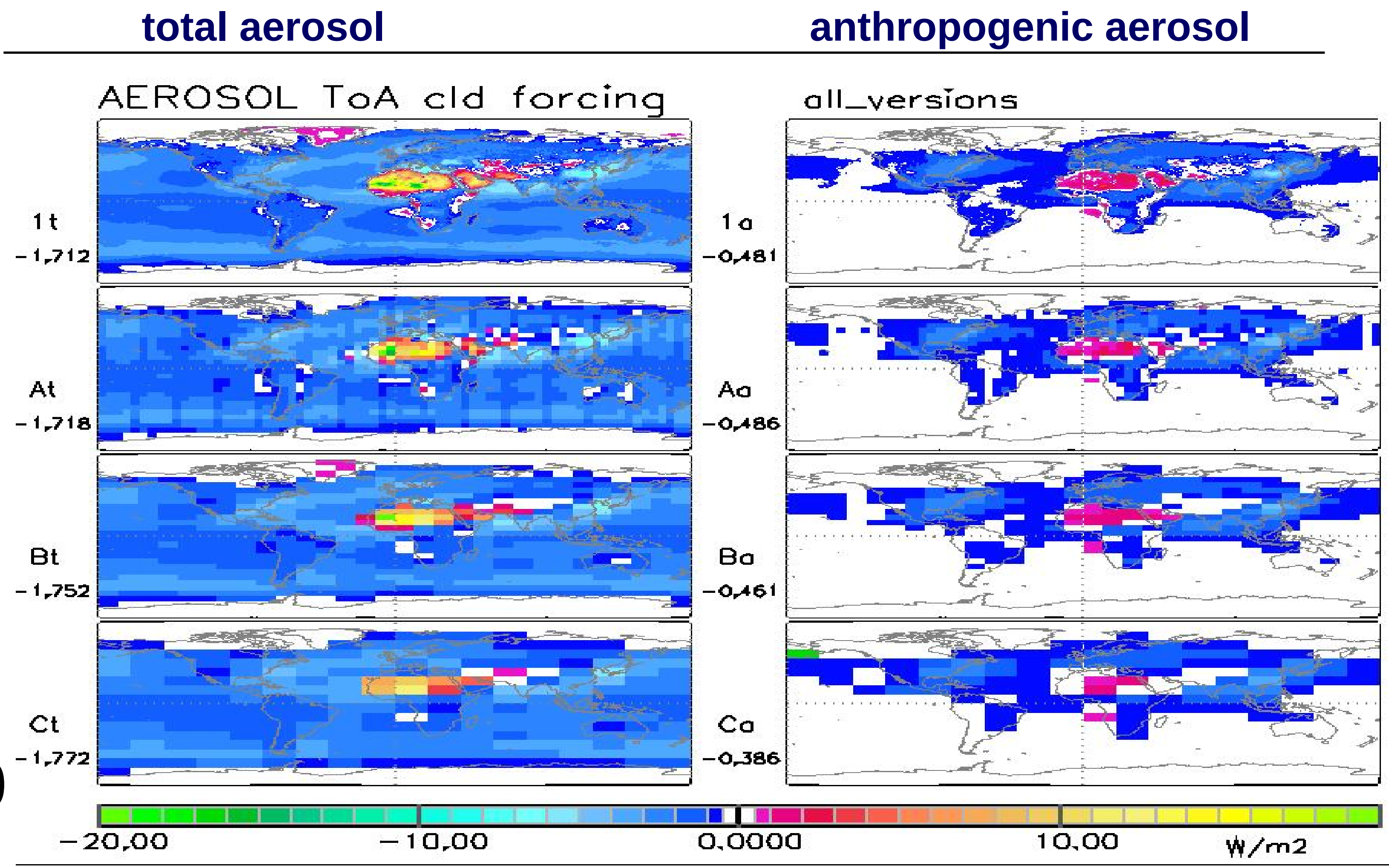
*…at 1x1 resolution each month at 64800 (360*180) grid-points*

environmental prop choices



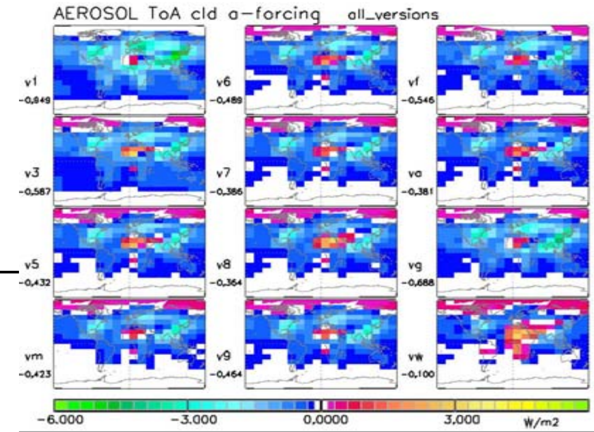
similar at lower resolution ⇨ OK

- 1*1
- 5*5
- 6*12
- 10*20



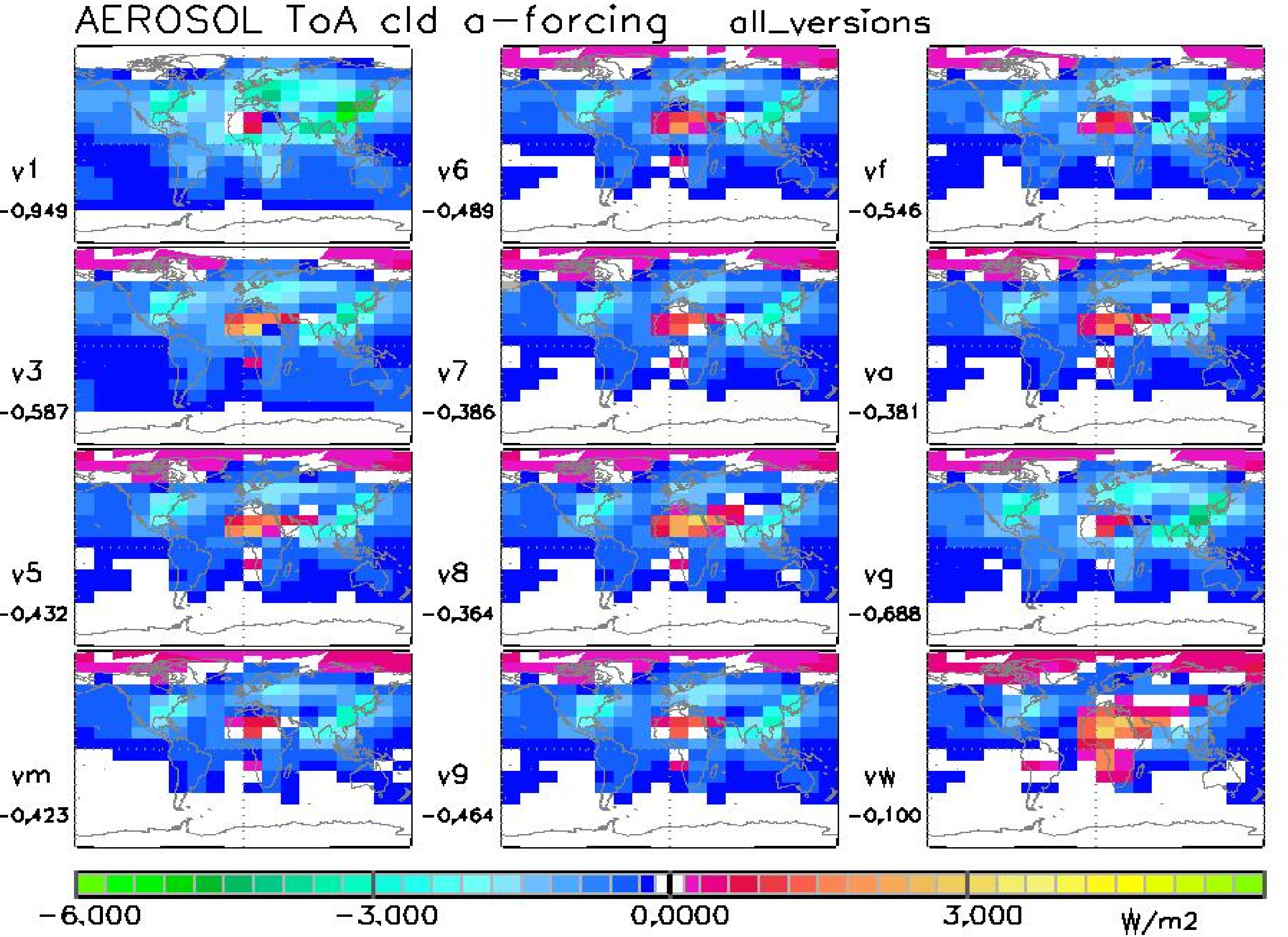
overall distribution is similar - although anthropogenic. all-sky 12*20 ToA forcing is lower at 0.386 (compared to .481 at 1x1)

sensitivites



discussed sensitivities

- **v1: Angstrom→ fine frac, dust backgrd, weak absorption**
- **v3: v1 … choice for coarse background: dust or salt**
- **v5: v3 … (bimodal)+(An,f=1.8) → fine frac, (total-natural)**
- **v7: v5 … fine abs threshold (w:1-.2f +.05c) [STANDARD]**
- **v6: v7 … anthropogenic not as (total-natural) difference**
- **vm: v7… but median fields (not AERONET enhanced)**
- **v8: v7 … but smaller dust sizes**
- **v9: v7 … weaker fine abs threshold (w: .95-.1f)**
- **va: v7 … solar surface albedo increased by 2%**
- **vg: v7 … asymmetry-factor reduced by 0.1**
- **vf: v7 … An,f dependency on low cld cover (1.9-.7lcc)**
- **vw: v7... co-ssa (absorption) increased by 50%**

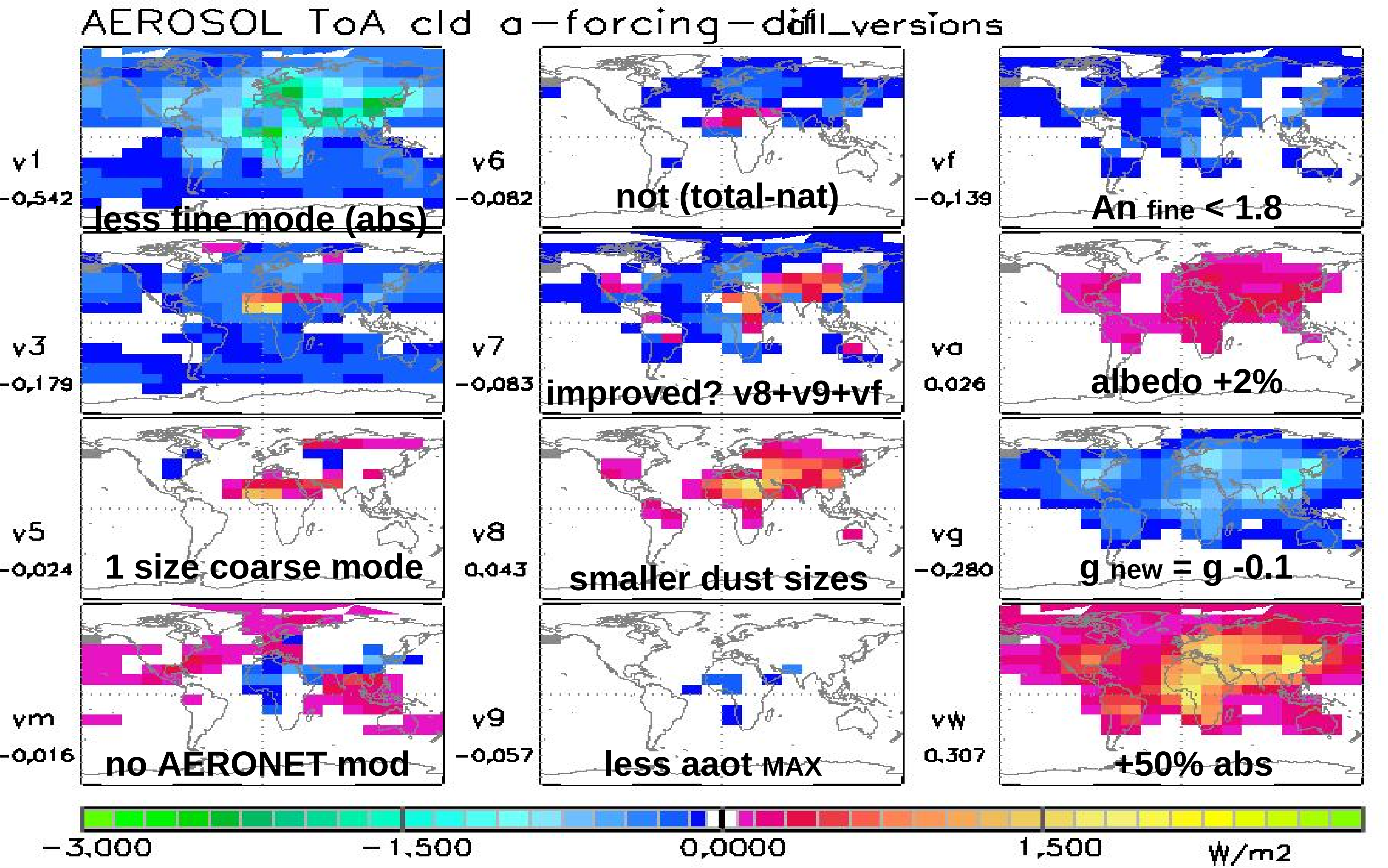

AEROSOL ToA cld a-forcing all_versions
v1
-0,949
v6
-0,489
vf
-0,546
v3
-0,587
v7
-0,386
va
-0,381
v5
-0,432
v8
-0,364
vg
-0,688
vm
-0,423
v9
-0,464
vw
-0,100
-6,000
-3,000
0,0000
3,000
W/m2

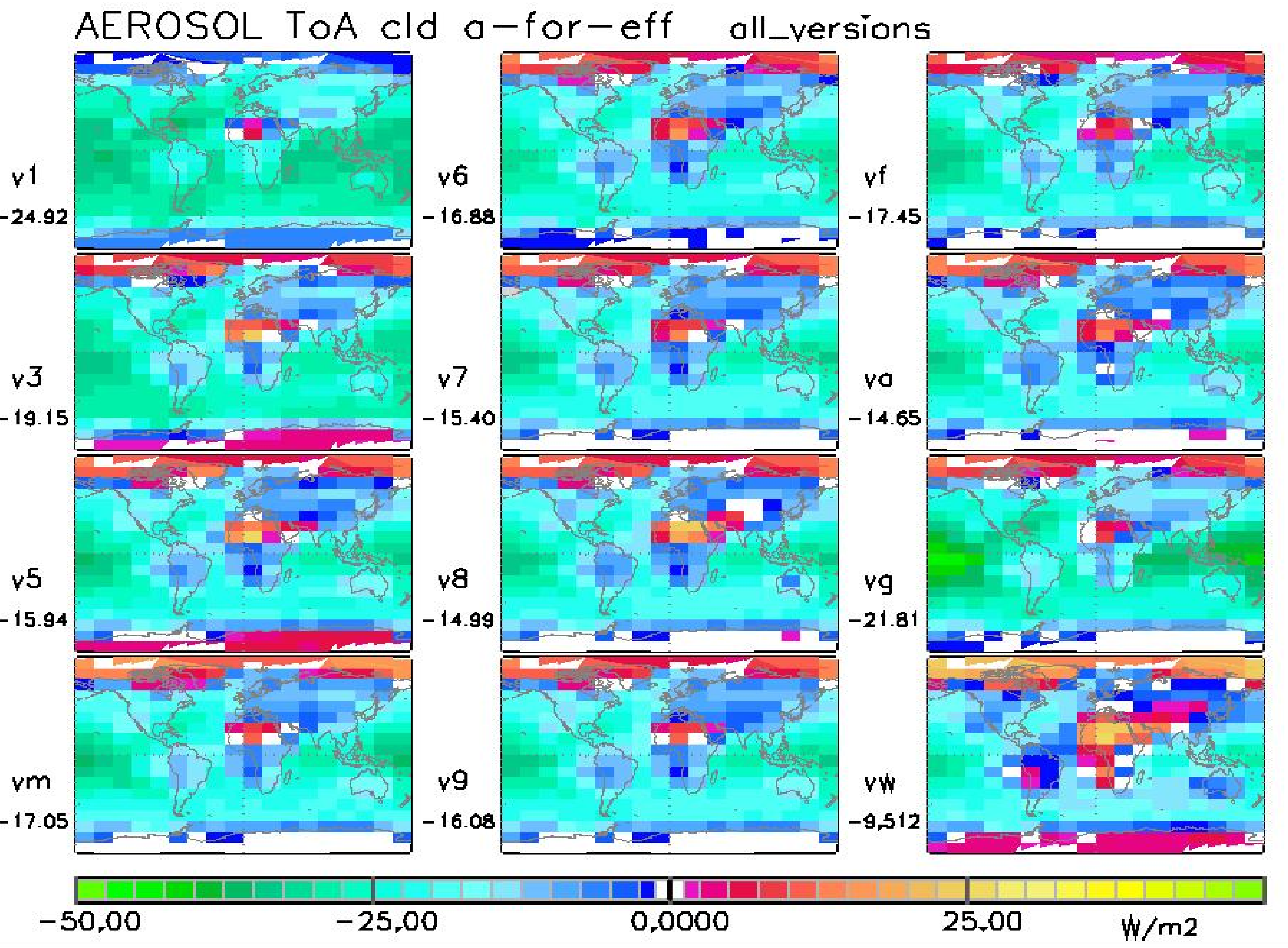
F sensitivites *– ToA, all-sky, ant*

discussed sensitivities ***(W/m2)***

- **v1:** ***-.949*** Angstrom→ fine frac, dust backgrd, weak absorption
- **v3:** ***-.587*** v1 ... choice for coarse background: dust or salt
- **v5:** ***-.432*** v3 ... (bimodal)+(An,f=1.8) → fine frac, (total-natural)
- **v7:** ***-.385*** v5 ... fine abs threshold (w:1-.2f +.05c) [STANDARD]
- **v6:** ***-.423*** v7 ... anthropogenic not as (total-natural) difference
- **vm:** ***-.489*** v7... but median fields (not AERONET enhanced)
- **v8:** ***-.364*** v7 ... but smaller dust sizes
- **v9:** ***-.464*** v7 ... weaker fine abs threshold (w: .95-.1f)
- **va:** ***-.381*** v7 ... solar surface albedo increased by 2%
- **vg:** ***-.546*** v7 ... asymmetry-factor reduced by 0.1
- **vf:** ***-.688*** v7 ... An,f dependency on low cld cover (1.9-.7lcc)
- **vw:** ***-.100*** v7... co-ssa (absorption) increased by 50%

F difference fields *– relative to v7*





AEROSOL ToA cld a-for-eff all_versions
v1
-24.92
v6
-16.88
vf
-17.45
v3
-19.15
v7
-15.40
va
-14.65
v5
-15.94
v8
-14.99
vg
-21.81
vm
-17.05
v9
-16.08
vw
-9.512
-50.00
-25.00
0.0000
25.00
W/m2

FE sensitivity *– ToA, all-sky, ant*

***discussed sensitivities** (W/m2)*

- **v1:** ***-25*** Angstrom→ fine frac, dust backgrd, weak absorption
- **v3:** ***-19*** v1 ... choice for coarse background: dust or salt
- **v5:** ***-16*** v3 ... (bimodal)+(An,f=1.8) → fine frac, (total-natural)
- **v7:** ***-15*** v5 ... fine abs threshold (w:1-.2f +.05c) [STANDARD]
- **v6:** ***-17*** v7 ... anthropogenic not as (total-natural) difference
- **vm:** ***-17*** v7... but median fields (not AERONET enhanced)
- **v8:** ***-15*** v7 ... but smaller dust sizes
- **v9:** ***-16*** v7 ... weaker fine abs threshold (w: .95-.1f)
- **va:** ***-15*** v7 ... solar surface albedo increased by 2%
- **vg:** ***-17*** v7 ... asymmetry-factor reduced by 0.1
- **vf:** ***-22*** v7 ... An,f dependency on low cld cover (1.9-.7lcc)
- **vw:** ***-10*** v7... co-ssa (absorption) increased by 50%

FE diff. fields *– relative to v7*