Radiative impact of aerosols in the Composition – IFS model

Interaction between radiation and data assimilation

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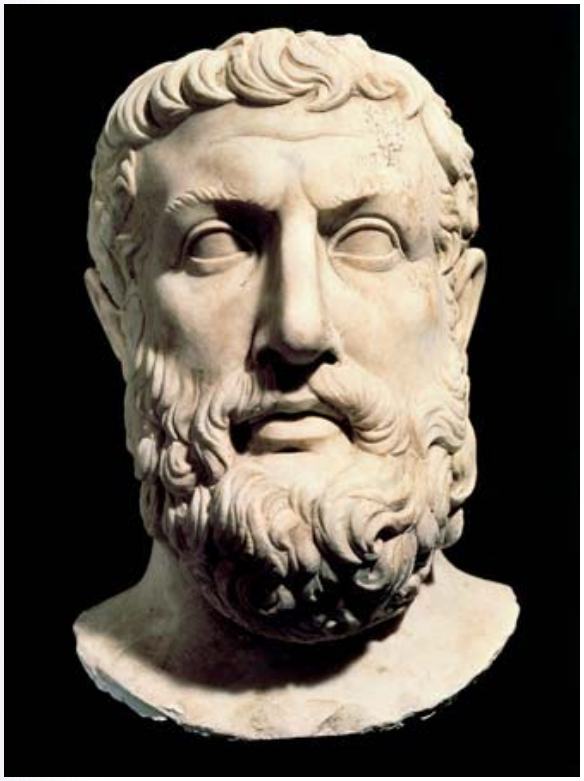
Preamble



Parmenides, Greek philosopher, 5th century BC:

"Nothing comes from nothing."

…or does it?

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Outline

Two case studies of the radiative impact of aerosols in C-IFS and IFS:

- In the ongoing CAMS reanalysis,
- In the IFS NWP (Alessio Bozzo's work): implementation of a CAMS based aerosol climatology into the IFS:

https://www.ecmwf.int/en/elibrary/17219-implementation-cams-based-aerosol-climatology-ifs

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Quick presentation of the version of C-IFS used for the CAMS reanalysis

- Simple sectional scheme for:
  - Dust: 3 bins
  - Sea-salt: 3 bins
  - Organic Matter (OM) and Black Carbon (BC)
  - Sulphate and SO_2
- Used in MACC/Copernicus for Near-Real Time (NRT) and reanalysis of atmospheric composition:
  - MACC reanalysis (2003-2012), T255L60
  - CAMSiRA reanalysis (2003-2016), T159L60
  - **CAMS reanalysis (ongoing), T255L60**
- Assimilates MODIS collection 5/6:
  - Control variable total mass mixing ratio,
  - Increments are distributed to each species depending on its relative proportion to total mass mixing ratio.
- Main changes in C-IFS for the CAMS reanalysis:
  - Sea-salt: sedimentation bug solved,
  - Secondary Organics Aerosol: new source scaled on CO, part of the OM species,
  - SO_2 removed from the assimilation system.

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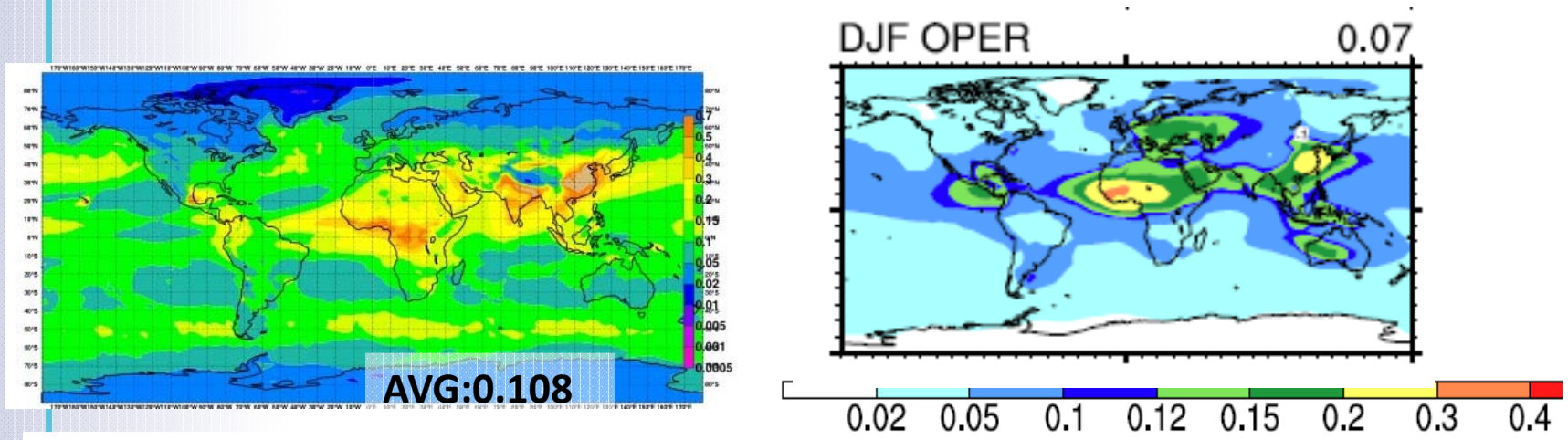
CAMS reanalysis test runs

- The CAMS reanalysis is using prognostic aerosols in the radiation scheme.
- Test runs with data assimilation were carried out to assess the impact of this over using an aerosol climatology (Jan-Feb 2010) in the radiation scheme: experiments **AER** and **REF**.
- Comparison of meteorology and aerosols between these two runs.



Total AOD at 550nm, CAMS reanalysis test run for Jan-Feb 2010 (left), Tegen climatology for DJF (right)

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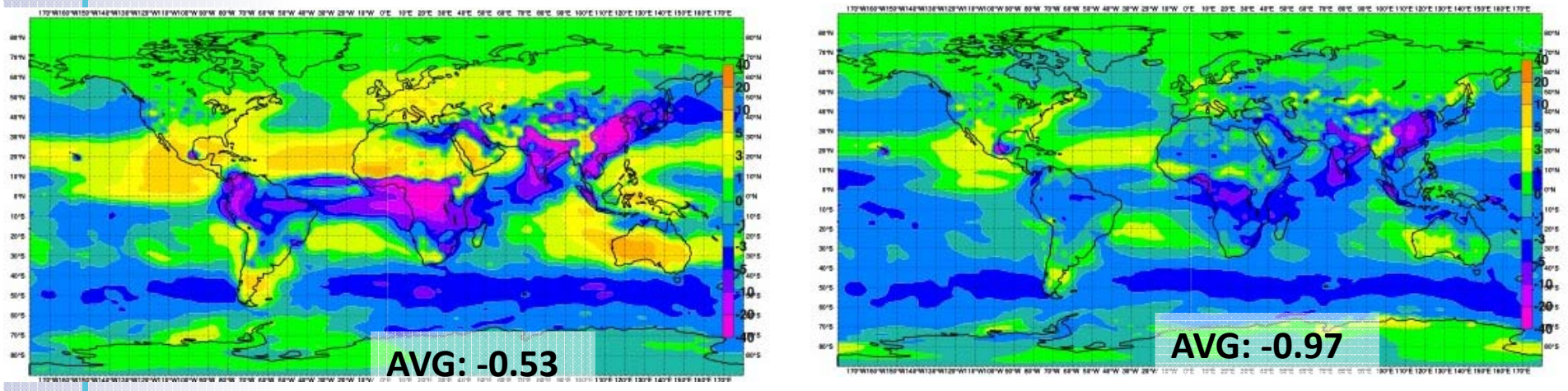
Impact on radiative fluxes at surface and top of the atmosphere

- Comparison of clear-sky SW radiative fluxes at surface and TOA
- Areas where the Tegen climatology has more extinction include most of N Hemisphere (without China and India).



Difference AER-REF for surface (left) and TOA (right) clear-sky SW fluxes, in W/m²

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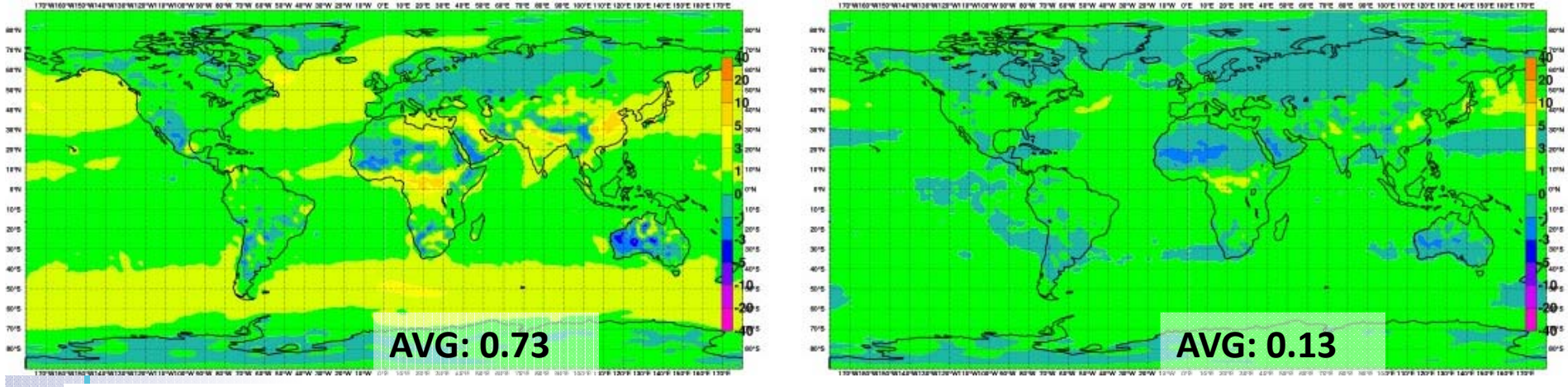
Impact on radiative fluxes at surface and top of the atmosphere

- Comparison of clear-sky LW radiative fluxes at surface and TOA
- Positive over oceans, negligible or negative over continents and especially Sahara (more dust with the Tegen climatology)



Difference AER-REF for surface (left) and TOA (right) clear-sky LW fluxes, in W/m²

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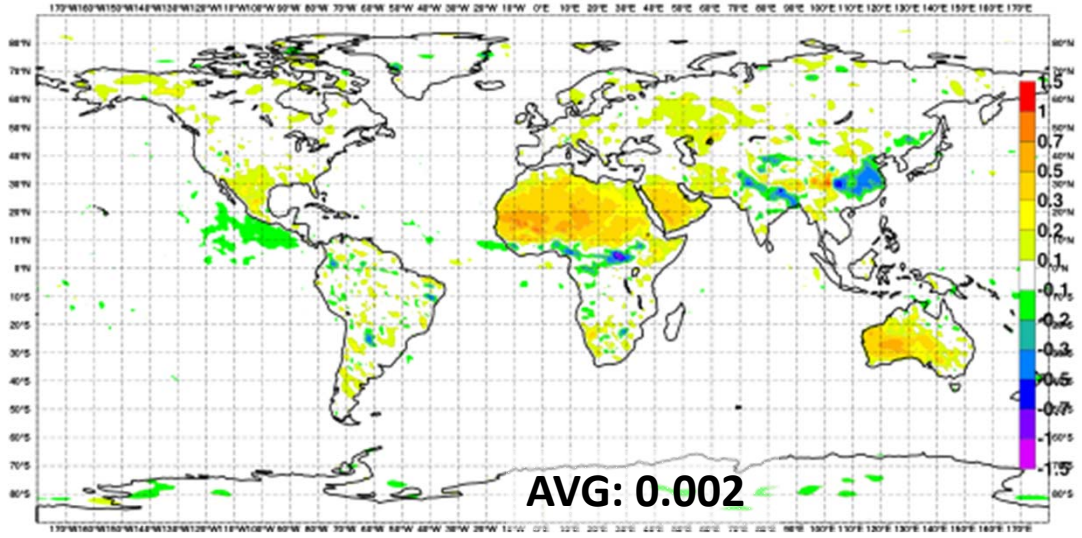
Impact on 2m temperature at 0UTC

- Over Sahara and Arabic peninsula: the larger SW fluxes with AER more than compensate the lower LW; t2m is higher
- Over China and India, exactly the opposite.



Difference AER-REF for 2m temperature at 0UTC, in °c

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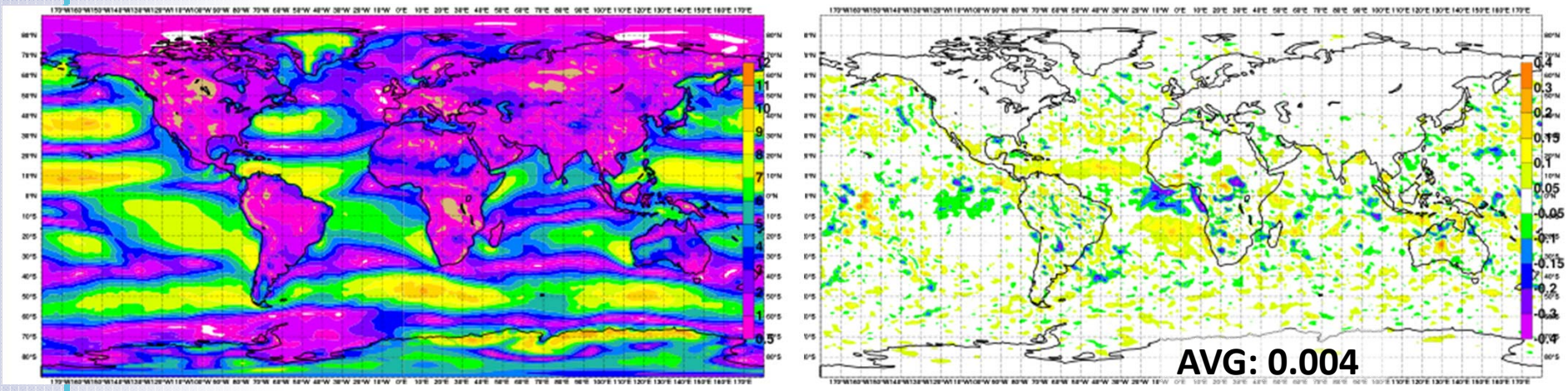
Impact on 10m wind speed

- Over oceans: winds often larger with AER, except close to the W coast of Africa
- Trade winds are slightly larger with REF over the Atlantic



Left: mean wind speed with AER; right difference AER-REF for 10m wind speed at 0UTC, in m/s

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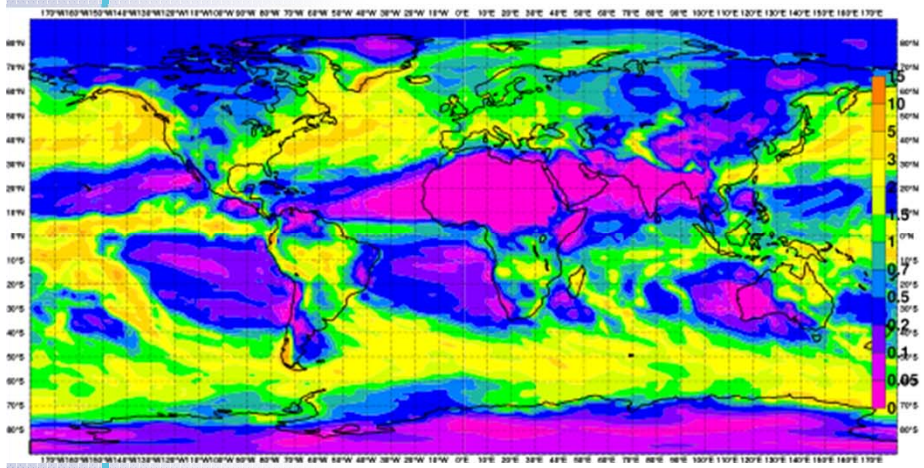
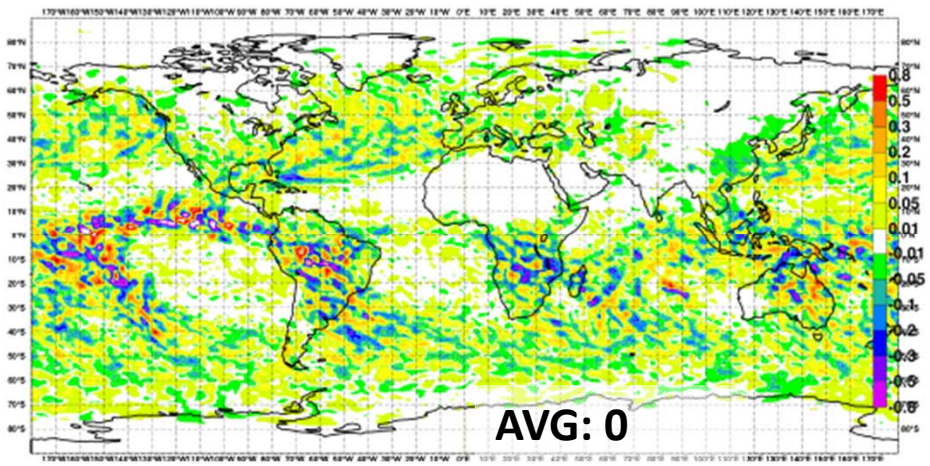
Impact on large scale precipitations

- ITCZ is clearly visible: rain events are “displaced”
- Over China: less large scale rain with AER





Left: mean daily large scale precipitation for AER (in mm/day), right, difference AER-REF

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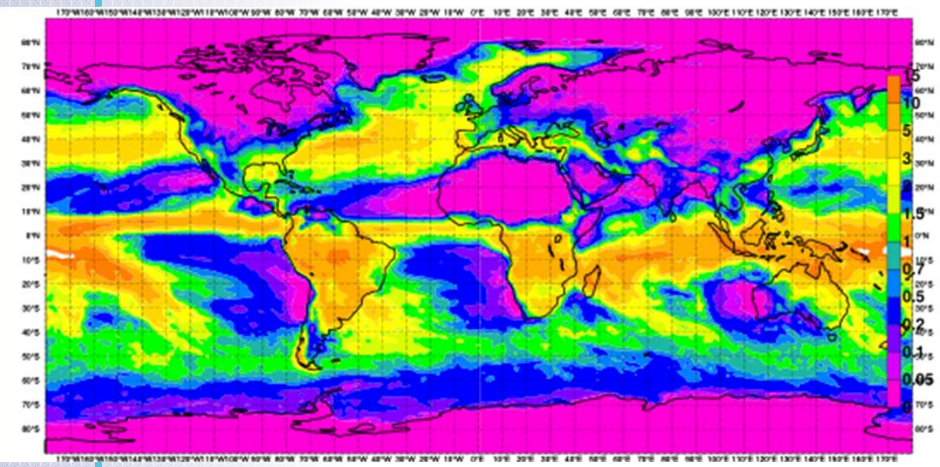
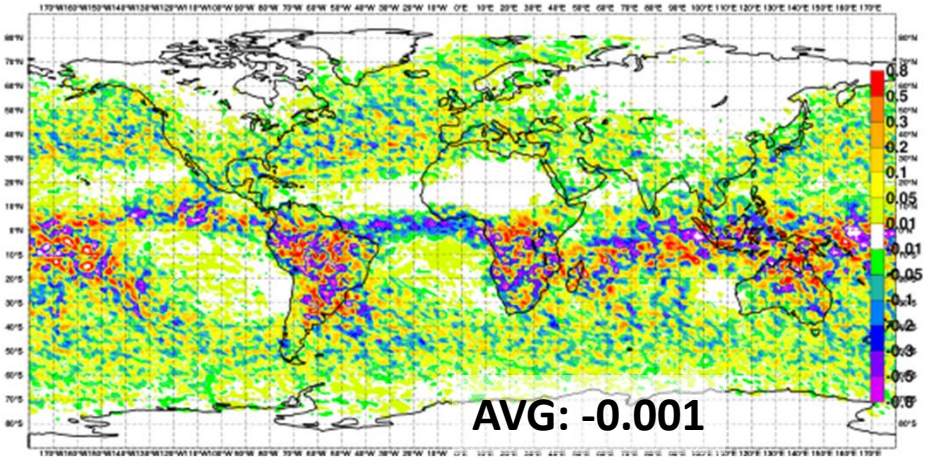
Impact on convective precipitations

Atlantic ITCZ less intense convective precipitations with AER, otherwise difficult to interpret!





Left: mean daily convectice precipitation for AER (in mm/day), right, difference AER-REF

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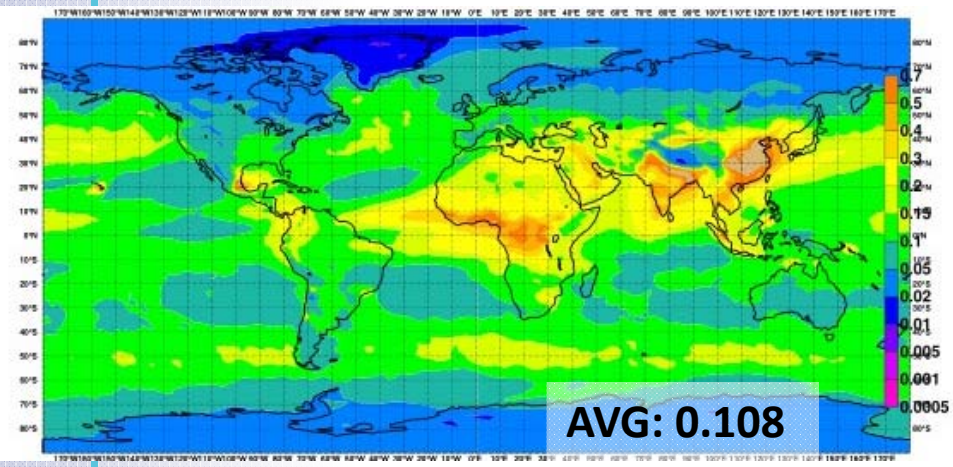
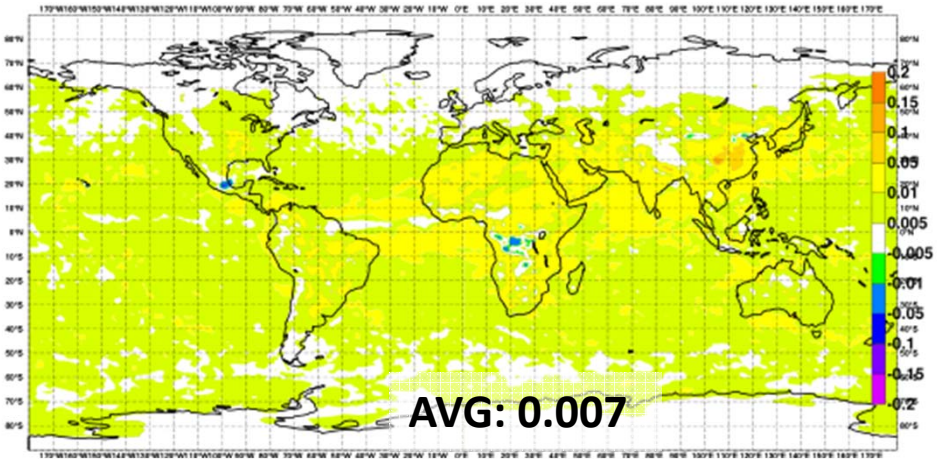
Impact on aerosols

- Positive difference with AER almost everywhere except over Mexico city and parts of equatorial Africa
- Where does this extra aerosol come from?





Left: total AOD at 550nm from AER; right: difference AER-REF.

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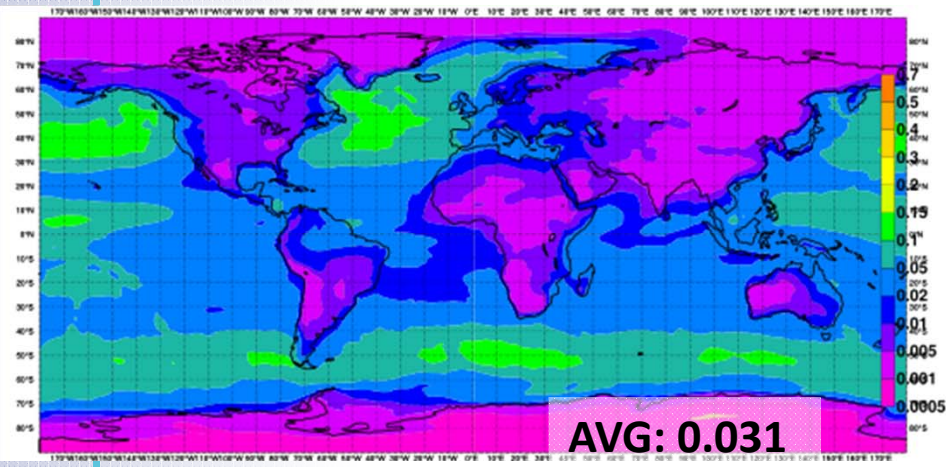
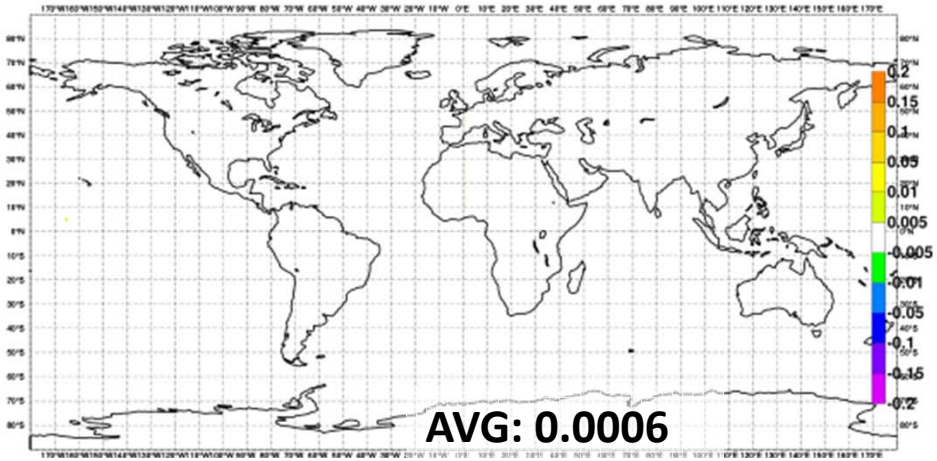
Impact on sea-salt aerosols

Very tiny positive difference for sea-salt, possibly from larger wind speeds on average





Left: sea-salt AOD at 550nm from AER; right: difference AER-REF.

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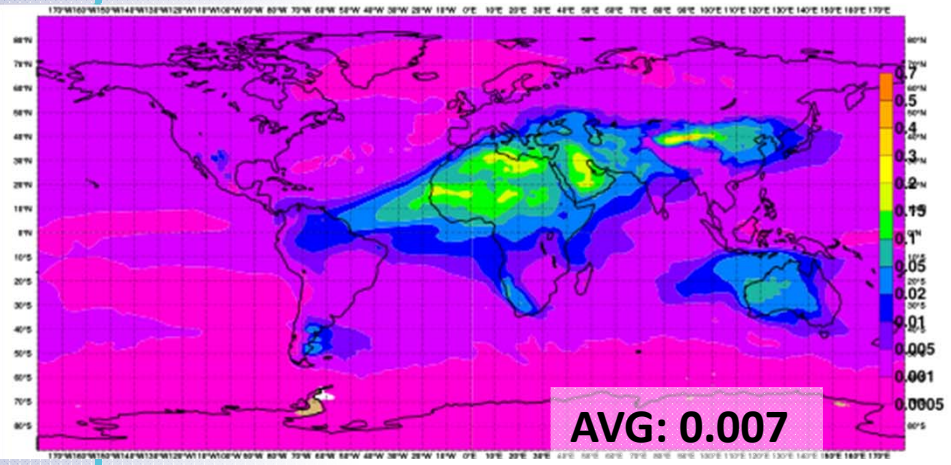
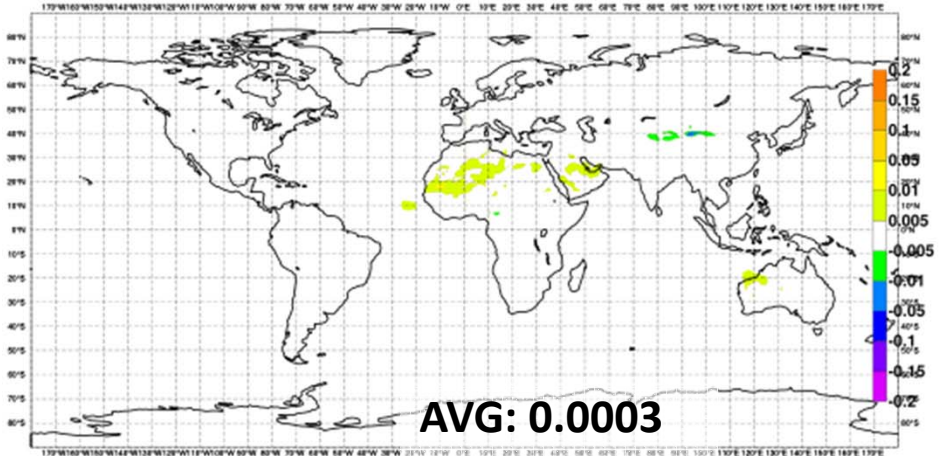
Impact on dust aerosols

Very tiny positive difference for over the Sahara





Left: dust AOD at 550nm from AER; right: difference AER-REF.

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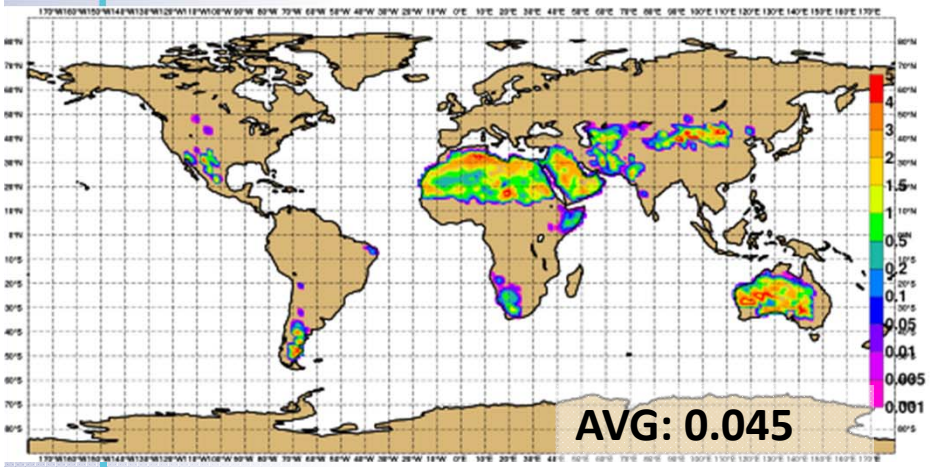
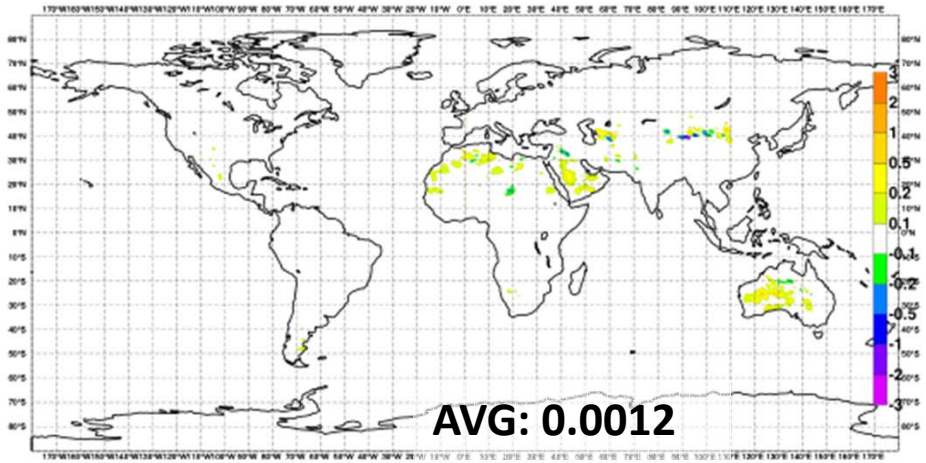
Impact on dust aerosols

- Caused by an increase in the dust sources (probably an increase in wind gustiness caused by higher surface temperature)





Left: mean dust bin 3 source in kg/m²/yr; right difference AER-REF.

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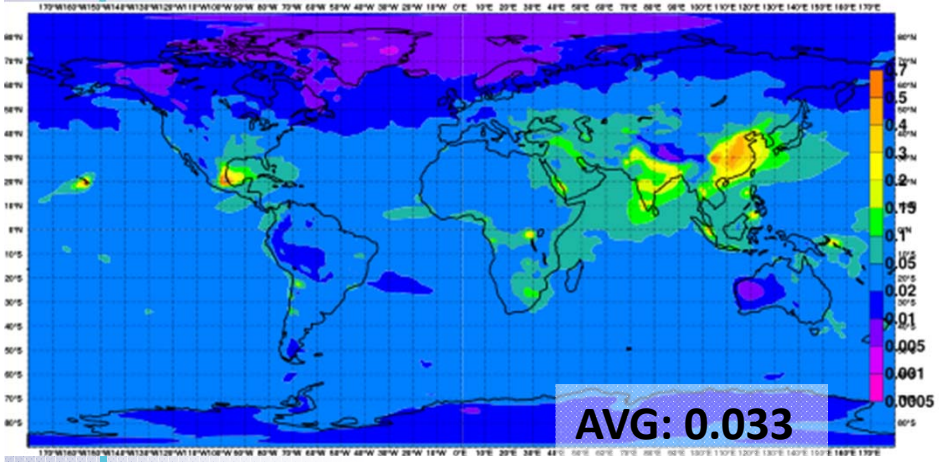
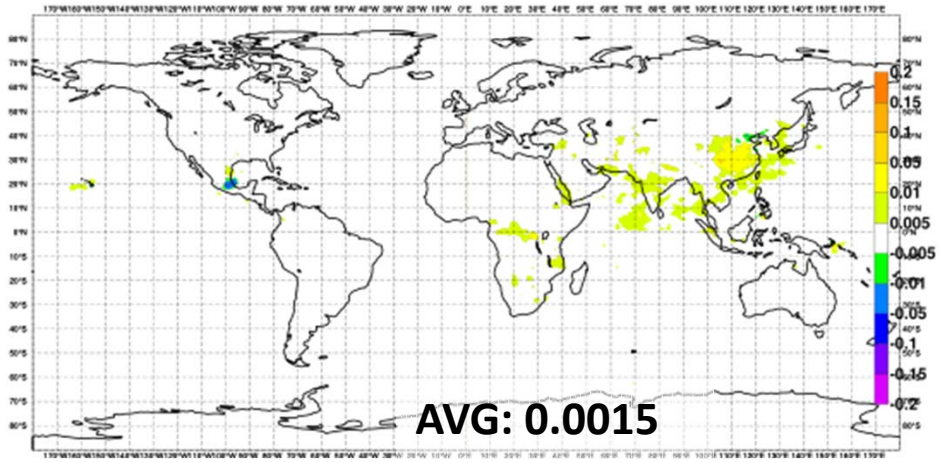
Impact on sulphate aerosols

- Significant difference between AER and REF over China and India
- Sources (from conversion) are nearly identical
- Sinks?





Left: sulphate AOD at 550nm from AER; right: difference AER-REF.

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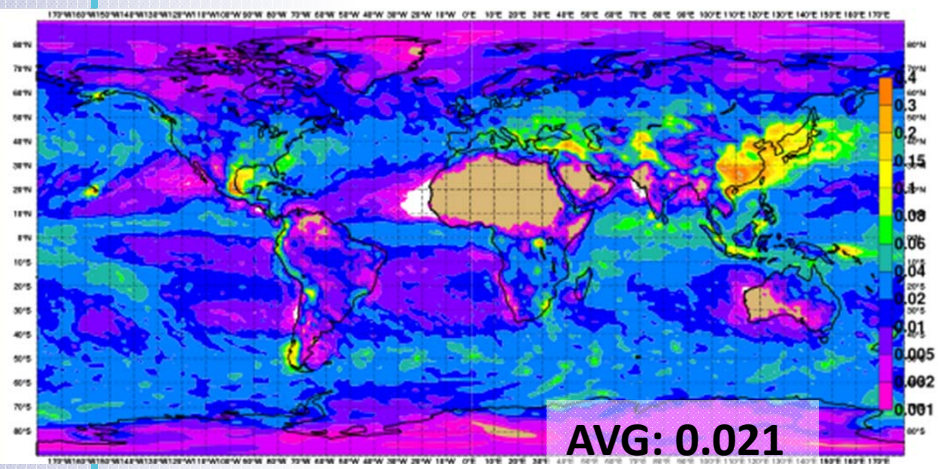
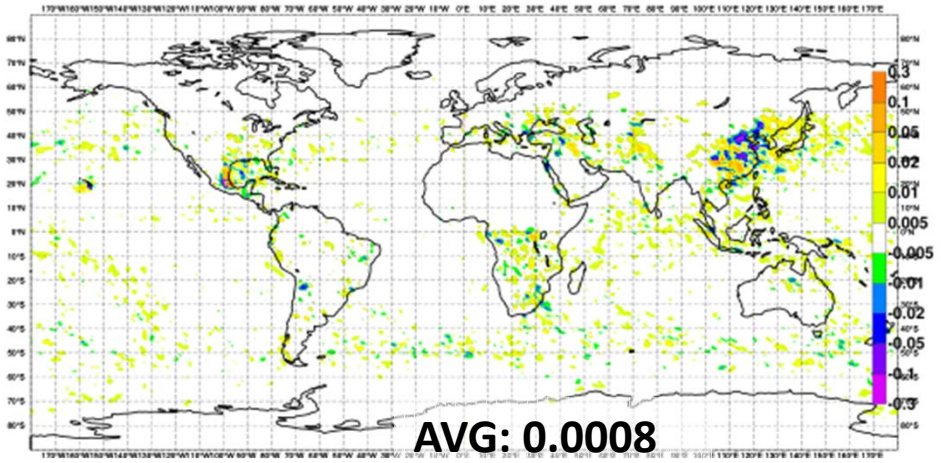
Impact on sulphate aerosols

- Wet deposition is smaller over parts of China (reduced large scale precipitation and maybe clouds)
- Overall wet deposition is increased with AER





Left: mean sulphate wet deposition in kg/m²/yr; right difference AER-REF.

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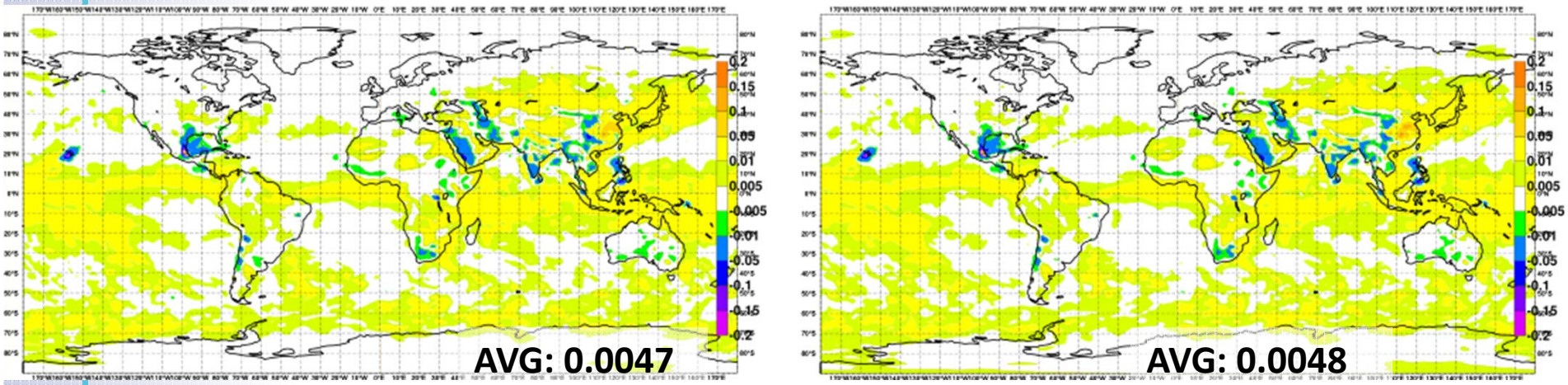
Impact on sulphate aerosols: data assimilation

- Globally not much difference between AER and REF
- Negative increments over volcanoes : Hawai and Mexico
- Negative increment over part of the Arabic Peninsula
- Positive increment almost everywhere else: why?



mean sulphate AOD increment: AER(left) and REF (right)

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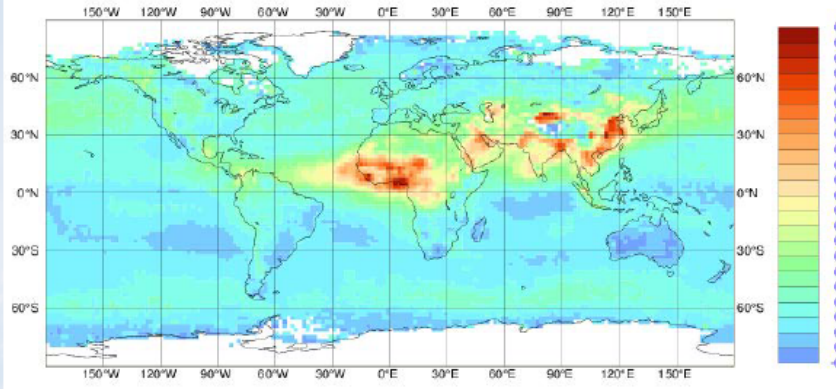
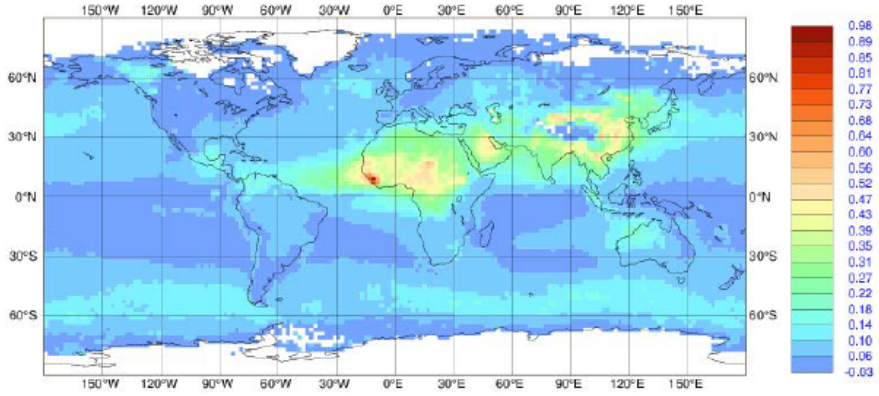
Impact on sulphate aerosols: data assimilation

- Because C-IFS is biased low against MODIS
  - Hence large increments exist (particularly over oceans) and need to be redistributed
  - Sulphate present over oceans because of DMS sources => it received some of the increments

MODIS only



No AOD



Picture by Melanie Ades: spring 2016, mean AOD from C-IFS with/without assimilation of MODIS collection 6

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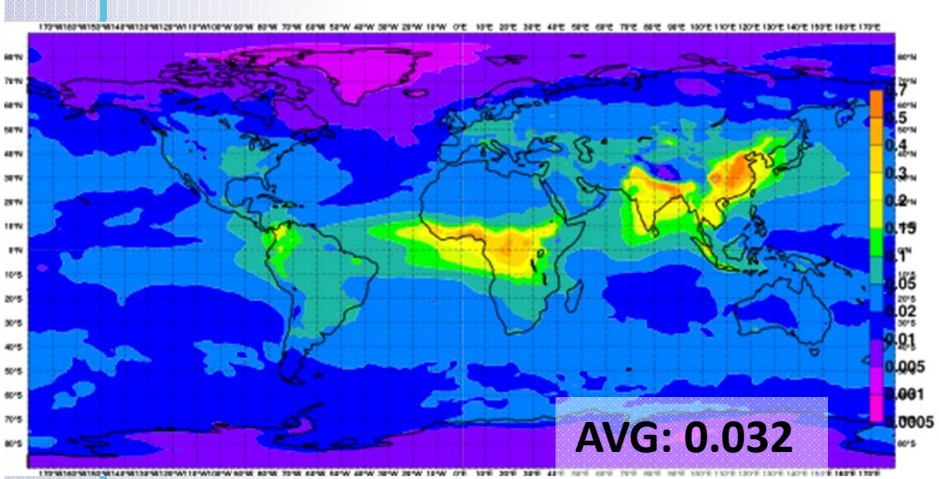
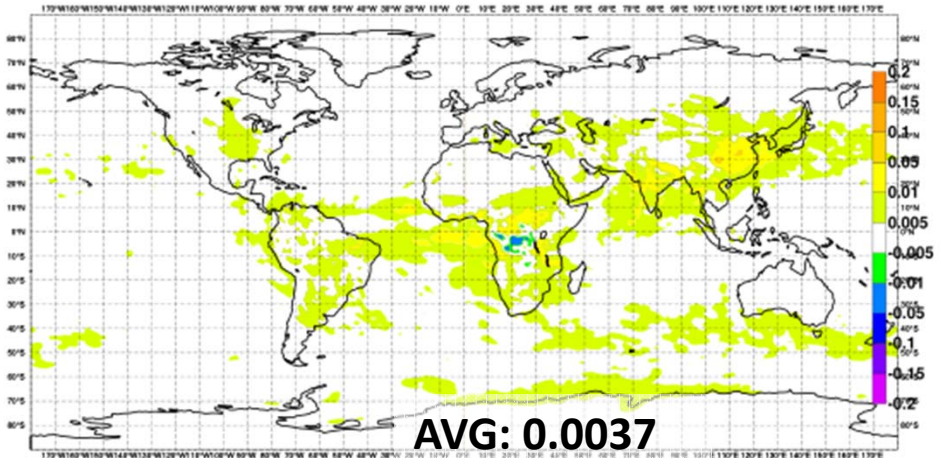
Impact on Organic Matter

- Significant difference between AER and REF over China, India, parts of Africa and Atlantic/Southern oceans
- OM AOD is ~ 10% larger with AER than with REF
- It explains more than half the difference between AER and REF total AOD
- Sources are exactly identical: no dependence on meteorology
- Sinks?





Left: OM AOD at 550nm from AER; right: difference AER-REF.

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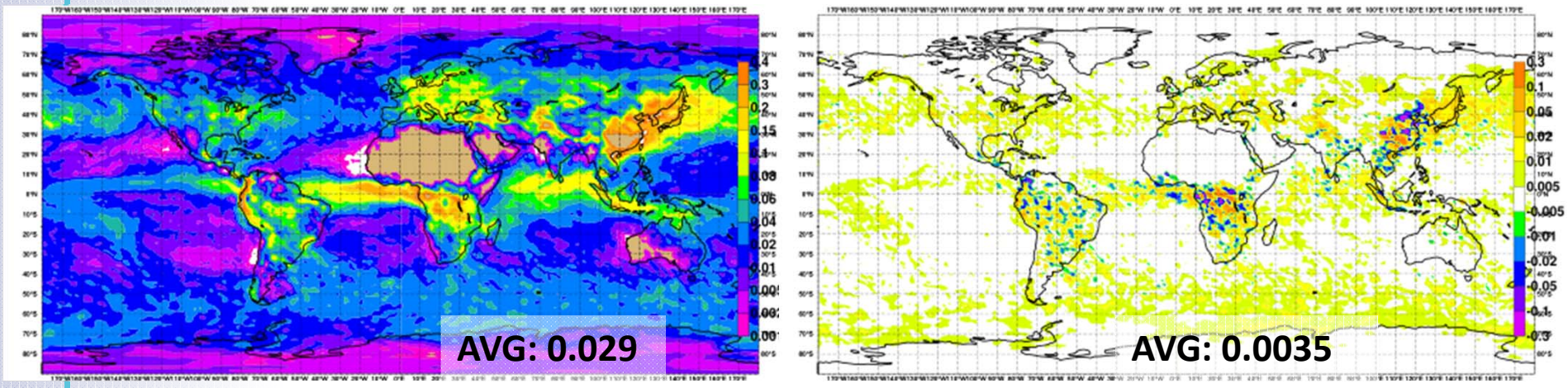
Impact on Organic Matter: wet deposition

- Dry deposition is close between AER and REF
- Wet deposition on average 10% larger with AER
- Same relative increase as for AOD/burden
- Same sources, larger sinks => the increase in OM burden with AER must come from the initial conditions



Left: mean OM wet deposition in kg/m²/yr; right difference AER-REF.

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Summary of the impact of prognostic aerosols in the radiation

- Most of the difference impacts OM
- Significant increase also for sulphate and sea-salt

	Total AOD	SS AOD	DU AOD	OM AOD	BC AOD	SU AOD
Diff AER-REF	0.0065	0.0007	0.0003	0.0037	0.0004	0.0015
%	100%	10,1%	4.6%	57%	6.1	23%

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Summary of the impact of prognostic aerosols in the radiation : increments

- Most of the (positive) increments goes to sulphate and OM
- Very small negative increments for dust: model more or less in line with MODIS
- Total increments are larger with AER, the increase goes into OM and sea-salt

	Total AOD	SS AOD	DU AOD	OM AOD	BC AOD	SU AOD
Increment REF/%	0.01/100%	0.0012/12%	-0.0002/-2%	0.0039/38%	0.0006/6%	0.0048/48%
Increment AER	0.012/100%	0.0016/13%	-0.0002/-2%	0.0047/39%	0.0006/5%	0.0047/39%

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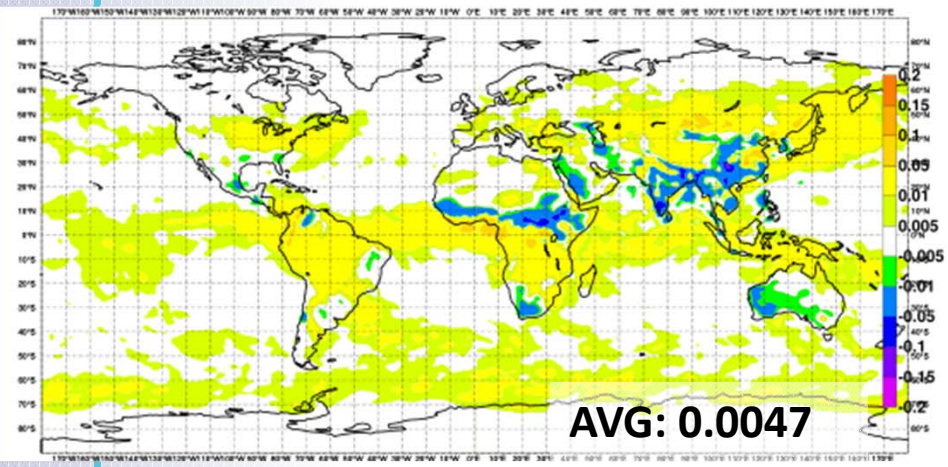
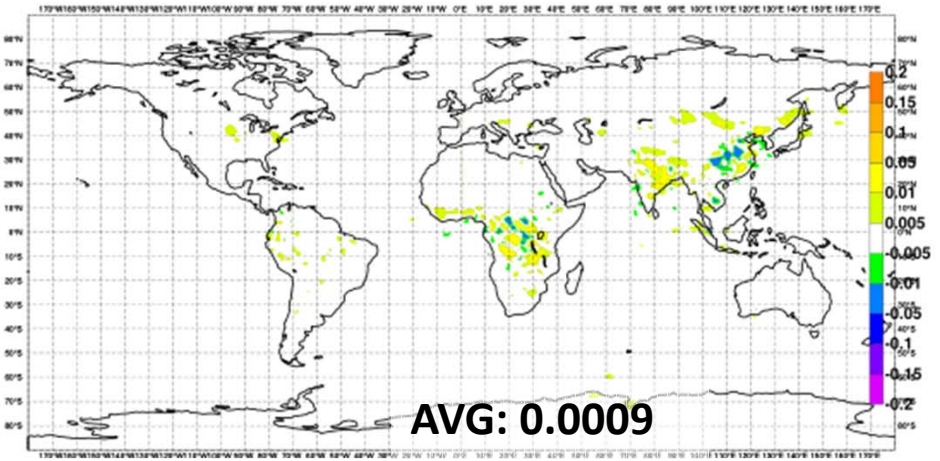
Impact on Organic Matter: increments

- Increments of OM are on average ~ 20% larger with AER
- Large increments over oceans, which clearly should not be here





mean OM AOD increment: AER(left) and difference AER-REF (right)

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Tentative explanation

With AER, higher sea-salt because of higher winds,

⇒ AOD analysis is also higher with AER,

	Analysis AOD	24h forecast AOD
REF	0.111	0.101
AER	0.120	0.108

⇒ Forecast decreases more (increased sinks because of higher burden),

⇒ Larger increments, especially over oceans,

⇒ Because of too low sea-salt, these increments are also distributed to OM (and sulphate to a lesser amount)

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Tentative directions for a cure

- Increase model sources (and burden/AOD) so that the difference with MODIS is not so large: ongoing
  - New sea-salt scheme,
  - New dust scheme,
  - New SOA and nitrates
- A dual control variable (fine and coarse AOD) in the assimilation could help,
- Assimilation of vertical profiles (LIDAR) could also probably help,
- Speciation of increments?

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Take home message/conclusion

- Nice (and unexpected) case of interaction between aerosol, radiation and data assimilation
- With data assimilation of integrated total quantities, model changes can have unforeseen consequences
- Model changes need to be tested in data assimilation mode

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