Stratospheric Smoke Injections from the 2019/20 Australian Bushfires: Impacts on Radiation, Global Circulation and Adjustments

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Australia’s ’black summer’ bushfires

Exceptional continental-scale drought caused **huge wildfires in SE Australia** in **December 2019 and January 2020**

(Image credit: CCN)

Widespread, devastating fires and massive smoke plumes over SE-Australia

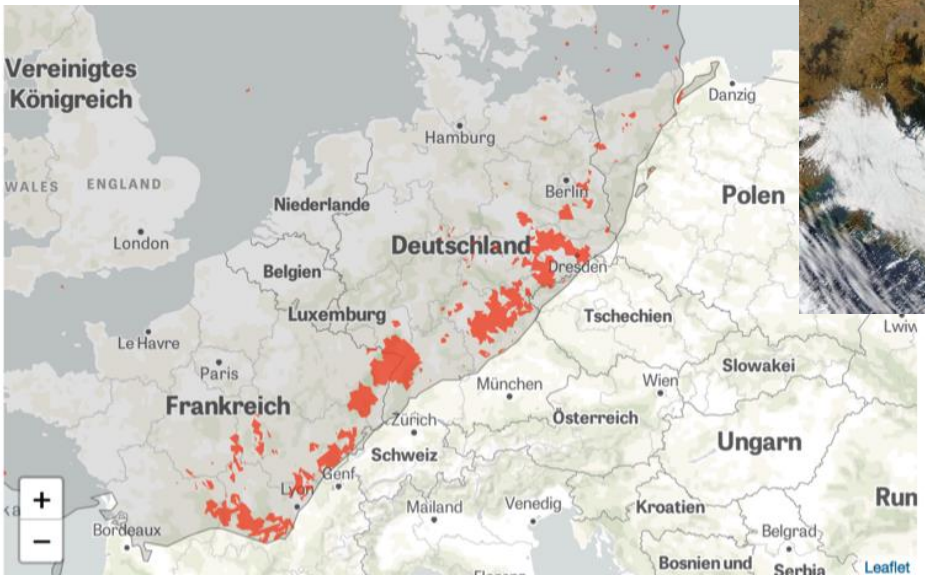
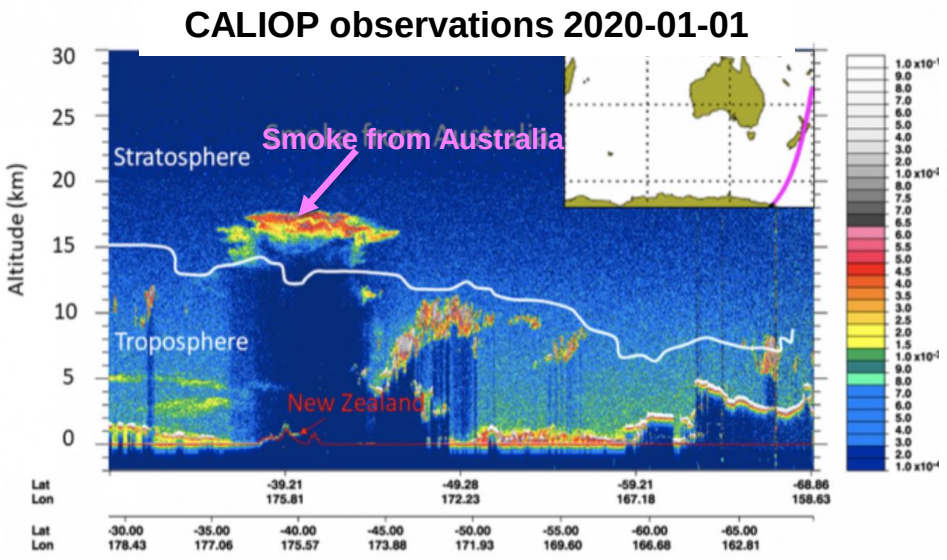


Image credit: Die Zeit www.zeit.de/wissen/umwelt/2020-03/klimawandel-auswirkungen-braende-australien-waldbraende-folgen-erderwaermung

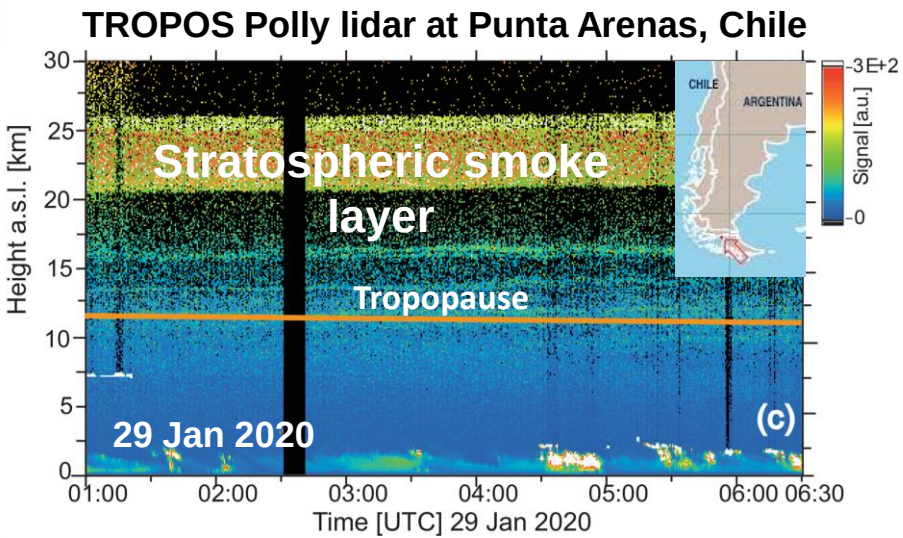
(Image credit: NASA/EOSDIS/LANCE/GIBS/Worldview/Joshua Stevens)

MODIS Aqua satellite Jan 4, 2020

Pyro-convection and vertical smoke transport



CALIOP attenuated backscatter, 1/1/2020: Smoke plume above 15 km
(NASA Disasters Program, JP Vernier NIA/NASA LARC)

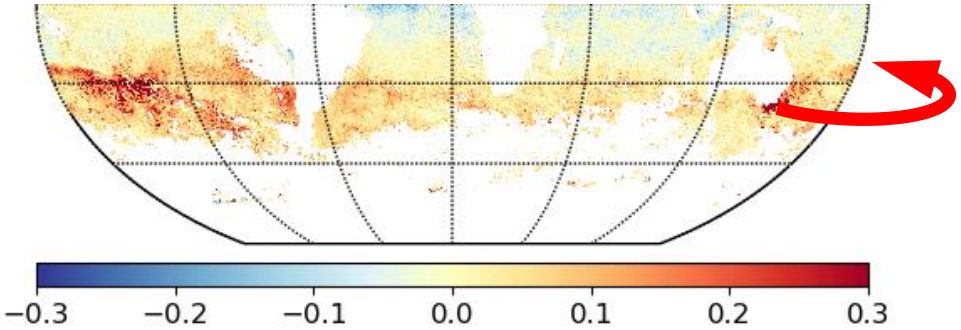


Ohneiser et al, ACP (2020)

- Deep pyro-convective events (pyroCbs) carried the wildfire smoke directly into the stratosphere *(Ohneiser et al, 2020, Kablick et al, 2020).*
- 0.3–2.1 ± 1.1 Tg *smoke aerosol injected into the stratosphere* *(Khaykin et al., 2020, Peterson et al., 2021)*

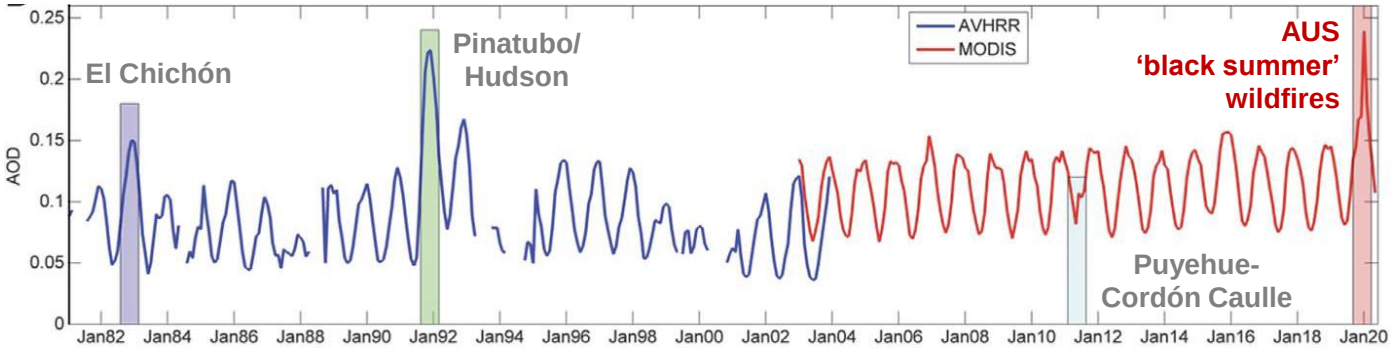
Impact on southern-hemisphere aerosol

AVHRR satellite: AOD anomaly Jan 2020 relative to 1981 – 2019



- Eastward smoke transport across southern mid and high latitudes within days.
- Black summer caused surface dimming comparable to a large volcanic eruption.

Zonal mean AOD over oceans averaged over 20°S – 70°S



Koren et al, Sci. (2021)

Global aerosol-climate simulations

HAMMOZ
AEROSOL & ATMOSPHERIC CHEMISTRY MODULES FOR ECHAM

- Aerosol-climate model ECHAM6.3-HAM2.1 (Tegen et al., 2019, GMD)
- T63-L47 grid, prescribed SST, nudged ERA5
- Modelled period: 01/2000 – 03/2020
- Sensitivity studies: 10/2019 – 03/2020
- Daily fire emissions from GFAS (Kaiser et a., 2012)
- Plus free-running ensemble of 36 members
  (perturbed upward increase in stratospheric horizontal diffusion)

Heinold et al., ACP, 2022

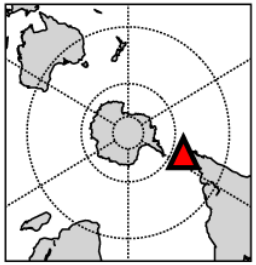
Senf et al., ACP, 2023

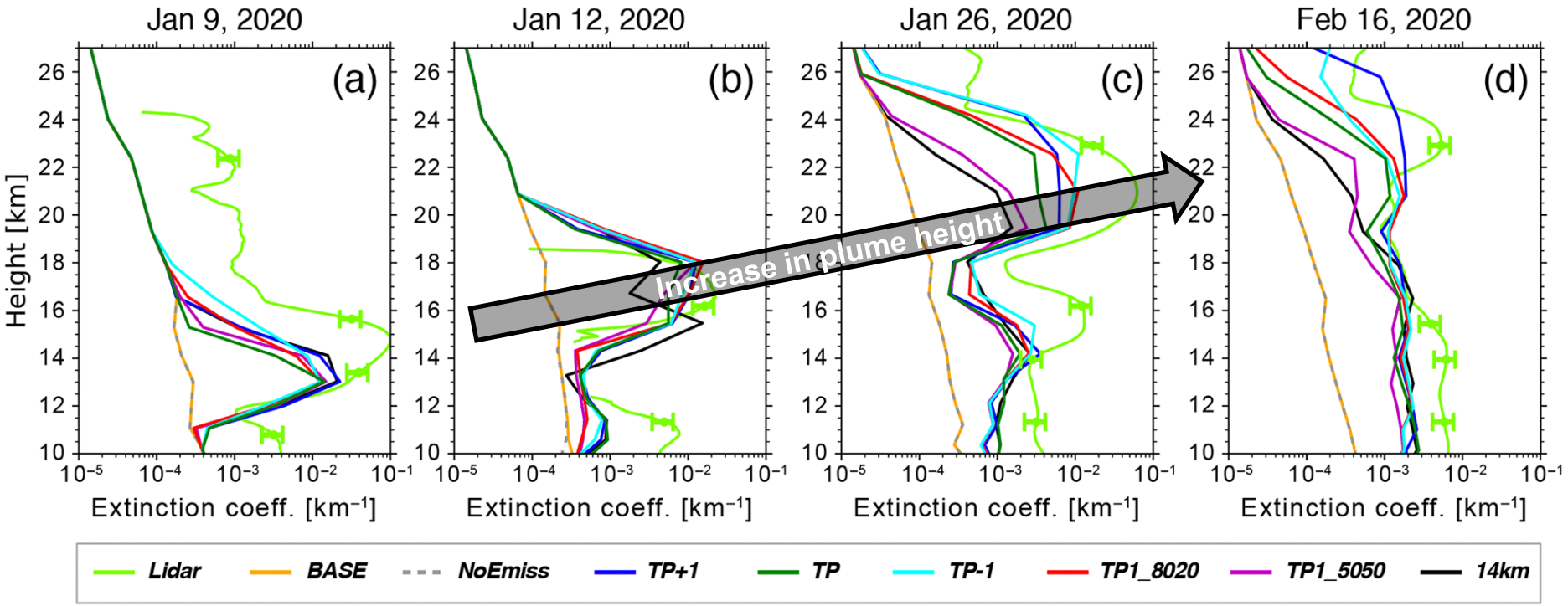
Sensitivity runs – Australian fire season 2019/2020

Scenario	Description
BASE	Standard emission height as prescribed in the ECHAM-HAM model for wildfires (75 % in PBL, 17 % in the first layer and 8 % in the second layer above PBL)
NoEmiss	Wildfire smoke emission set to zero for the pyroCb days: 29–31 December 2019 and 4 January 2020 in south-eastern Australia
TP+1	Wildfire smoke emission from southeastern Australia injected into the model layer above the tropopause for the pyroCb days
TP	As *TP+1*, but smoke injection into the model layer containing the tropopause
TP−1	As *TP+1*, but smoke injection into the model layer below the tropopause
TP1_8020	As *TP+1*, but only 80 % of the emitted smoke injected above the tropopause and 20 % distributed between tropopause level and surface
TP1_5050	As *TP+1*, but only 50 % of the emitted smoke injected above the tropopause and 50 % distributed between tropopause level and surface
14km	Wildfire smoke emission from southeastern Australia injected into the model layer around 14 km height for the pyroCb days as suggested from satellite lidar observations

Lidar observations vs model results

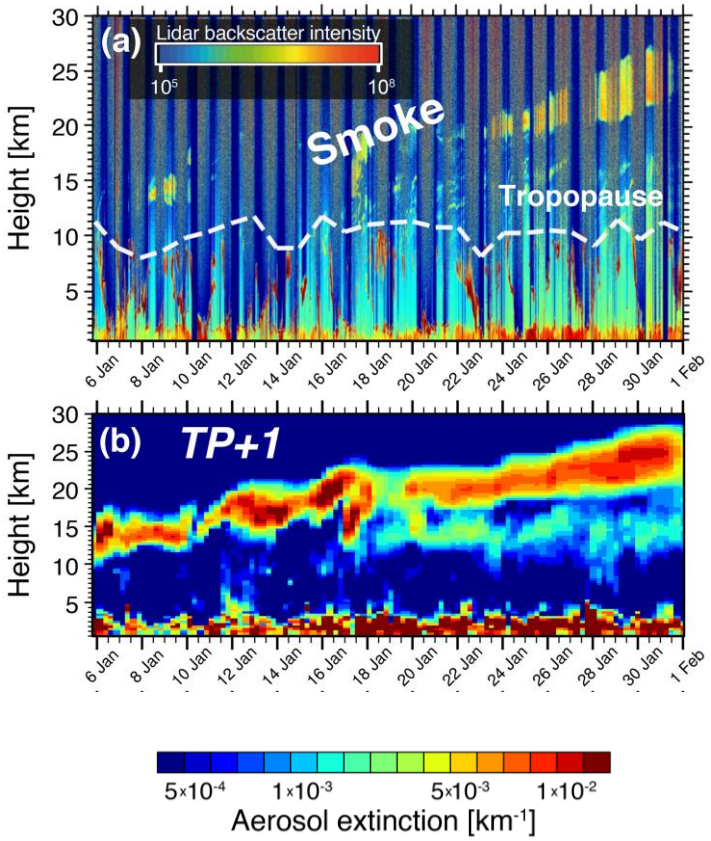
@ Punta Arenas, Chile (53.14°S, 70.89°W)

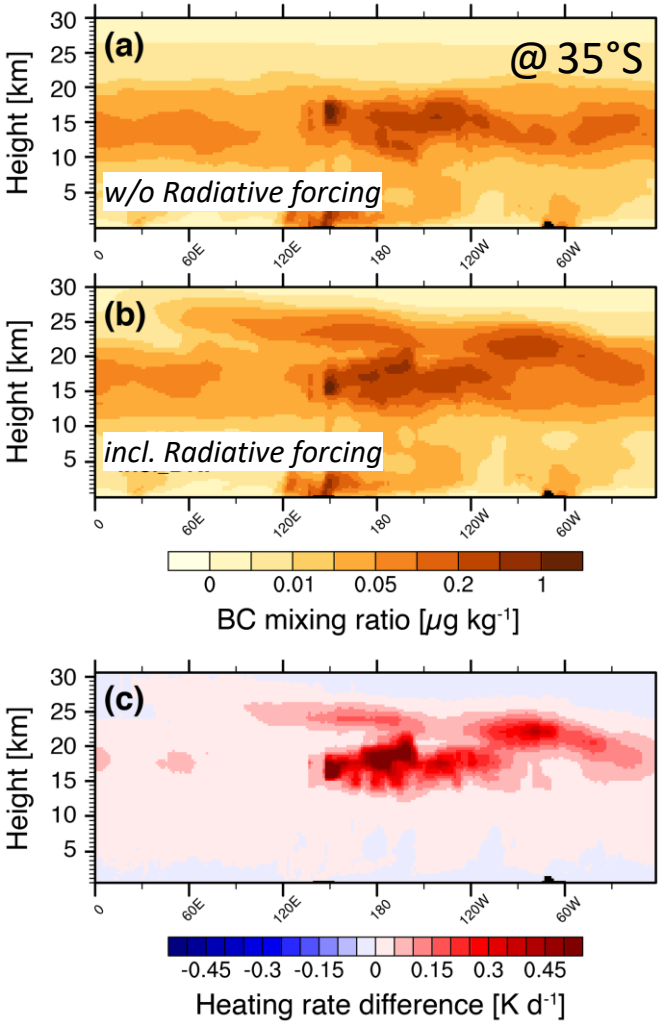




Heinold et al., ACP, 2022

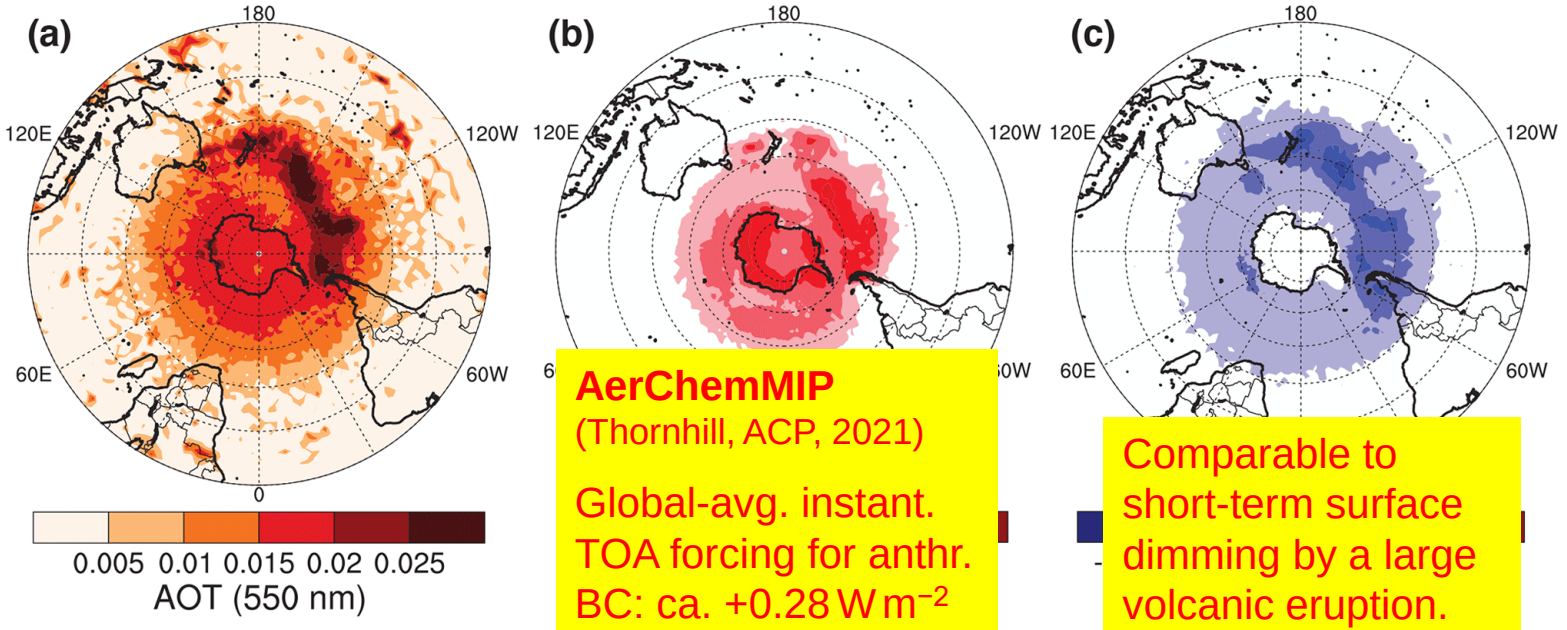
Radiative self-lofting





Instantaneous solar radiative forcing

Heinold et al., ACP, 2022



AerChemMIP
(Thornhill, ACP, 2021)

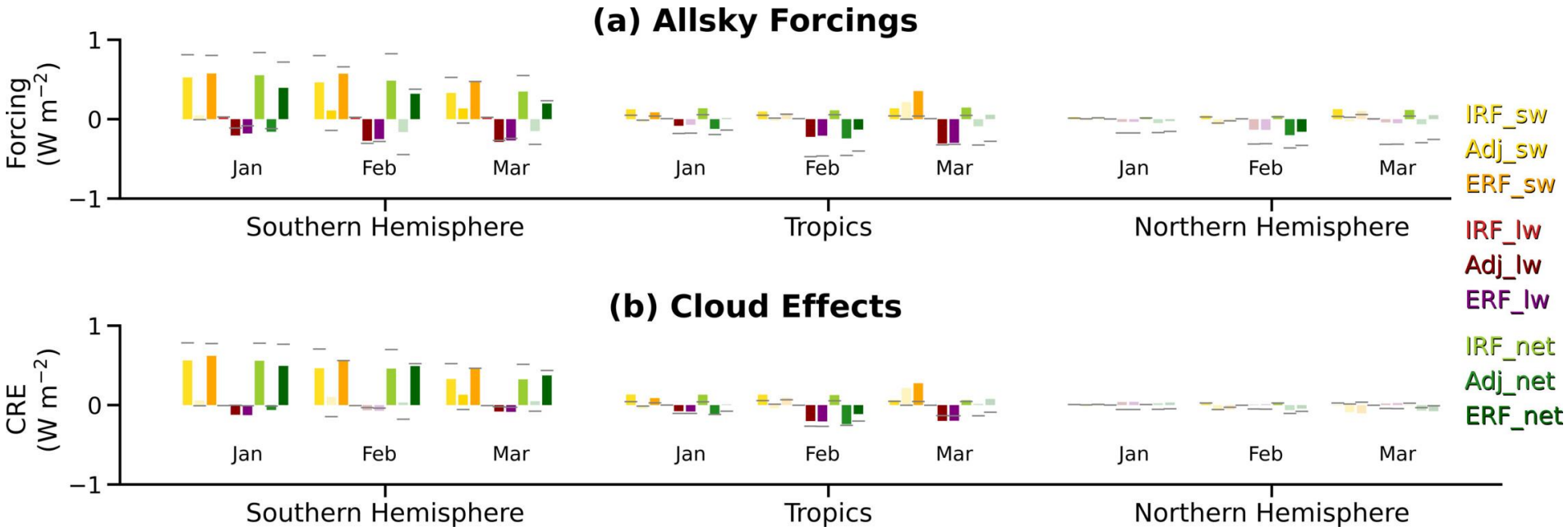
Global-avg. instant. TOA forcing for anthr. BC: ca. +0.28 W m^{-2}

Comparable to short-term surface dimming by a large volcanic eruption.

	TOA all sky	TOA clear sky	BOA all sky	BOA clear sky
JFM Average	+0.37 to +0.50	−0.02 to +0.02	−0.42 to −0.50	−0.68 to −0.81

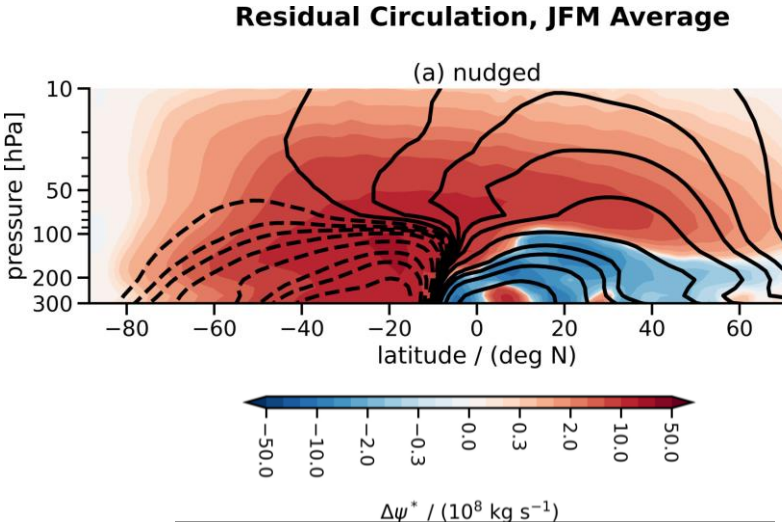
Effective radiative forcing (ERF) of smoke aerosol

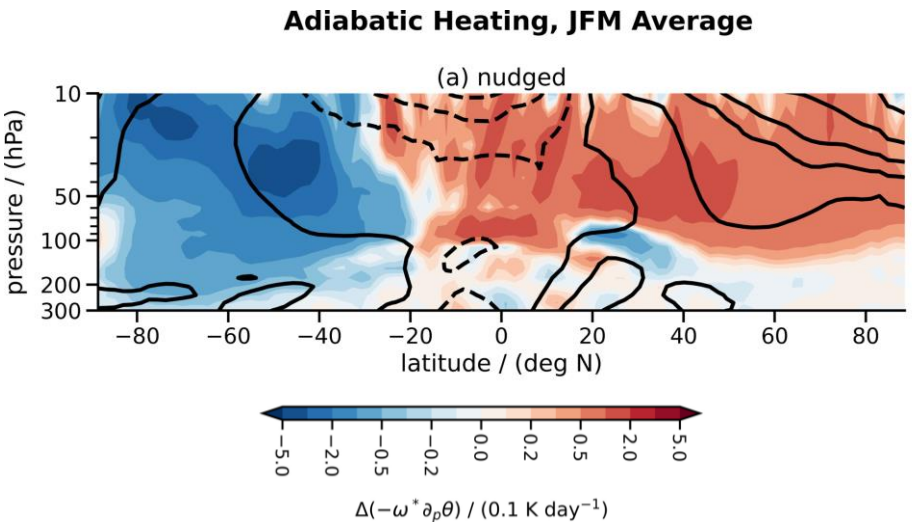
Senf et al., ACP, 2023



- Clouds have a significant impact on ERF at TOA turning shortwave ERF to positive values in contrast to previously reported clear-sky values.
- BUT: Atmospheric adjustments nearly balance the initially positive instant. forcing.

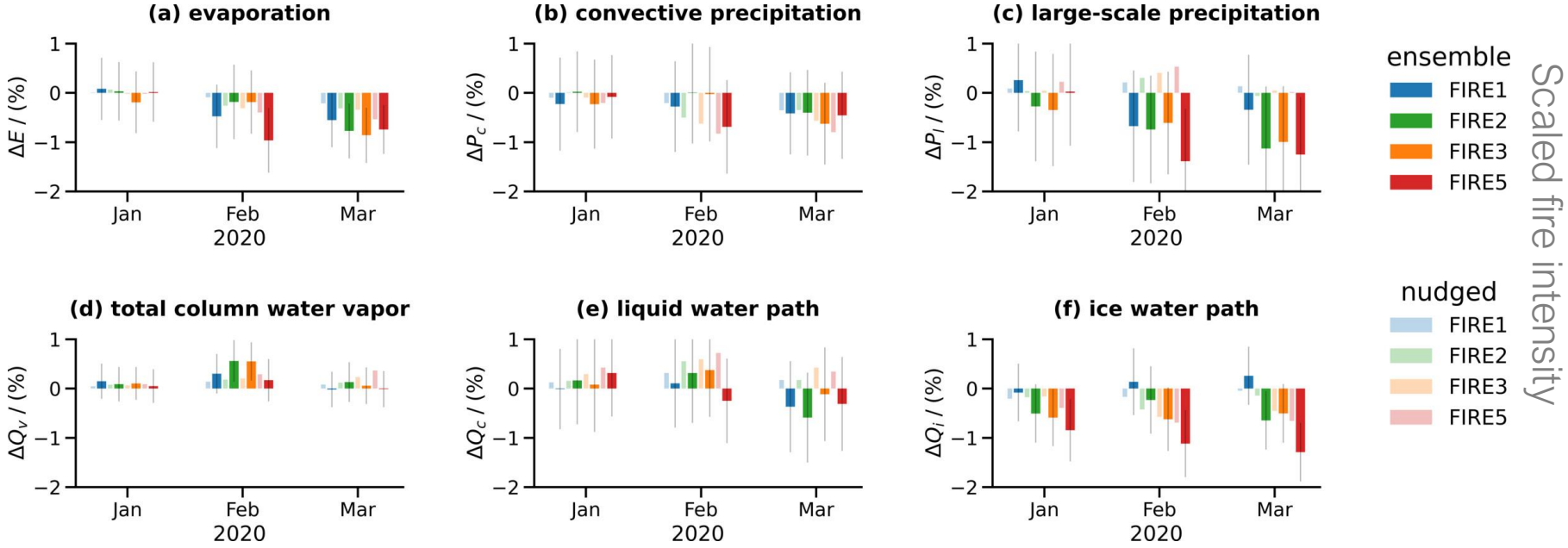
Impact on stratospheric circulation





- The smoke causes a local / non-local warming, partly compensated by longwave cooling.
- Stratospheric adjustments lead to changes in global circulation:
  - **SH**: less adiabatic heating by the residual circulation is required to compensate radiative cooling → SH circulation branch is weakened.
  - **NH**: circulation branch is slightly strengthened → energy from the initially localized smoke-induced shortwave heating is redistributed to the tropics and NH.

Impact on global hydrological cycle



- Cirrus is reduced by up to 1% due to the warming by Australian smoke because of a reduction in the upper tropospheric relative humidity.
- Resulting tropospheric adjustments impact the hydrological cycle with subsequently reduced amounts of ice water path, surface precipitation and evaporation.

Wrapping up

2019-2020 Australian wildfires

- The ‘Black Summer’ fires considerably perturbed the SH aerosol in the upper troposphere / stratosphere.
- Single extreme wildfire events can have global impacts influencing the interplay of tropospheric and stratospheric cycles in complex ways.
- With an expected increase in extreme wildfires, high-altitude fire plumes need to be adequately considered in climate projections.

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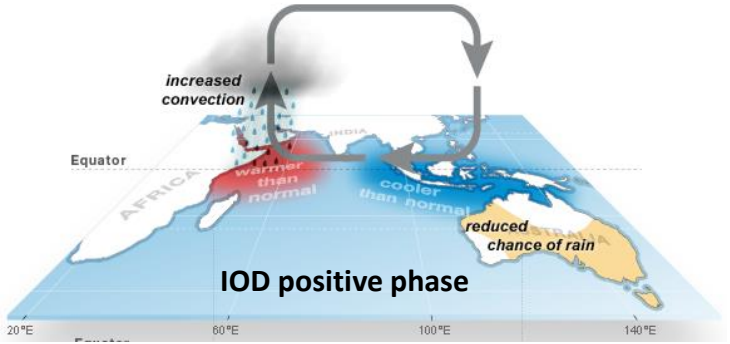
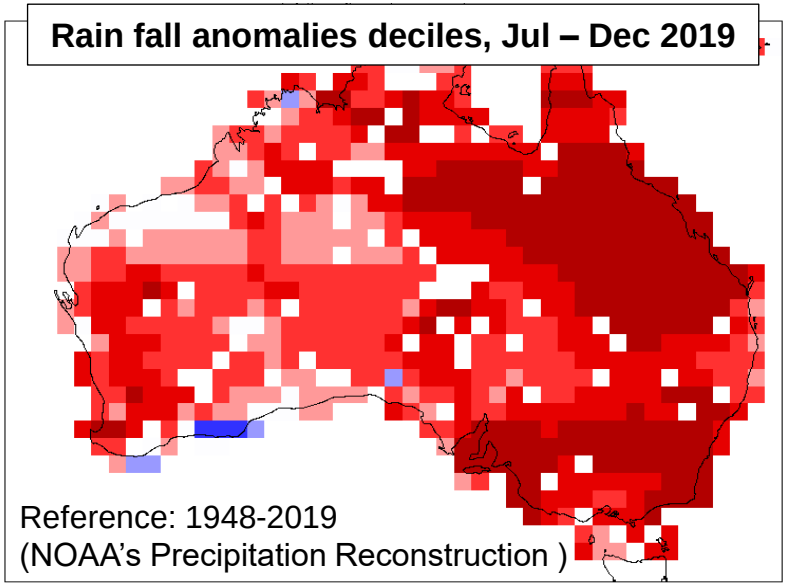
Indian Ocean Dipole (IOD) – El Niño (ENSO) interactions

Positive phases of IOD and ENSO in 2019

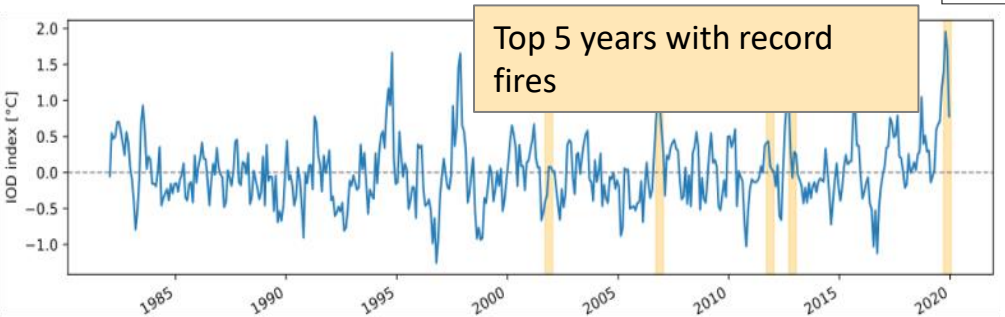
→ exceptional drought in central and eastern AUS



Rain fall anomalies deciles, Jul – Dec 2019

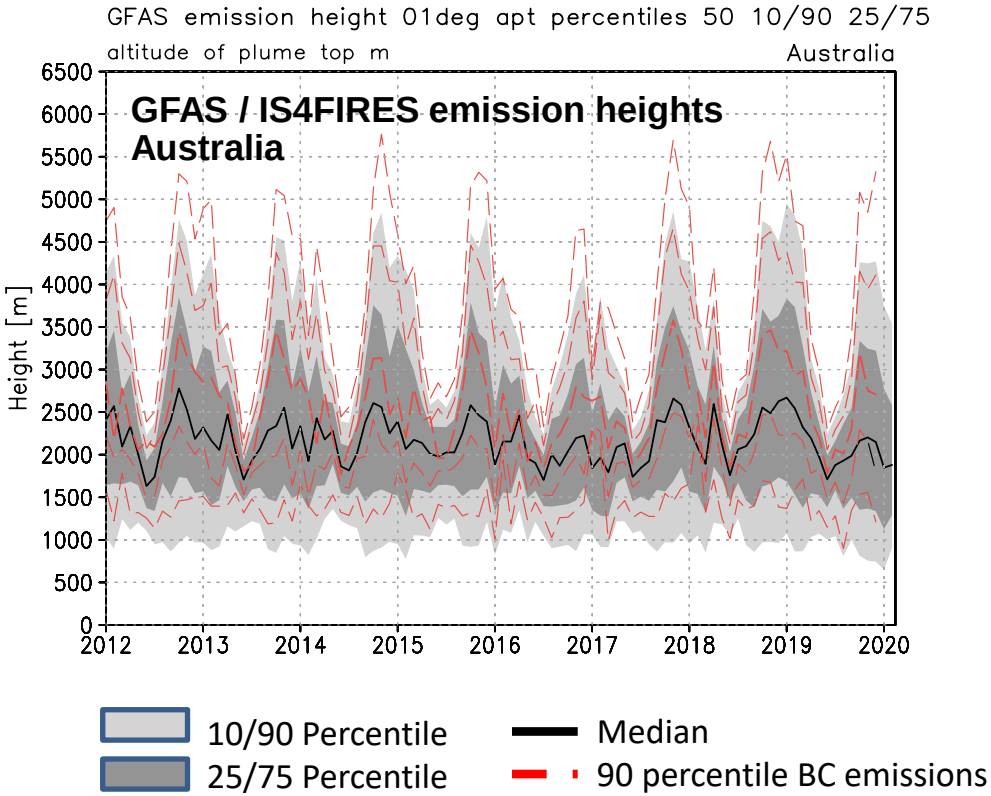


IOD time series for 1982 – 2019



Australian rainfall much lower than average in the months before wildfire season

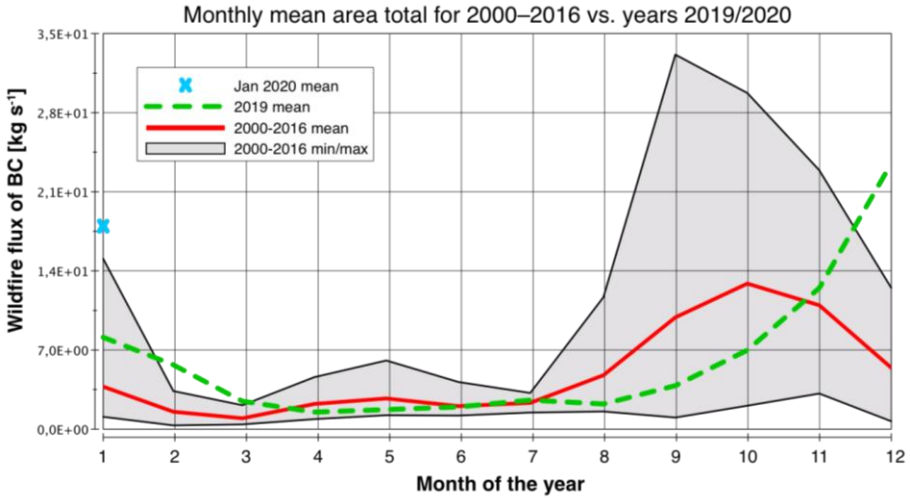
Challenge – pyro-convective fire injection heights

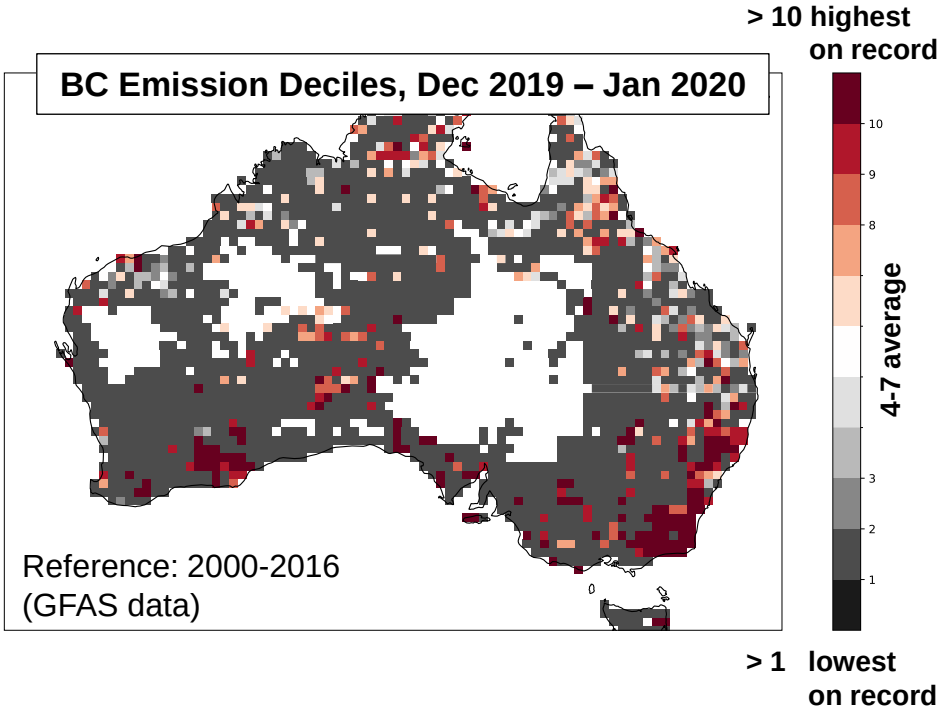


Global Fire Assimilation System (GFAS)

- assimilates fire radiative power observations from satellite obs. -> daily estimates of emissions (BC, OC) from biomass burning
- Maximum injection height in Australia for BC emissions at 90th percentile: 10.5 km

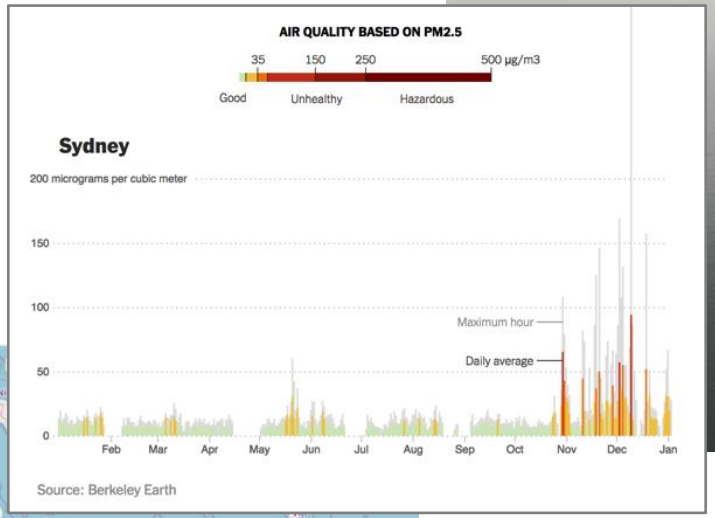
2019-2020 Australian wildfire emissions

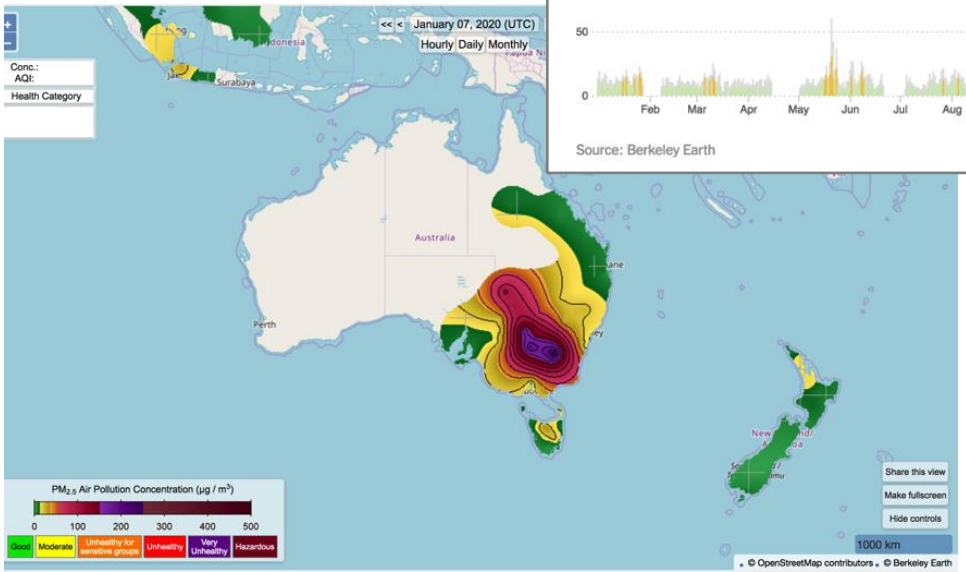


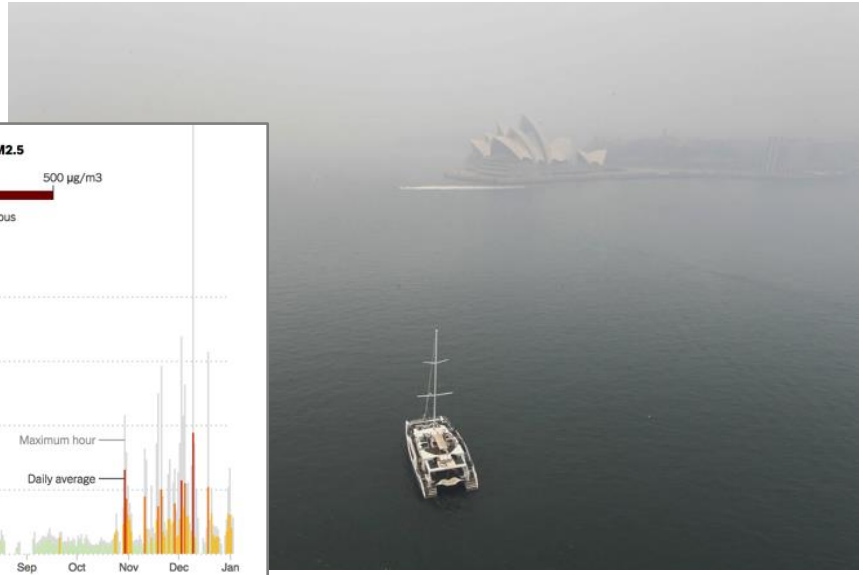


> 1.5 higher fire emissions and an area burnt twice as large (> 18m ha) than previous record fires.

Impact on ‘local’ air quality



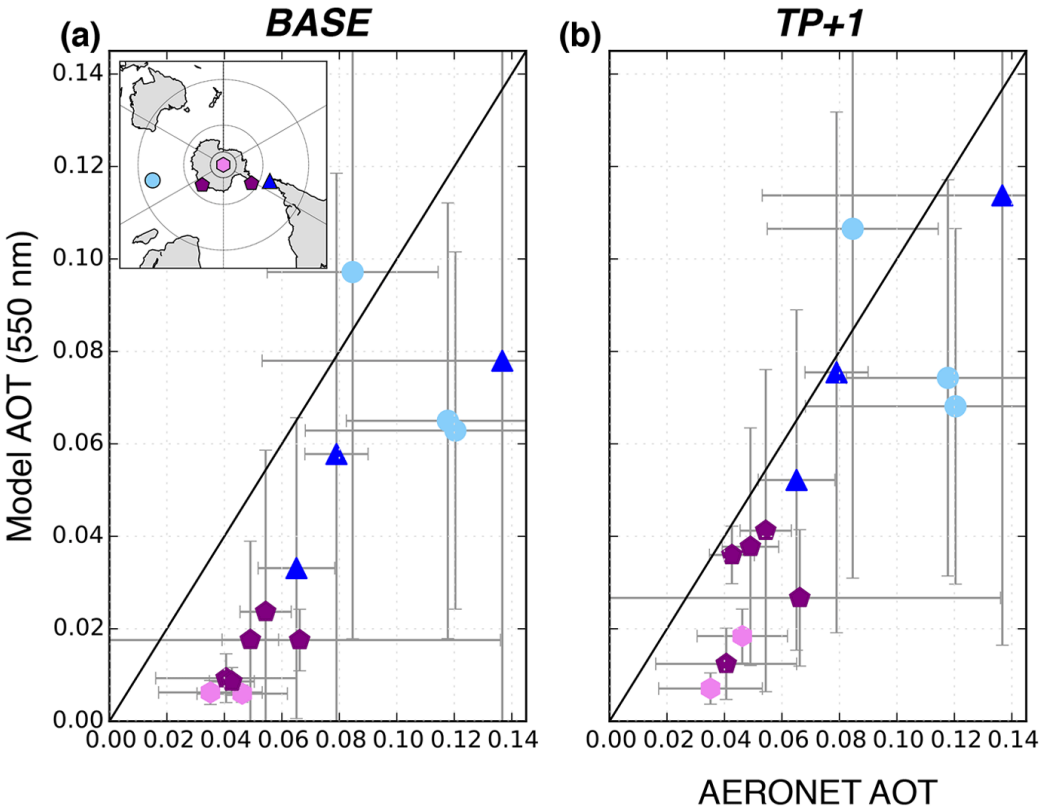


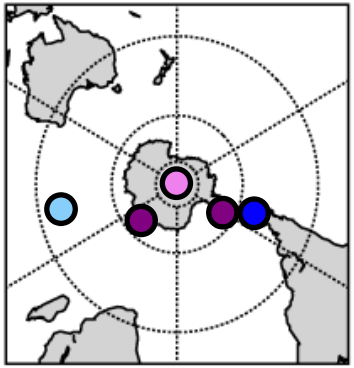


(Image credit: James D. Morgan/Getty Images)

Sydney Opera house, December 2019

AERONET observations vs model results





- Antarctic Stations (Marambio, Vechernaya Hill)
- South Pole
- Amsterdam Island
- Punta Arenas

Jan-Mar 2020

Heinold et al., ACP, 2022

Radiative flux perturbations (200 hPa – TOA)

Senf et al., ACPD, 2023