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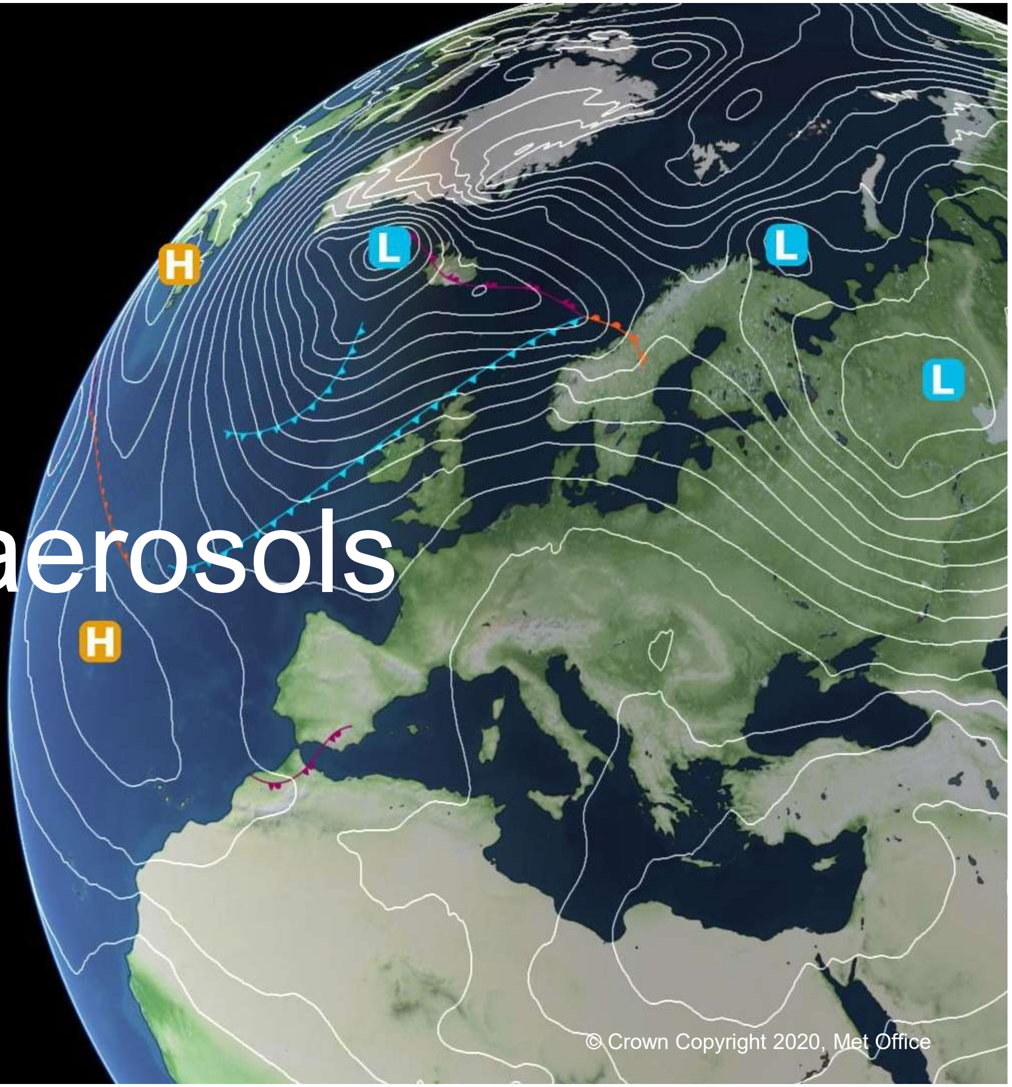
Self-raising aerosols

Ben Johnson, Jim Haywood



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Background

- Vertical distribution of aerosol important direct radiative effects, aerosol-cloud interactions, and long-range transport
- Model biases in elevation of absorbing aerosols
- What lifts aerosol vertically?

- Initial buoyancy of plumes from large fires / chimneys
- BL mixing
- Deep convection
- Large-scale ascent
- Numerical diffusion
- Anything else?

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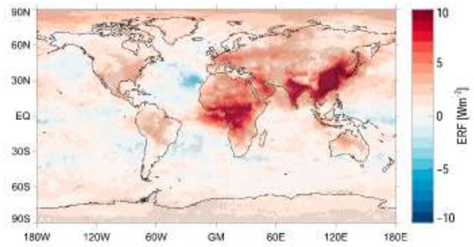
Black carbon aerosol is unique as it strongly absorbs solar radiation

- Strong regional impacts on radiative energy balance and precipitation, but these are quite sensitive to altitude of the BC

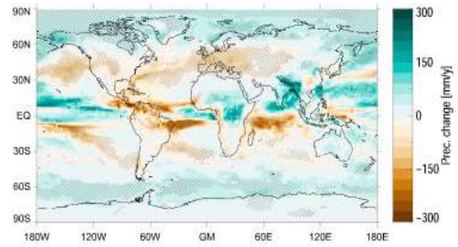
- Absorb of solar radiation by the BC could help to maintain its buoyancy…

- Does this maintain the buoyancy of the plume or even enhance regional-scale ascent in polluted regions?

BC effective radiative forcing



BC induced precipitation change



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Hypothesis

Radiative heating from BC aerosol elevates aerosols higher in the atmosphere

Experiment with HadGEM3-GA7.1

- **Control simulation** **-** No BC absorption
- **Experiment** - BC absorption included

- 20 year runs with HadGEM3-GA7.1 (N96)
- Interactive aerosol radiation, cloud and atmos dynamics
- Emissions and SSTs based on 2014 CMI6 timeslice

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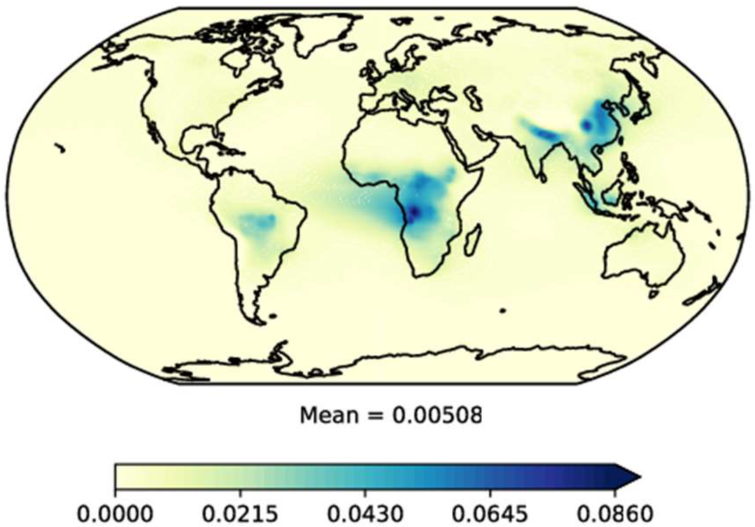
Global distribution of BC in the atmosphere



- The abundance of BC aerosol is indicated here by absorption optical depth (AAOD)
- This corresponding to the amount of sunlight the BC can potentially absorb in the atmosphere.
- The radiative heating rate also depends on solar illumination

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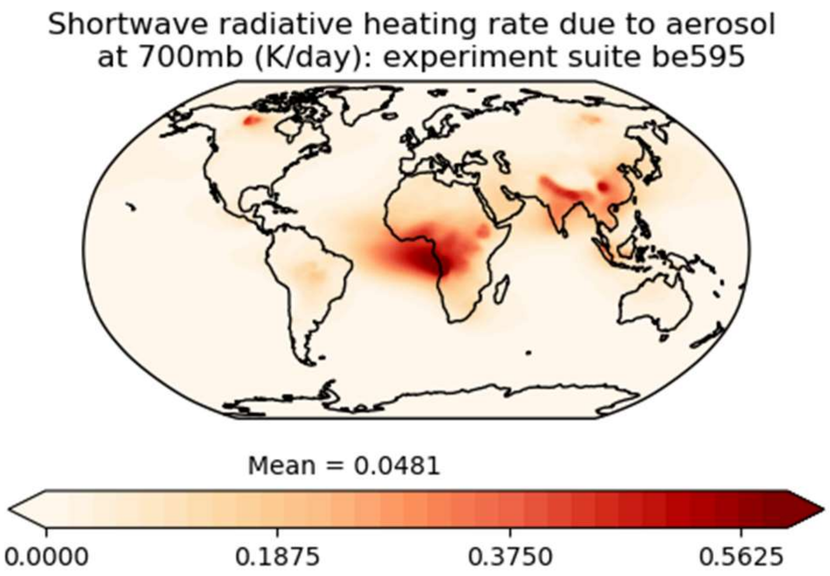
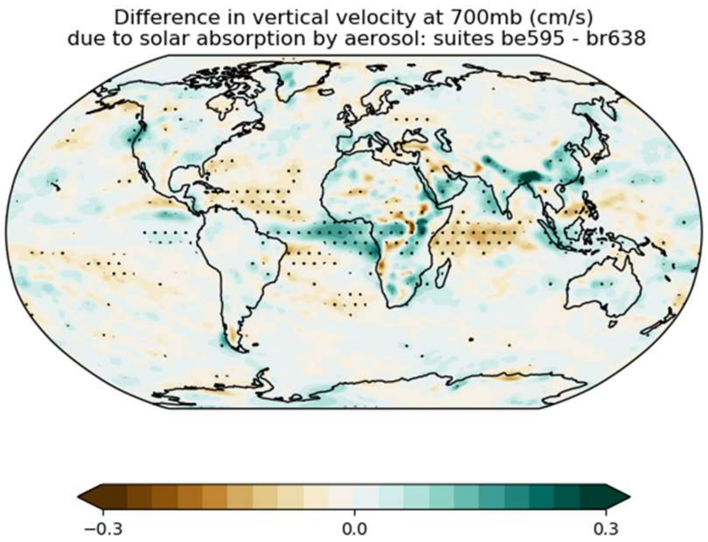
BC radiative heating in the atmosphere



- Plot shows the annual mean from the control simulation
- BC contributed ~90% of the heating
- Remainder was from mineral dust
- Strongest heating at 700mb is from African biomass burning plumes and BC-rich haze over Southern & Eastern Asia

Impact of aerosol absorption on large-scale vertical velocity



- Statistically significant changes in large-scale vertical motion over broad areas (stipples indicate 95% confidence)
- BC heating causes ascent of around 0.2 cm/s (~ 1km in 5 days) in absorbing aerosol layers over tropical Atlantic and Asia
- Compensating descent in Indian ocean and subtropical Atlantic

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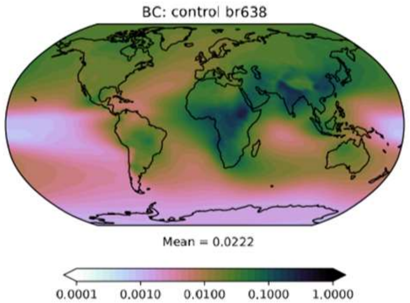
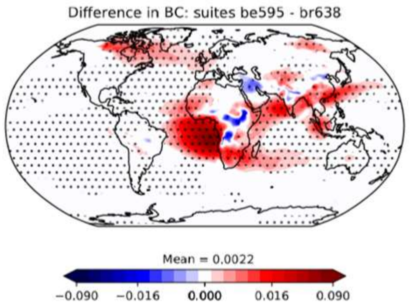
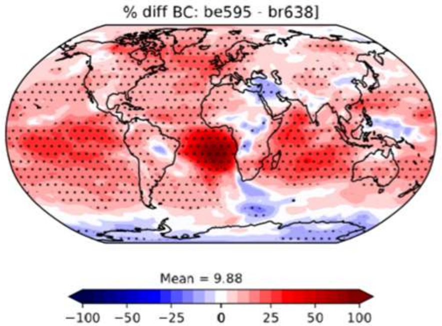
Change in BC mass concentration at 600mb







- BC mass at 600mb is increased almost everywhere
- Biggest absolute and relative increase are Tropical – SE Atlantic
- Strong relative increases over remote oceanic regions
- Some reductions over central Africa, middle East, and Antarctic.
- Relative increases at 300mb were much more uniformly spread (not shown)

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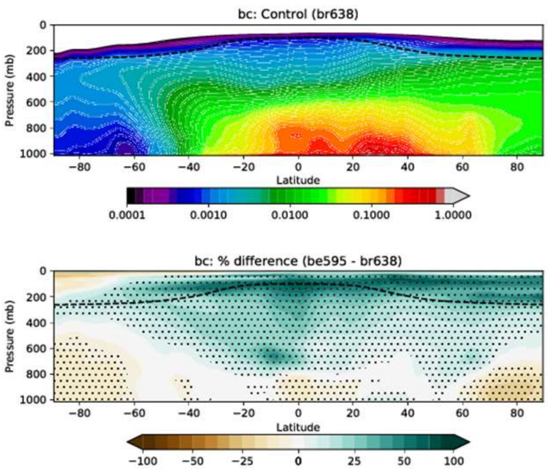
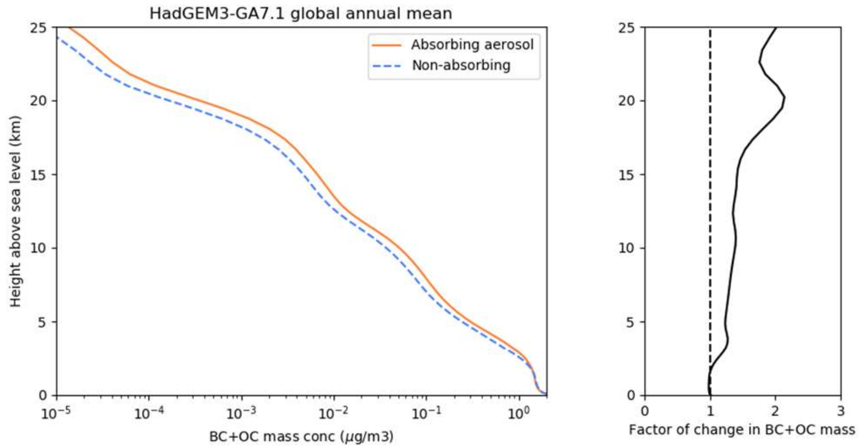
Increases of BC and OC in the upper troposphere & stratosphere

BC mass concentration (ug/m^3)





Note the logarithmic scale →

- Concentrations generally increase above 800mb
- Large relative increases in the stratosphere

- Absolute concentrations are lower higher up but large relative increases in UTLS could be important for ice-phase microphysics and heterogeneous chemistry

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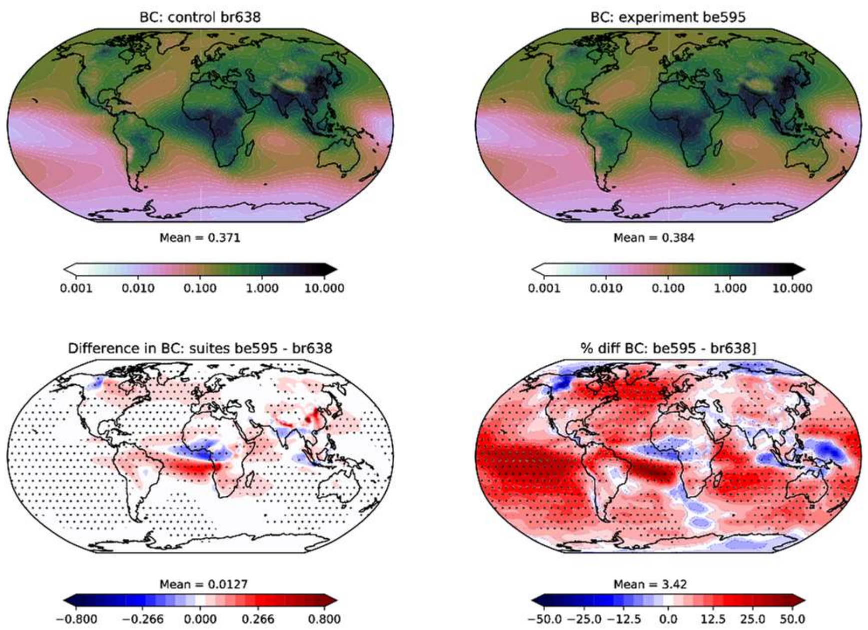
Does absorption increase BC mass loading?

BC column-integrated mass loading (mg/m^2)



- Column mass up by 4%
- North-South shift from West Africa to Tropical Atlantic
- Strongest relative increases over remote oceans

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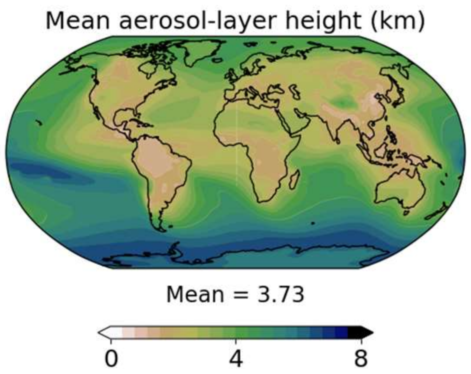
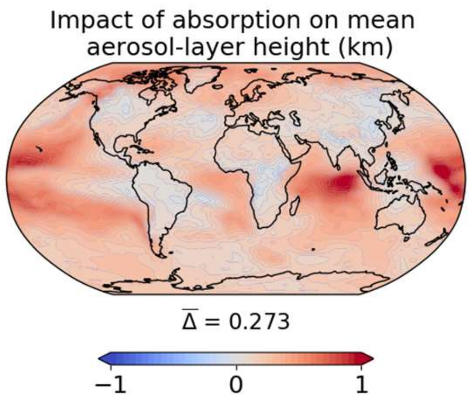
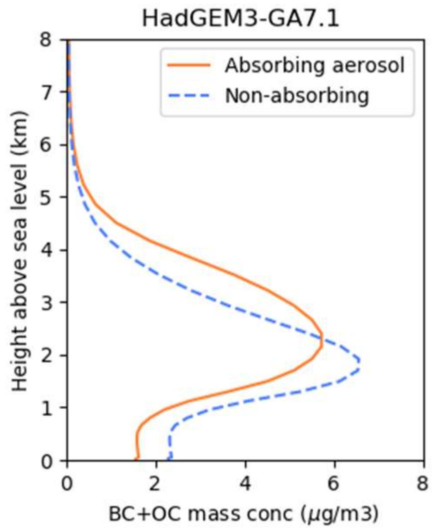
Elevation of aerosol layers due to SW heating

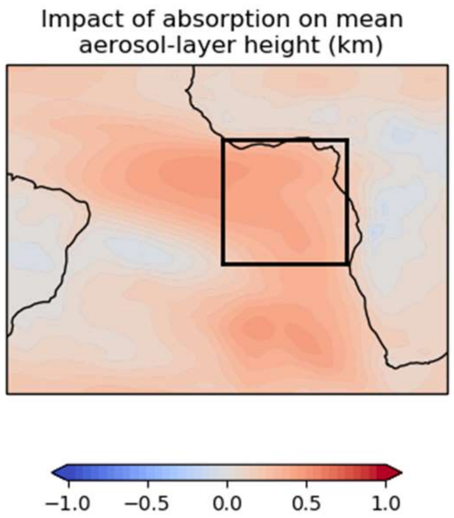




- Absorption by BC helps to raise carbonaceous aerosol (BC + OC) out of the BL into the free-troposphere (>2km)
- Carbonaceous aerosol layers rise by on average ~270m
- Biggest gains occur in remote oceanic regions affected by long-range transport of elevated aerosol layers
- Aerosol may continues to rise with time the further it is transported

Elevation of biomass burning aerosol over SE Atlantic





- Results are for Aug-Sept when biomass burning emissions peak
- BC heating elevates the biomass burning aerosol ~1km
- This will delay or prevent the mixing of aerosol into the stratocumulus clouds of the marine BL.
- Potentially important consequences for aerosol-cloud and aerosol-radiation interactions in this region!

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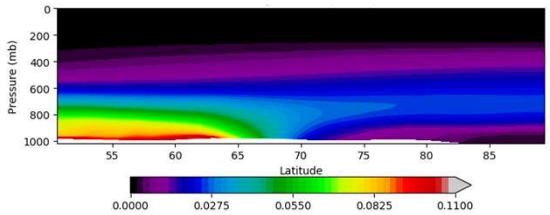
Cross section of BC mass over Arctic during JJA

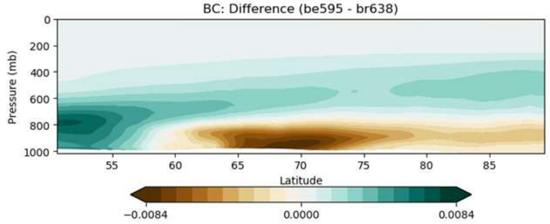
With absorption included:

- More BC ascends into the FT and slides up the polar front.
- Elevated layers are higher over Arctic and less makes it into the Arctic at low levels.

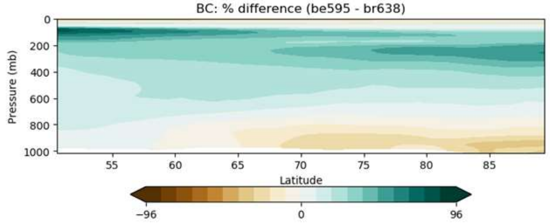
Control run



Absolute difference



Relative difference



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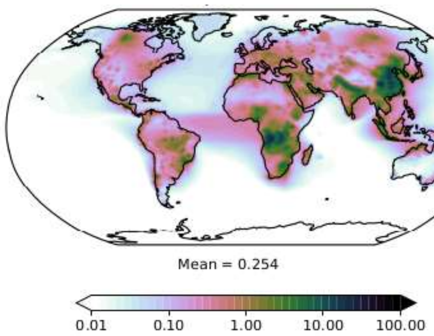
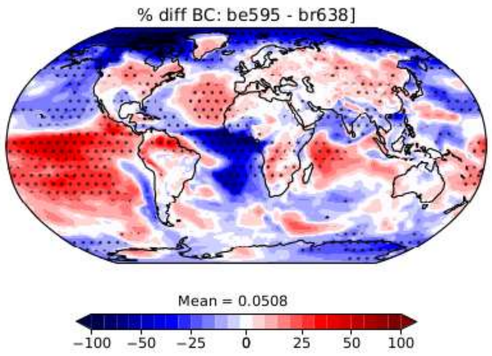
Surface BC concentration during JJA





- Decreases in Arctic due to more lofting of mid-latitude sources
- Decreases over tropical-south Atlantic due to elevation of BB layer
- More surface BC over NH subtropical Atlantic and tropical-southern Pacific and Indian Ocean, presumably due to compensating descent and/or longer range transport into those regions.

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Conclusions

- Accurate representation of BC absorption / radiative heating is important for the elevation and long-range transport of the BC and other co-emitted aerosols
- Biases in the vertical distribution of biomass burning have often attributed to models failing to lift smoke at its source (plume rise), but errors in aerosol absorption properties could be just as important.
- This is potentially important for capturing the overlap between aerosol and cloud and subsequent aerosol-cloud interactions / aerosol forcing

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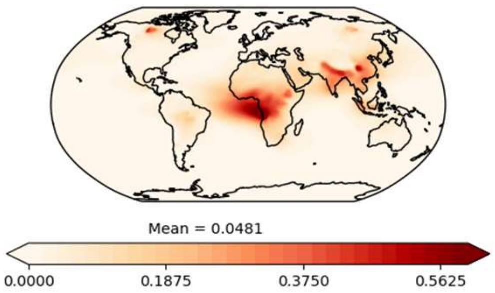
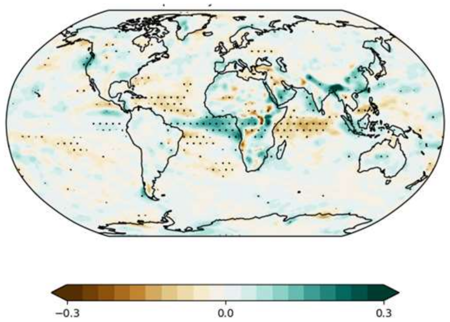
Single slide summary…

Self raising aerosols

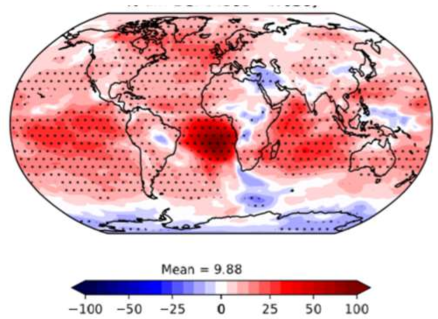
BC radiative heating (700mb)



ΔW at 700mb

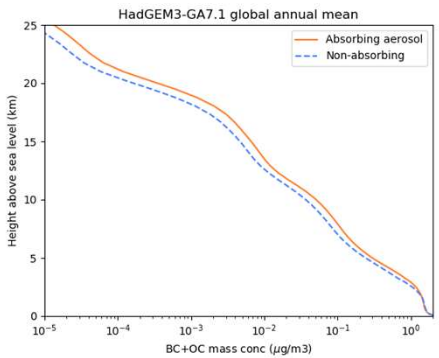


ΔBC mass (600mb)



BC heating enhances uplift raising aerosol concentration in the mid troposphere and above.

Results from HadGEM3-GA7.1 experiments with BC absorption ON/OFF. Results are annual mean differences from 20 year runs.



BC mass concentration (ug/m^3)