simple aerosol representations in a global and seasonal context to address aerosol direct and indirect radiative effects

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it’s about regional and seasonal distributions
( although also global averages are calculated )

• aerosol climatology
  • amount, absorption, size (AOD, SSA, ASY)
  • associated CCN (and IN)

• aerosol radiative impacts
  – aerosol direct effect - 0.35 W/m² (TOA, all-sky)
  – aerosol indirect effect - 0.75 W/m² (TOA, all-sky)
  ... and the combined effect is smaller than the sum
AOD climatology

half in coarse sizes (>1μm) – half in fine sizes (<1μm)
total vs. coarse vs. fine

input for radiative transfer simulations
amount / not absorbed / size
input for radiative transfer simulations
AOD: natural vs anthropogenic

$\sim 2^{(0.09)} \text{ to } 1^{(0.04)}$ ratio
anthropogenic AOD

highest during NH summer
direct radiative effects
overview with annual maps

AEROSOL radiative effects

cir ToA T
-3.19

cir ToA S
-4.40

cir ToA A
-0.984

cir sur T
-6.10

cir sur S
-8.07

cir sur A
-2.60

cir T A
-1.21

cir S A
-1.82

cir A A
-0.345

cir T
-4.47

cir S
-5.45

cir A
-1.93

-40.00 -25.00 -10.00 5.000 W/m2
direct anthropogenic effects

clear-sky vs all-sky ... TOA vs surface
direct forcing: ... - 0.35 W/m²

strongest regional contrasts in NH spring
surface effect: -1.9 W/m²

strongest reductions in NH summer
atmos effect: + 1.6 W/m²
solar warming by anthropogenic aerosol
BC sensitivities

• estimating forcing component contributions

• BC
  – translate all fine-mode absorption in BC-AOD
    • too high … ignoring OC contribution
    • too low … ignoring BC contributions in the coarse size mode

• BC forcing estimates
  – clear-sky + 0.25 W/m²
  – all-sky + 0.35 W/m²
SU sensitivities

• estimating forcing component contributions

• SU
  – multiply the anthr. AOD with sulfate fine-mode fraction (.040 → .024), prescribe sulfate SSA
  – prescribe sulfate with \( r_{\text{eff}} = 0.2\,\mu\text{m} \) for .024 AOD

• SU forcing estimates
  – clear-sky - 1.0 W/m²
  – all-sky - 0.7 W/m²
sensitivities

anthr component AEROSOL direct forcing

BC all-sky, ToA

SU all-sky, ToA

BC dr-sky, ToA

SU dr-sky, ToA

0.365

-0.688

0.236

-1.06

-9.000

-6.000

-3.000

0.0000

W/m2
indirect radiative effects

• simple sensitivities ... what if
  – low cloud droplet # is evenly factor-increased
    • in a ‘C5’ cloud from 10.5 to 9 μm: 1.75 * more drops
    • in a ‘C1’ cloud from 6 to 5 μm: 1.88 * more drops
    • in log-normal from 10 to 7.4 μm: 2.47 * more drops
    • in log-normal from 10 to 9.5μm: 1.18 * more drops

• now with more realistic changes ...
  – droplet increases ... based on (tot/nat) -ratios
    – using anthrop. CCN and natural CCN at 1km
      • (ant /m3 +nat /m3) /nat /m3 all CCN → drops (lin)
      • ln(1+(ant+nat)/10^4) / ln(1+nat/10^4) (ln4)
      • ln(1+(ant+nat)/10^5) / ln(1+nat/10^5) (ln5)

choice
1.75 * more drops in a C5 cloud
no changes to liquid water in low clouds
1.88* more drops in a C1 cloud
no changes to liquid water in low clouds
1.88* more drops in a C1 cloud
SW TOA effect by season

Twoomey effect

all-sky, C1 (6um->5um)
2.47* more drops in a ln cloud
no changes to liquid water in low clouds
2.47* more drops in a ln cloud
SW TOA effect by season
1.18 more drops in a LN cloud
no changes to liquid water in low clouds
1.18* more drops in a ln cloud
no changes to liquid water in low clouds
towards aerosol indirect forcing using climatology predicted CCN concentrations

• quantifying CCN ... requires
  • the vertical distribution (AOD \rightarrow ext.)
  • the fine-mode size-distribution (ignore Aitken)
  • the aerosol composition (via ‘kappa’ hygro.)
  • the anthrop. fraction of the fine-mode
  • \rightarrow critical radius (as function of SS)
    – all sizes > critical radius (at base) become CCN

• all CCN activate as cloud droplet
  • CCN # at cloud base are applied to low cloud
  • droplet radii are reduced by CCN # increase
  • no changes to cloud liq.water content allowed
CCN / IN are concentrations
applied information on AOD vertical distribution
other important ingredients

kappa $\rightarrow$ size, anthrop. fraction in fine-mode

(anthr.) CCN relevant properties

- kappa (type)
  - 0.672

- fine radius (um)
  - 0.193

- fine ant fraction
  - 0.480

- anthr. AOD 550nm
  - 0.040
anthrop? \(\leftrightarrow\) depends on pre-industrial

3 models ... three suggestions

fine-mode AOD

anthropog. AOD

pre-industrial AOD

what AOD was there to begin with?
CCN / IN concentrations (log10 scale) for different supersaturations and altitudes.
natural CCN (log10 scale) at low altitude cloud base
natural CCN
at low altitude cloud base
Anthropogenic CCN (log10 scale) at low altitude cloud base
anthropogenic CCN at low altitude cloud base (max e
anthropogenic CCN at low altitude cloud base (max set to 800/cm³)
anthropogenic CCN
at low altitude cloud base (max set to 800/cm³)
1. experiment

- assume that **ALL** extra anthropogenic CCN ... become new cloud droplets

- new CCN = old CCN * ratio
  - ratio = (ant CCN + nat CCN) / (nat CCN)
\[
\frac{\text{antCCN} + \text{natCCN}}{\text{natCCN}} - \text{ratios}
\]

The ratio is largely independent on supersaturation.
(ant$\text{CCN} + \text{nath$\text{CCN}$) / nat$\text{CCN}$ - ratios

for 0.1% super-saturation, seasonal

CCN factor

DJF
3.02

JJA
2.32

MAM
2.47

SON
2.68
aerosol low cloud indirect effects
liquid water remains constant
SW cloud effect: - 5.6 W/m²

seasonal variations
2. experiment

• assume the following CCN to drop conversion
  – ALL CCN become new cloud droplets
    • if CCN concentrations are low
  – a fraction of CCN becomes new cloud droplets
    • if CCN concentrations are high

• new CCN = old CCN * ratio
  • ratio = \( \frac{\ln (1 + \text{[ant CCN] + [nat CCN]} / 10^{**4})}{\ln (1 + \text{[nat CCN]} / 10^{**4})} \)

CCN in # /m3
\frac{\ln(1+\text{ant}+\text{nat})}{\ln(1+\text{nat})} - \text{ratios with CCN values (/m) divided by 10000}
cloud drop size reductions

radius reduction

In-4 (10um is the base-line)
aerosol low cloud indirect effects

liquid water remains constant
aerosol low cloud indirect effects

liquid water remains constant
3. experiment (best estimate)

- assume the following CCN to drop conversion
  - ALL CCN become new cloud droplets
    - if CCN concentrations are low
  - a fraction of CCN becomes new cloud droplets
    - if CCN concentrations are high

- new CCN = old CCN * ratio
  - ratio = \( \frac{\ln (1 + [\text{ant CCN} + \text{nat CCN}]/10^{**5})}{\ln (1 + [\text{nat CCN}]/10^{**5})} \)

CCN in # /m3
ln(1+ant+nat) / ln(1+nat) - ratios
with CCN values (/m) divided by 100000

CCN factor

ln(1+[ant+nat]/5)/ln(1+nat#/5)
cloud drop size reductions

radius reduction

In-5 (10um is the base-line)
aerosol low cloud indirect effects
liquid water remains constant
aerosol low cloud indirect effects
liquid water remains constant
direct forcing: $-0. W/m^2$

strongest regional contrasts in NH spring
direct forcing: only - 0.18 W/m²
indirect → brighter clouds → direct is halved
summary

- climatologies
  - of atmospheric and surface properties in combination with off-line radiative transfer:
    - a quick path to explore regional/seasonal or parameter variability in the global contexts

- application-example: aerosol climate impacts
  - spatial and temporal variability
    - direct forcing ca - 0.35 W/m² (global avg)
    - indirect forcing ca - 0.75 W/m² (global avg)

... and the combined effect is smaller than the sum
• on seasonal details of aerosol direct radiative effects
  – total (SW and LW impacts combined)
  – solar (SW impacts only)

• note, anthropogenic impacts are a fraction of the solar (SW) impact, as anthropogenic contribution as they may occur to the coarse mode (e.g. dust) are ignored
SW+LW … at ToA, clear-sky

total AEROSOL direct effects

clr-sky, toa

DJF -3.28

JJA -3.27

MAM -2.95

SON -3.28

-16.00 -4.000 8.000 20.000 W/m²
SW+LW ... at ToA, all-sky

total AEROSOL direct forcing

all-sky, ToA

DJF
-1.43

all-sky, ToA

JJA
-1.06

all-sky, ToA

MAM
-1.03

all-sky, ToA

SON
-1.34

-8.000 2.000 12.000 22.000 W/m²
SW ... at TOA, clear-sky
what a satellite “sees”

solar AEROSOL direct effects

DJF
-4.24

JJA
-4.63

MAM
-4.23

SON
-4.20

-20.00 -11.00 -2.000 7.000 W/m2
SW ... at surface, all-sky

solar AEROSOL surf effects

DJF
-4.36

JJA
-6.59

MAM
-5.66

SON
-4.84
SW ... at surface, clear-sky

solar AEROSOL surf effects

- DJF: -6.82
- JJA: -9.39
- MAM: -8.25
- SON: -7.28

W/m²
SW ... in atmos, all-sky

solar AEROSOL atmos effects

all-sky, ToA

DJF 2.47

MAM 3.97

all-sky, ToA

JJA 4.74

SON 3.04

-1.000 13.000 27.000 41.000 W/m^2