Simulation of Biomass Burning aerosol in HadGEM3

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AEROCOM, Steamboat Springs, Sept 2014

Introduction

- The Met Office Hadley Centre Earth System Model HadGEM3 – UKESM1
- UKCA & GLOMAP-mode aerosols
- SAMBBA field campaign
- Evaluation of biomass burning aerosols
- Sensitivity to modelling assumptions

The UK Earth System Model (UKEMS)

Project headed by Colin Jones

- A collaboration between the Met Office Hadley Centre and the UK Natural Environment Research Council (NERC).
- A world-leading Earth System Model for CMIP6 and beyond.
- Built on HadGEM3 with several new components

  Atmosphere = Based on HadGEM3 with UKCA (UK Chemistry & Aerosols)

  Ocean = Nemo + MEDUSA (Biogeochemistry)

  Land = JULES (includes TRIFFID vegetation, hydrology, soil and full carbon cycle)

  Cryosphere = CICE (sea ice), BISICLES (ice sheets)

Core development team (**of 16**) funded equally by NERC/Met Office

GLOMAP-mode / UKCA-mode aerosol scheme

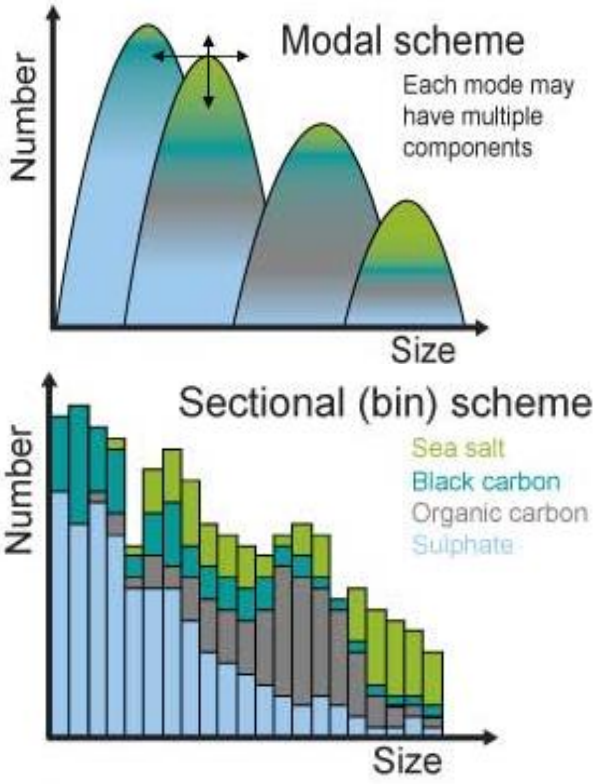
Aerosol scheme developed as part of UK Chemistry and Aerosol (UKCA) project for Met Office Unified Model (HadGEM3, UKESM, NWP).

Based on GLOMAP-bin resolved aerosol model but

with log-normal size modes of internally mixed aerosol:

Sulphate, black and organic carbon, sea salt.

Nitrate and dust will be added in near future.



Simulates full aerosol life cycle:

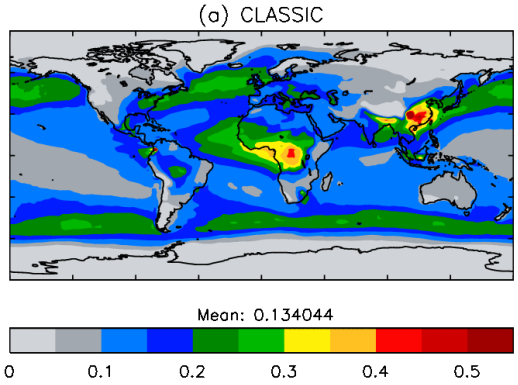
- Primary emissions (sulphate, BC/OC, sea-salt, dust)
- Secondary sulphate particle formation (nucleation)
- Coagulation (within modes, between modes).
- Condensation (sulphuric acid, bulk condensible organic)
- Cloud processing
- Dry deposition and sedimentation
- In-cloud and below-cloud scavenging

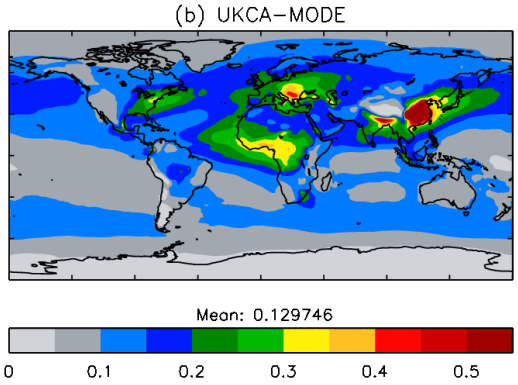
This will replace the CLASSIC aerosol scheme from HadGEM2 (externally mixed aerosol species with specified properties)

GLOMAP-mode references: Manktelow et al (GRL, 2007), Woodhouse et al (Atmos Env, 2008; ACP, 2010), Schmidt et al (ACP,2010), Mann et al, (GMD,2010), Mann et al (ACP, 2012)

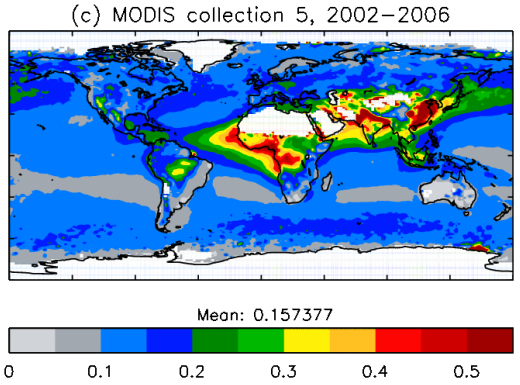
Aerosol performance in HadGEM3: Annual mean AOD_{550} comparisons

HadGEM3





MODIS

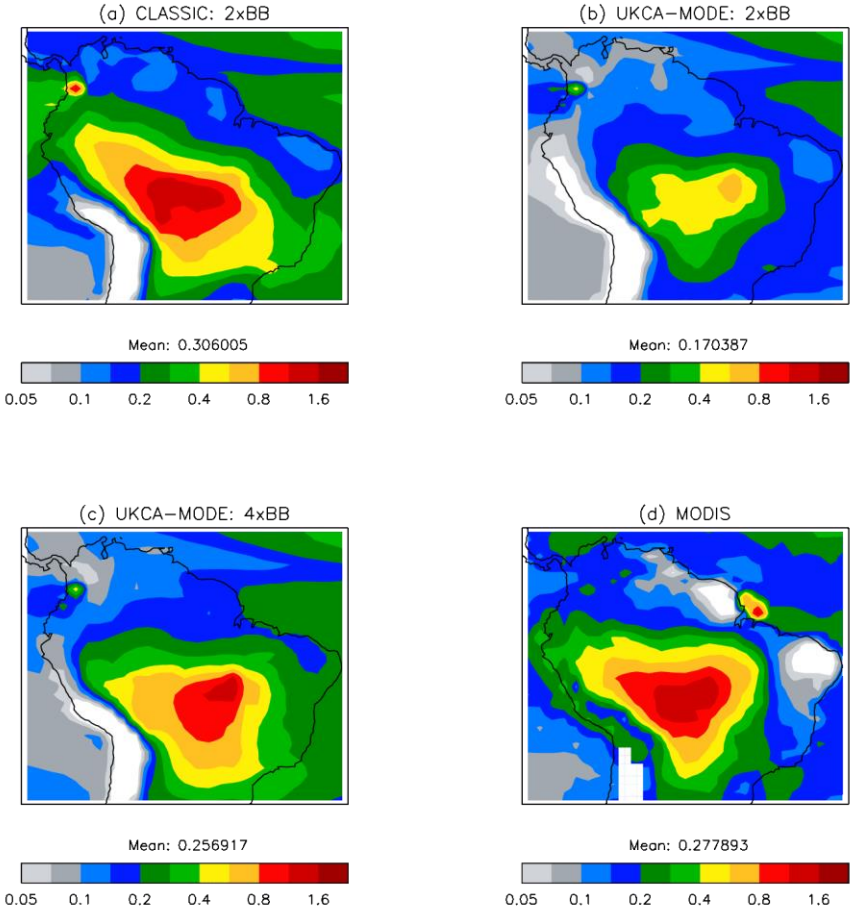


- Model simulations are from a development version of HadGEM3 targeted for use in UKESM
- UKCA-MODE aerosol scheme show improvements over CLASSIC aerosol scheme in some areas but degradation in other areas (e.g. not enough over Tropical Africa and S. America)
- BB emissions are from GFED3.1 for 2002-2011

Thanks to Jane Mulcahy and Nicolas Bellouin

Evaluation of Aerosol Optical Depth (AOD) over S. America during BB season

Sept monthly mean AOD_{550} from UM and MODIS



Upscaling of GFED emissions is required to gain agreement with MODIS AOD

Aerosol model	Scaling
CLASSIC*	~ 2
UKCA-MODE	~4

- BB emissions were from GFED3.1 2002-2001.

SAMBBA field campaign

(South American Biomass Burning Analysis) – Sept/Oct 2012

Met Office

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NATURAL ENVIRONMENT RESEARCH COUNCIL

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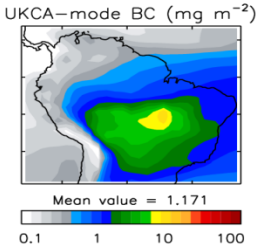
SCIENTIA VINCES

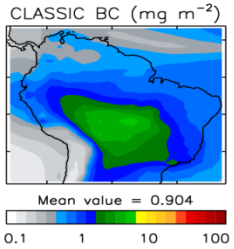
INPE

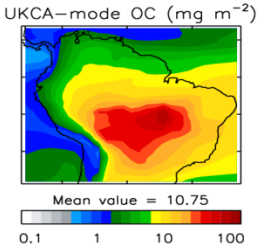
Evaluation of aerosol composition
HadGEM3 vs SAMBBA ground obs

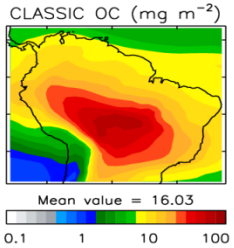
Met Office

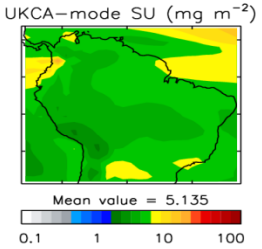
Column integrated aerosol burden

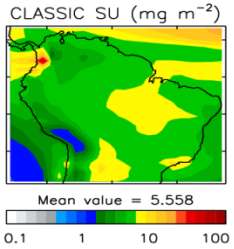


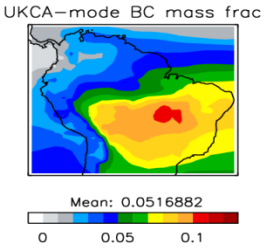


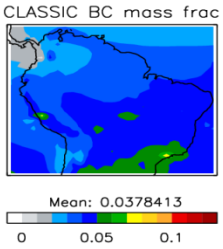




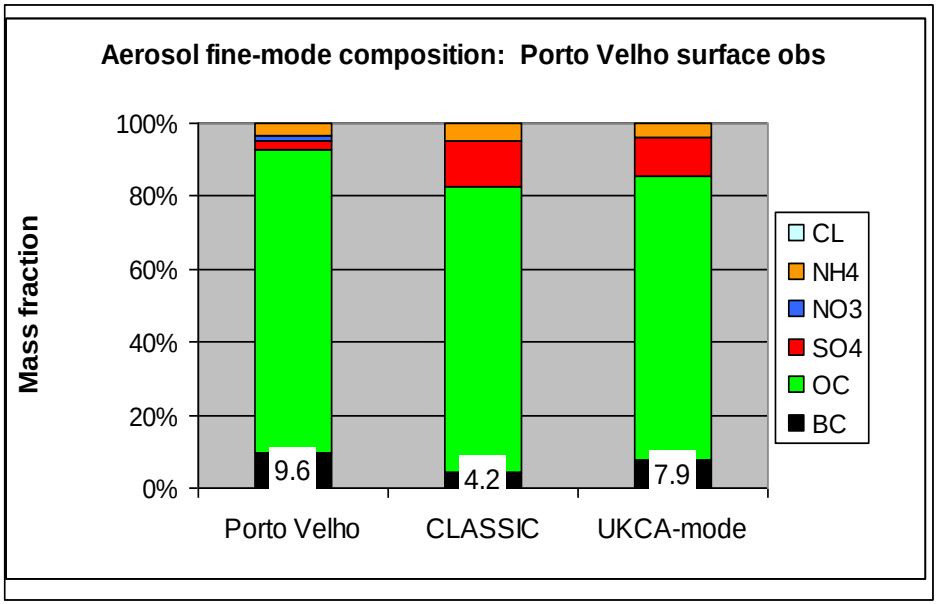








- Aerosol in Amazonia dominated by organic carbon
- Models have lower BC mass & BC mass fraction than SAMBBA ground obs but UKCA-mode is closer to obs

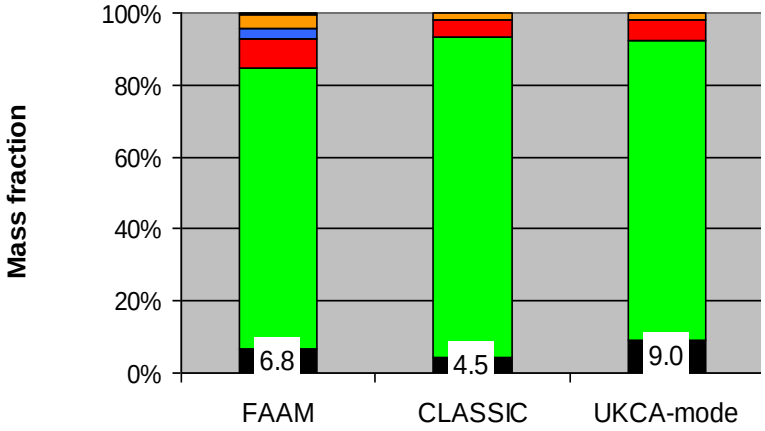


Thanks to Joel Brito for ground obs

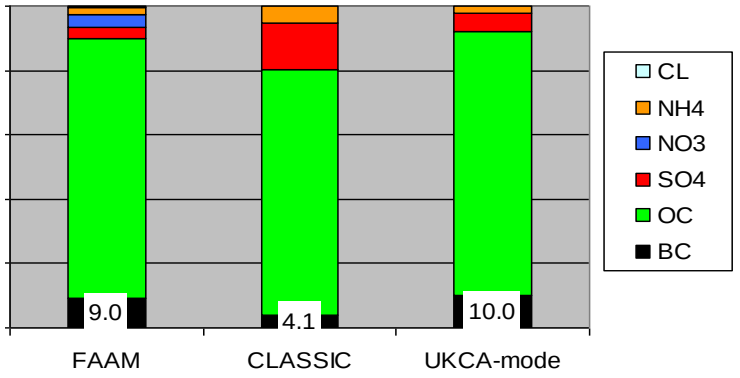
Aerosol composition

HadGEM3 vs SAMBBA FAAM obs

Western region



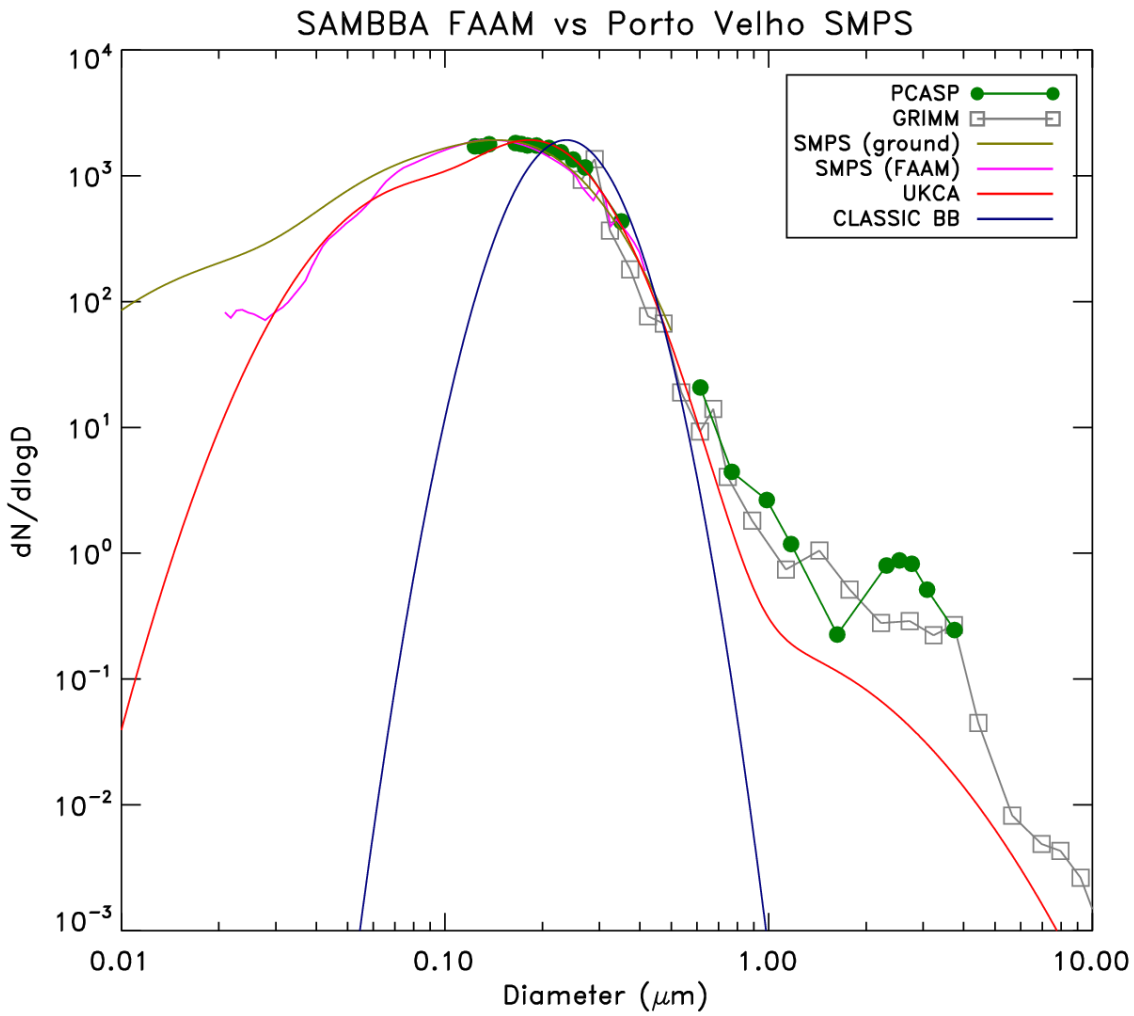
Eastern region



- FAAM averages show little change in composition from east – west ?
- Models have lower BC mass fraction than FAAM obs but UKCA-mode is closer to FAAM obs
- Models have too great contribution from sulphate in Eastern region / too little BB aerosol (was only ¼ as much BC+OC there) due to limited GFED emissions in East region

Thanks to Eoghan Darbyshire for FAAM obs

Campaign mean aerosol size distributions vs modelled monthly mean: Western region

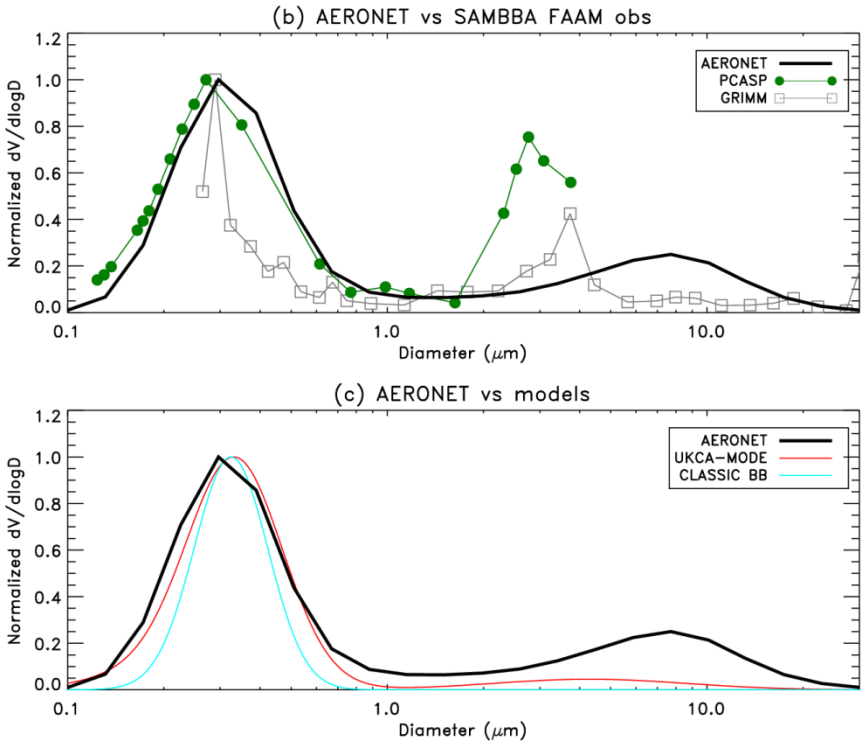


- Amplitude of SMPS and model curves were normalized to give equal peak concentrations as the PCASP
- Observations give consistent curve, except for SMPS d<0.1μm
- UKCA-MODE captures the size distribution over most of the observed size range. CLASSIC represents only the mid accumulation mode

Thanks to Eoghan Darbyshire for FAAM obs, Joel Brito for ground obs

AERONET size distributions

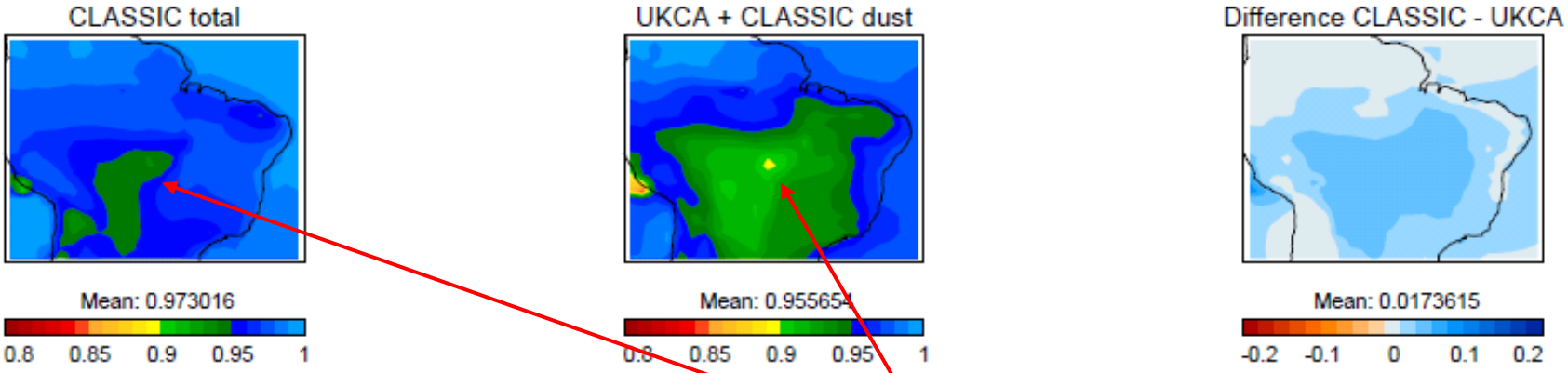
AERONET = 14-year September mean from Alta Floresta



- (b) AERONET vs SAMBBA FAAM observations, normalized by peak concentration.
- (c) AERONET vs monthly mean output, column-integrated mean over Alta Floresta

Aerosol absorption

Single scattering albedo$_{550}$ = [scattering / extinction]



- Models show the moist values of SSA calculated from AAOD / AOD, monthly mean for September
- Minimum values are 0.93 for CLASSIC, 0.89 for UKCA-mode
- AERONET, longer-term average at Alta Floresta for September = 0.92

* Results are from an earlier simulation with UM vn7.3

Evaluation of optical properties at 550nm

Data source	$K_{ext\ 550}(m^2/g)$	ω_{550}	$Å_{440-675}$	g_{550}
SAMBBA FAAM Neph & PSAP (mean of all BB flights)	n/a	0.91	1.8	n/a
SAMBBA FAAM PCASP fine-mode logfit with RI = 1.5 + 0.02i*	4.28	0.89	2.0	0.61
AERONET, Alta Floresta, 1999 – 2012, September mean	3.6	0.92	1.7	0.64
CLASSIC** Total BB mixture (dry / moist)	5.01 / 7.73	0.91 / 0.94	2.3 / 2.0	0.58 / 0.64
UKCA** Fine-mode mix	3.83 / 8.25	0.85 / 0.92	2.1 / 1.9	0.58 / 0.64

*This is consistent with SCAR-B (Reid et al., 1998), or the assumptions of (i) 5% BC by mass, (ii) WCP (1986) refractive index, (iii) homogeneous / linear mixing rule

** Results are from an earlier simulation with UM vn7.3

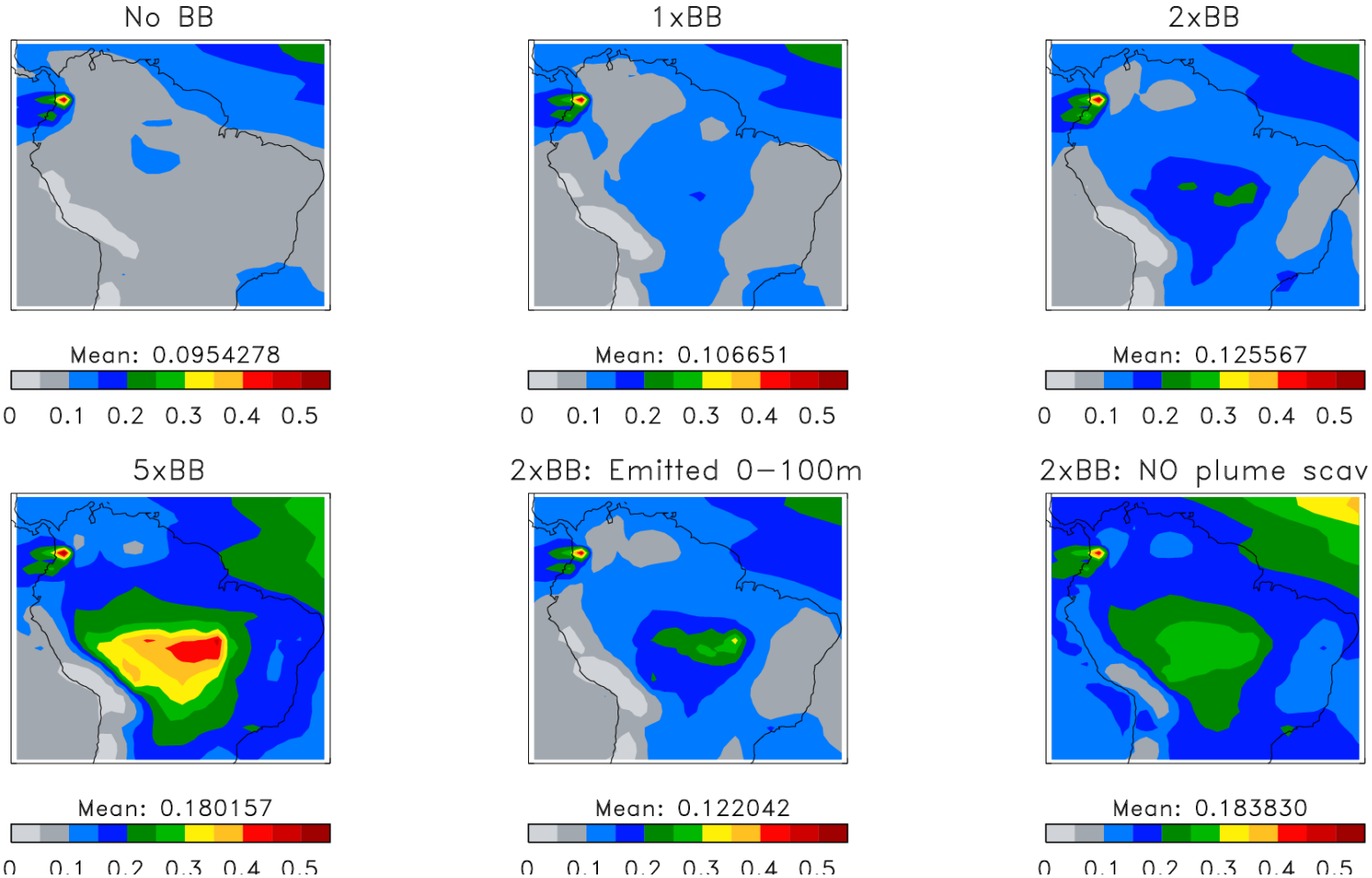
Sensitivity tests

(preliminary tests for AEROCOM phase III BB emission experiment)

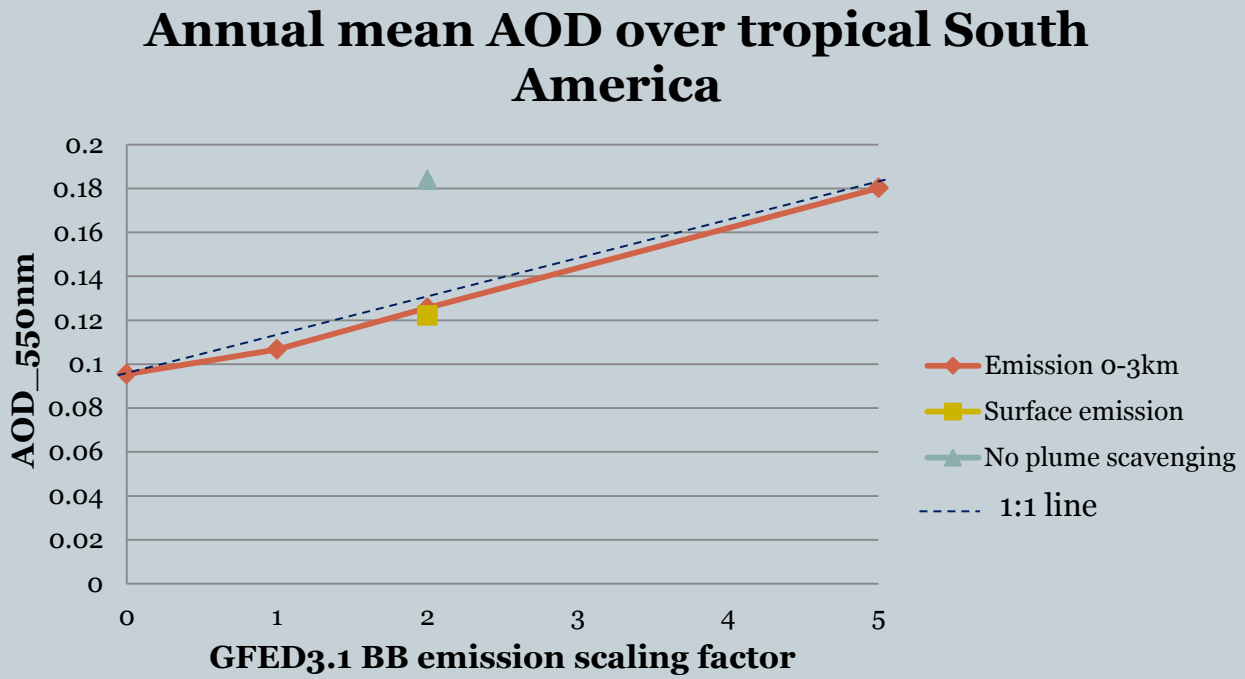
1. No BB emission
2. 1 x BB emission — GFED3.1
3. 2 x BB emission — injection 0-3km
4. 5 x BB emission
5. 2 x BB emission — injection 0 – 100m.
6. 2 x BB emission — No plume scavenging*
7. 2 x BB emission — Atmos nudged to reanalysis

*Plume scavenging removes aerosol from vertical mass flux in moist convective plumes. When this is OFF conventional scavenging occurs in proportion to convective precip rate.

Annual mean AOD_550nm from sensitivity simulations

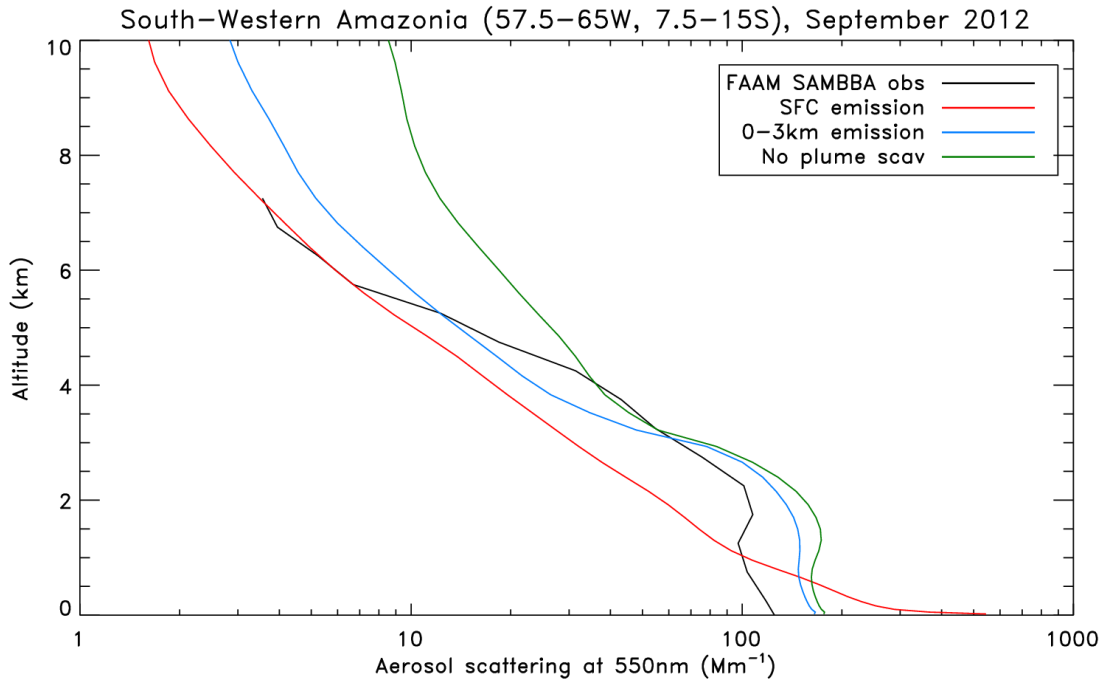


Does AOD increase linearly with BB emission?



Yes ☺

Aerosol vertical distribution



BB emissions injection height:

-All emitted at SFC (lowest model level)
-All emitted 0-3km (uniform with height)

Model data is for all fine-mode aerosol

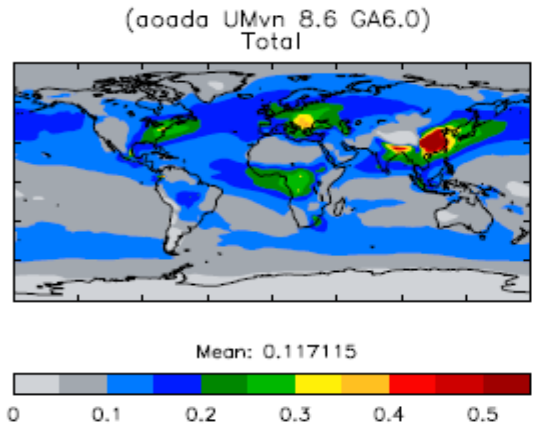
•FAAM aerosol scattering from nephelometer, corrected to ambient humidity using Kotchenruther & Hobbs (1998) [SCAR-B]

•Massive (4x) increase in surface concentration in SFC only run. Total column loading is about the same.
•Lack of plume scavenging leads to ~20% increase in column loading.

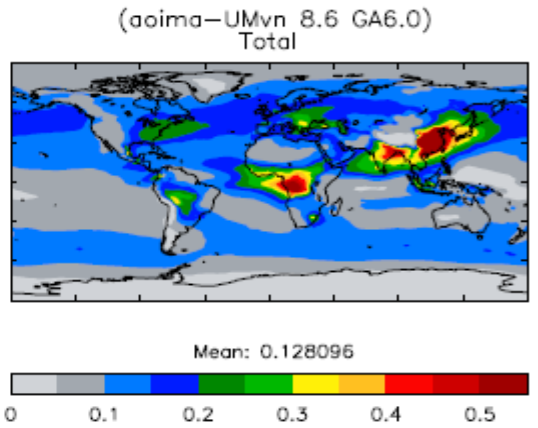
Impact of nudging atmosphere to reanalysis

Annual mean AOD_550nm

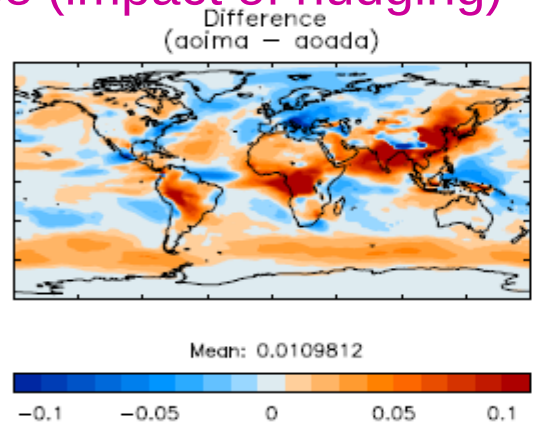
Free-running atmosphere

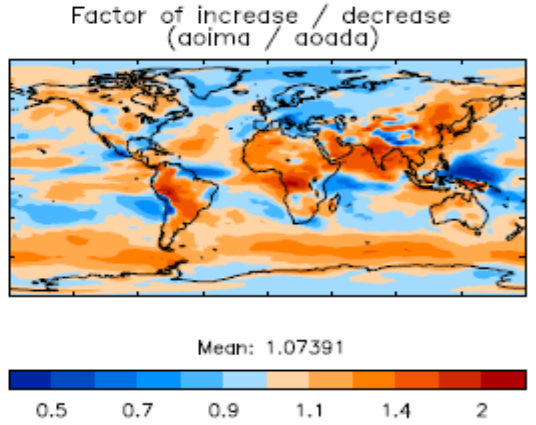


Wind and temp nudged to ERA-40



Difference (impact of nudging)





Conclusions

- HadGEM3 UKCA-MODE produces a reasonable simulation of BB aerosols AOD, composition, size distribution.
- UKCA-MODE aerosols show some improvements over CLASSIC, including:

  - broader and more realistic size distribution

  - More absorption of solar radiation
- BB emissions from GFED3.1 were doubled to get sufficient AOD (are the emissions too weak, or is the atmospheric model wrong).
- Necessary tuning factor depends to injection height, and aerosol removal rate (affected by many processes).

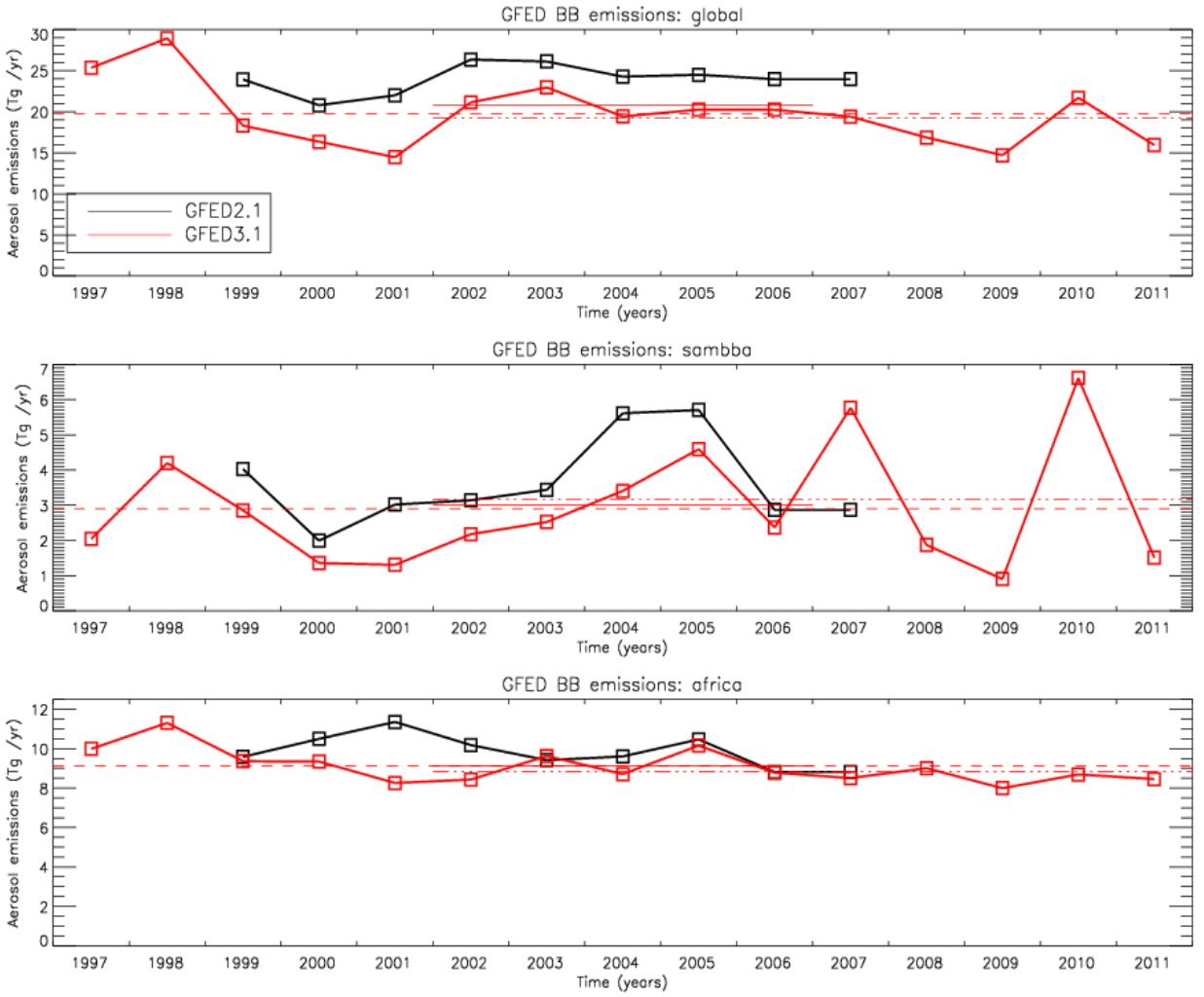
Future work

- Better constraints on solar absorption (BC fraction, RI, mixing state)
- AEROCOM BB emissions experiment (tuning of total BB emissions & injection height)
- Quantify effective radiative forcing BB aerosol
- Regional / global climate responses

Thank you for your attention!

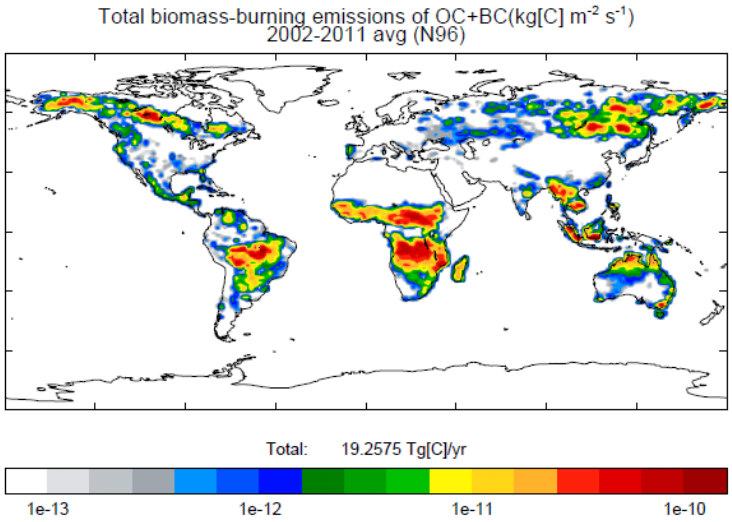
New biomass burning emissions from GFED3.1

- GFED3.1 has lower emission than GFED2.1
- I recommend using mean emissions from 2002-2011 (MODIS era) for “present day” climate simulations / evaluation work.

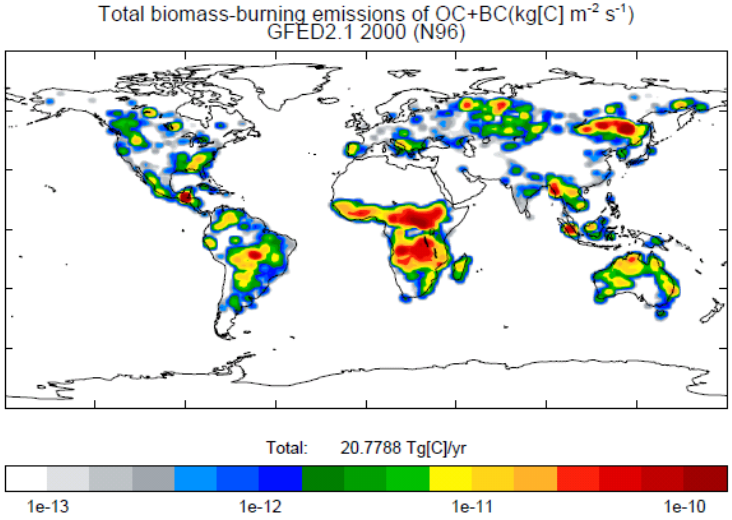


Annual mean BB aerosol emissions

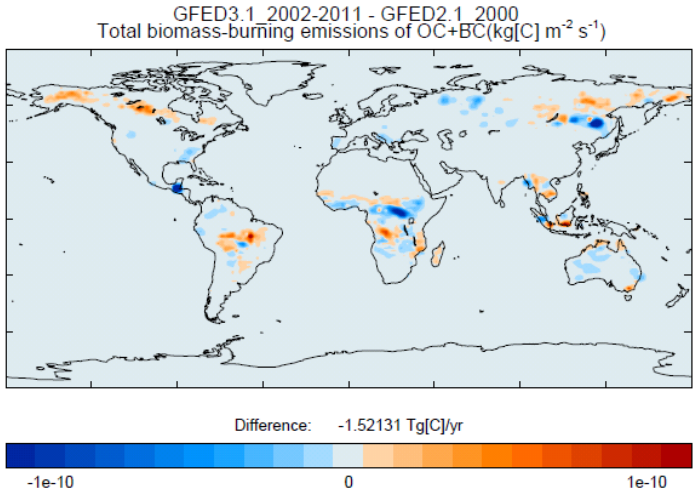
GFED3.1 2002-2011



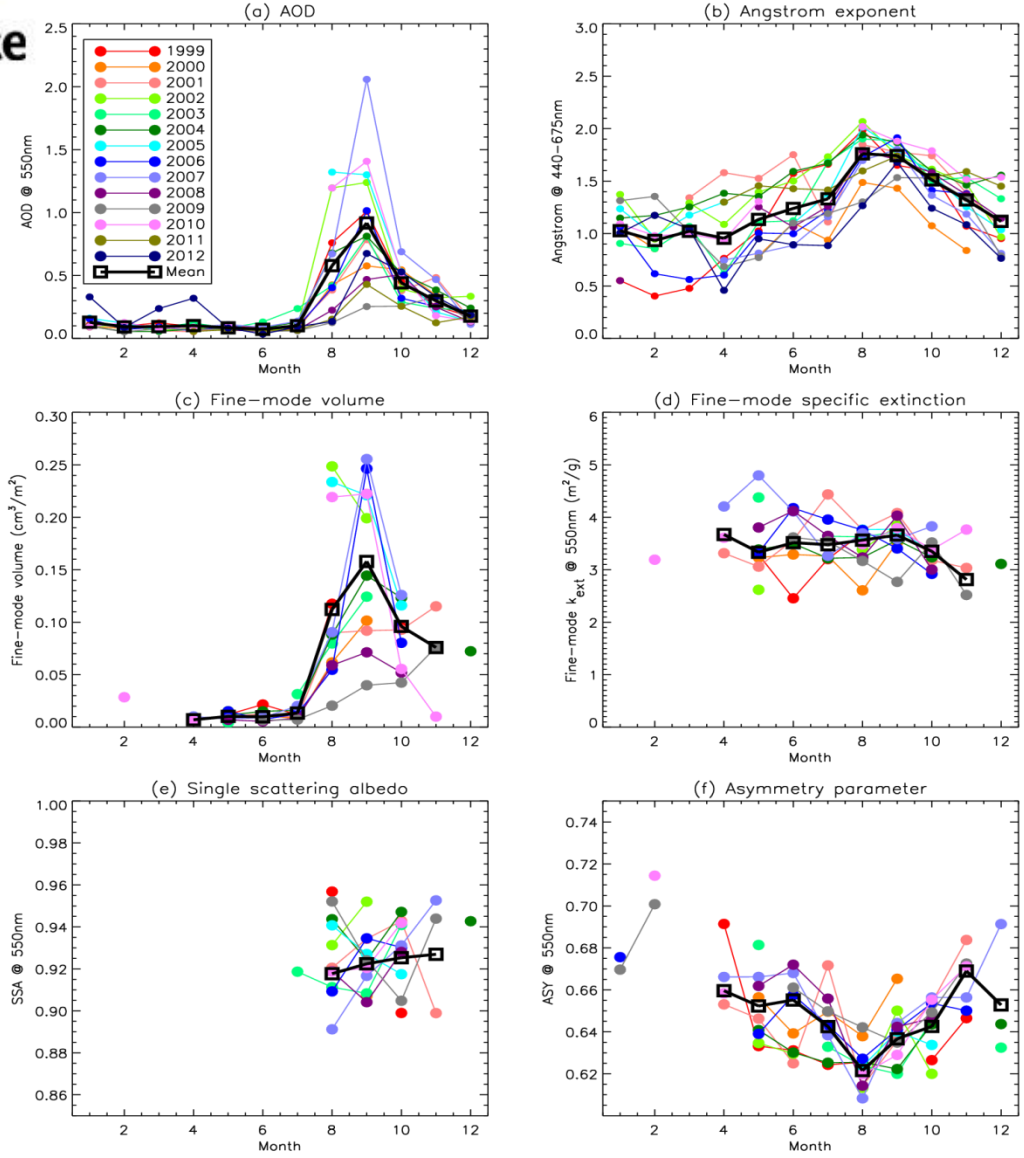
GFED2.1 2000



Difference (GFED3.1 – GFED2.1)

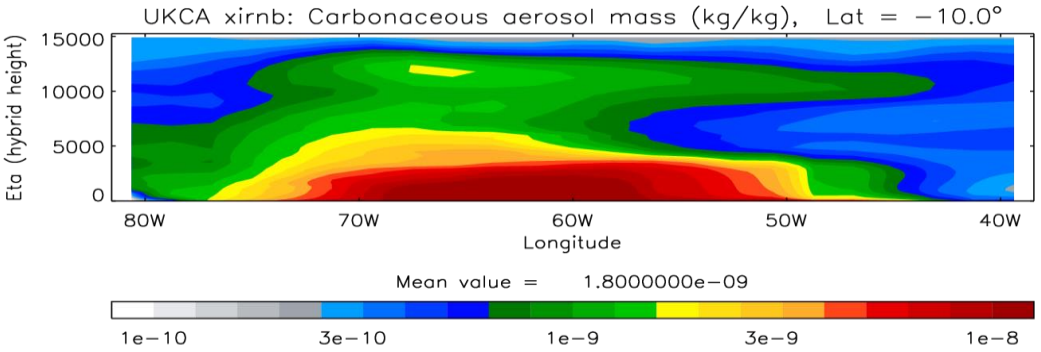


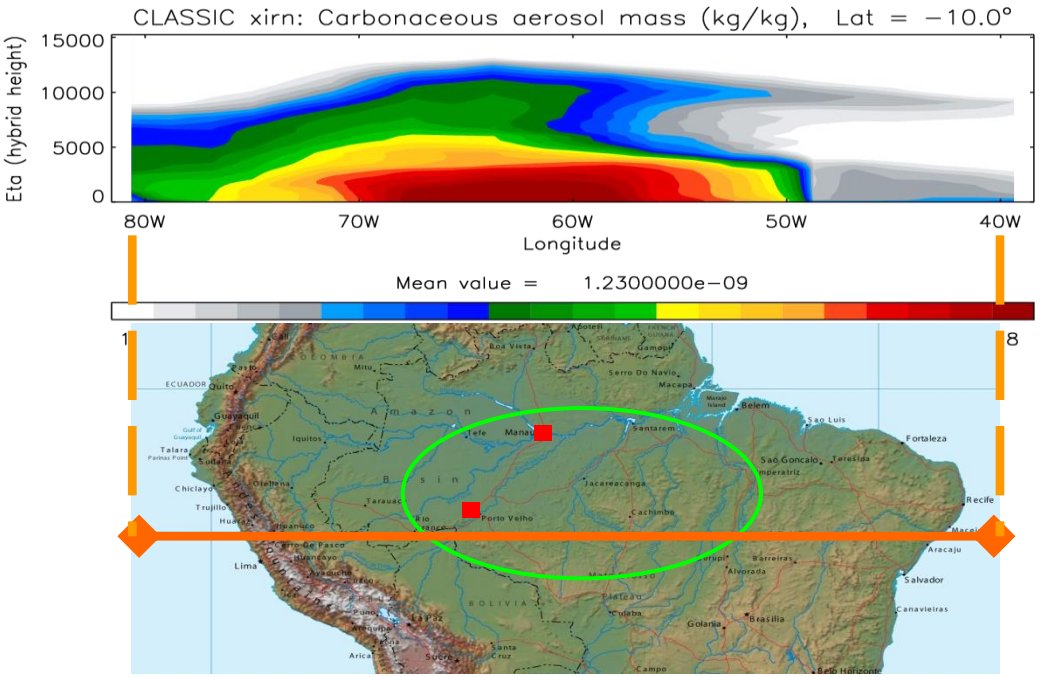
AERONET optical properties



- AERONET inversion products from Alta Floresta, monthly means 1999-2012.
- SSA can only be retrieved for AOD > 0.4.

Cross sections of carbonaceous aerosol mass mixing ratio





- UKCA-MODE and CLASSIC are similar except in the upper troposphere