Modeling air quality in the Middle East during the 2017 AQABA campaign

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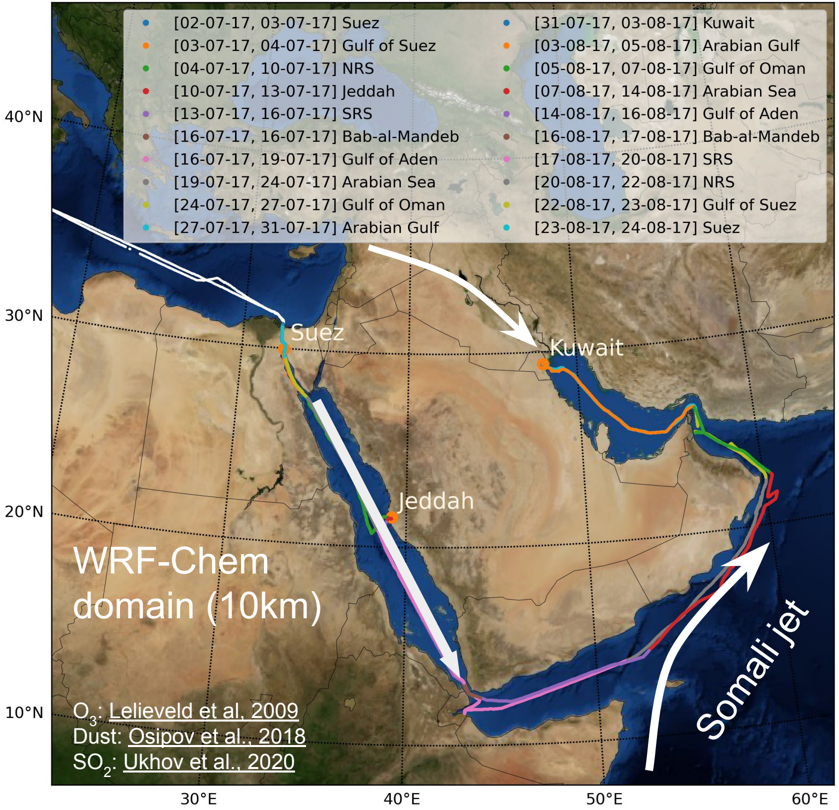
Introduction

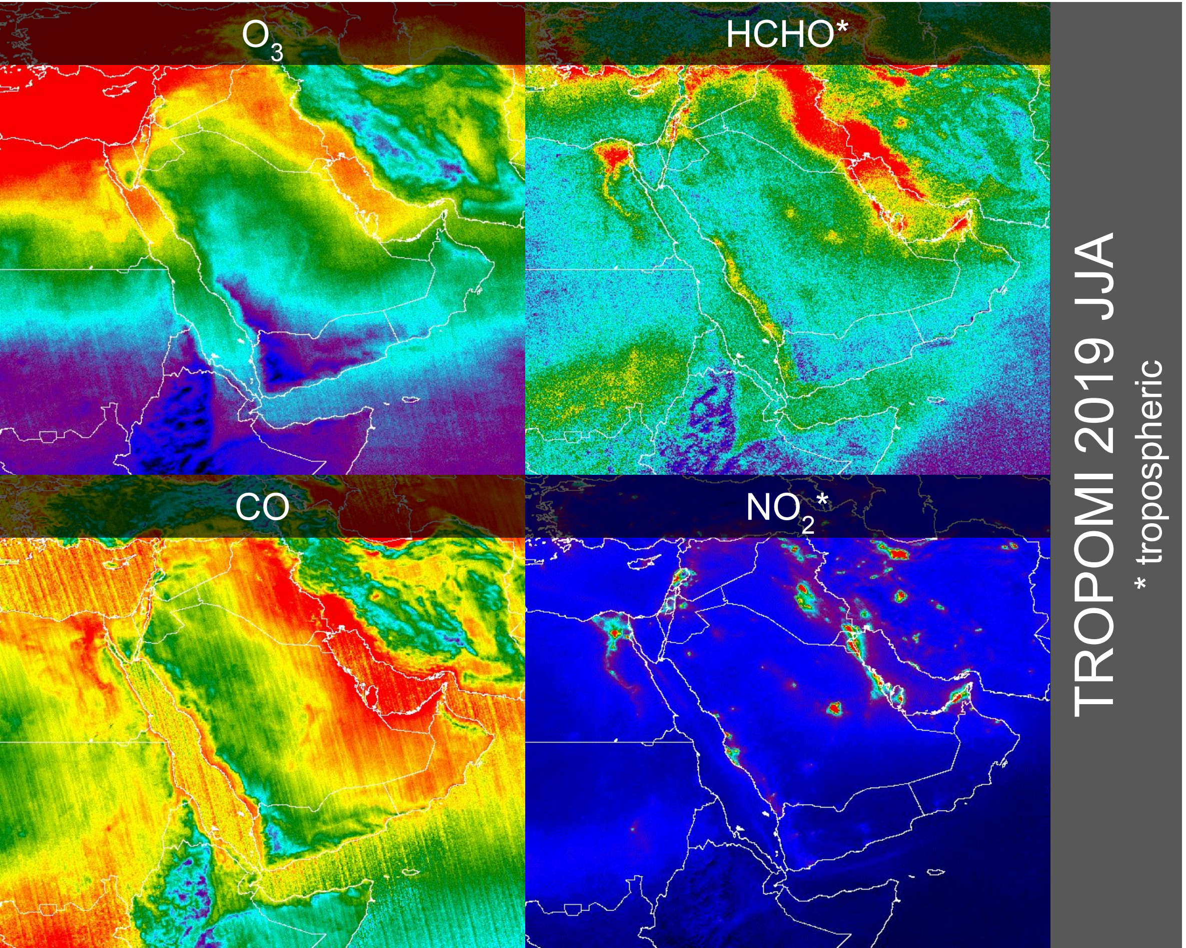
- Vast natural & anthropogenic emissions produce a distinct type of the air pollution in the Middle East (ME)
- The profound anthropogenic influence in ME is evident through the share of the global emissions
- Mineral dust is conventionally assumed to dominate air pollution in the Middle East, often disregarding the uncertain role of human-induced trace gases and aerosols
- Primarily, the lack of observational constraints represents a modeling challenge and hampers our understanding of the ambient air quality in the region.

AQABA 2017

Air Quality and Climate Change in the Arabian BAsin



Ozone chemistry in the Middle East



Auspicious conditions for high ozone:

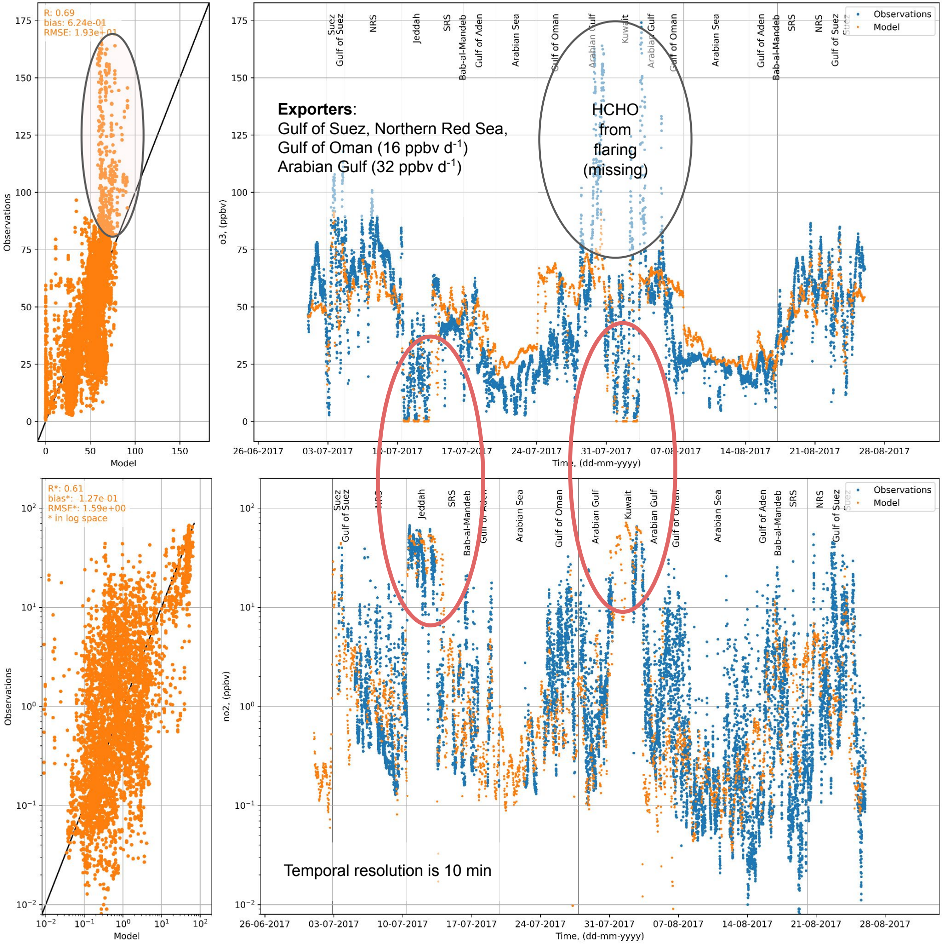
- Stratosphere-troposphere exchange (66% in winter and 25% in summer of the tropospheric column)
- Long-distance transported air pollution from Mediterranean
- Tropics, intense UV and tropospheric photochemistry due to low column O_3 (Brewer-Dobson circulation)
- Strong local ozone formation by indigenous emissions of NOx and reactive hydrocarbons in industrial and urban areas.

Net O_3 production is mostly NOx-limited or happens in the transition regime between NOx and VOC limitation (Mediterranean, northern Red Sea and Gulf of Oman regions) (Tadic et al. 2019)

Main O_3 sinks:

- O_3 photolysis and the subsequent reaction of O(1D) with H_2O (60 %–80 %)
- reaction of O_3 with HO_2, (10 %–30 %)
- reaction of O_3 with OH (10 %–30 %).

Ozone chemistry



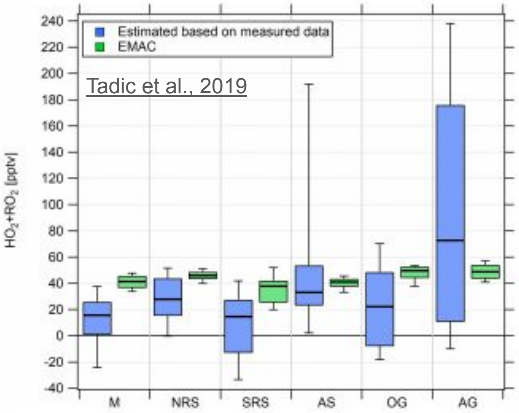


Figure 7. Comparison of box and whiskers plots of the regional estimated noontime ($HO_2 + RO_2$) median based on measured data and simulated ($HO_2 + RO_2$) data for the period from 18 July 2017 onwards.

Ozone titration: Daytime $NO_2 + h\nu \rightarrow NO + O$

$O + O_2 + M \rightarrow O_3 + M$

Nighttime $NO + O_3 \rightarrow NO_2 + O_2$

HCHO is a source of HO_2:

$$HCHO + h\nu \longrightarrow H + HCO (\lambda \leq 330\,nm)$$

$$HCHO + h\nu \longrightarrow H_2 + CO (\lambda \leq 361\,nm)$$

$$H + O_2 + M \longrightarrow HO_2 + M$$

$$HCO + O_2 \longrightarrow HO_2 + CO$$

Long-term exposure to O_3 and NO_2 (JA mean)

Ozone limits

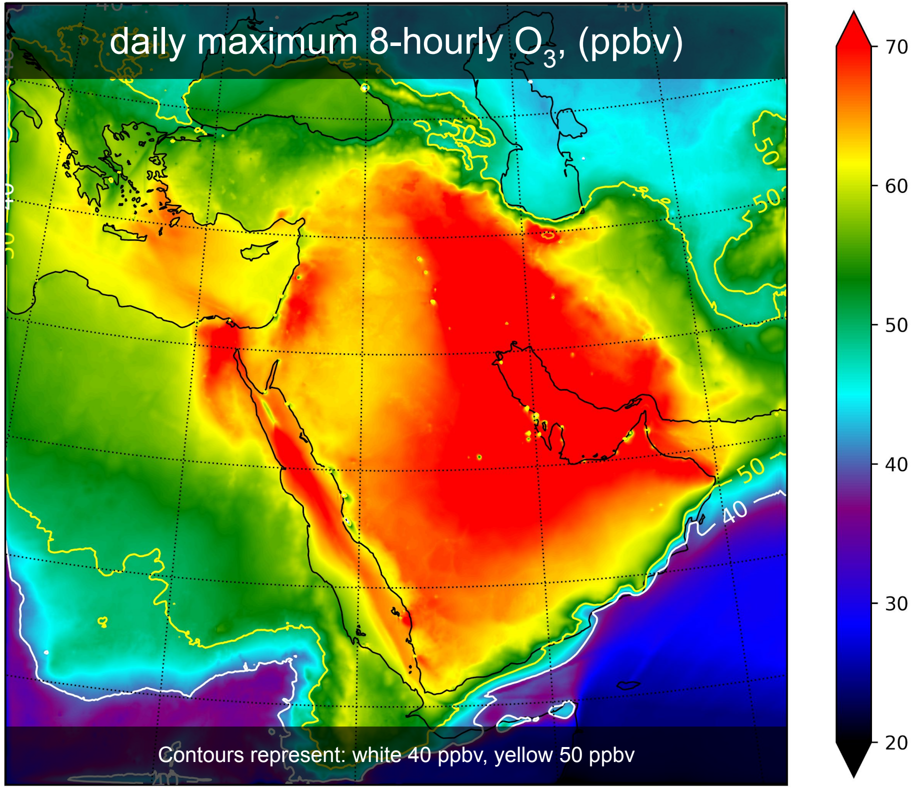
EU phytotoxicity limit: 40 ppbv

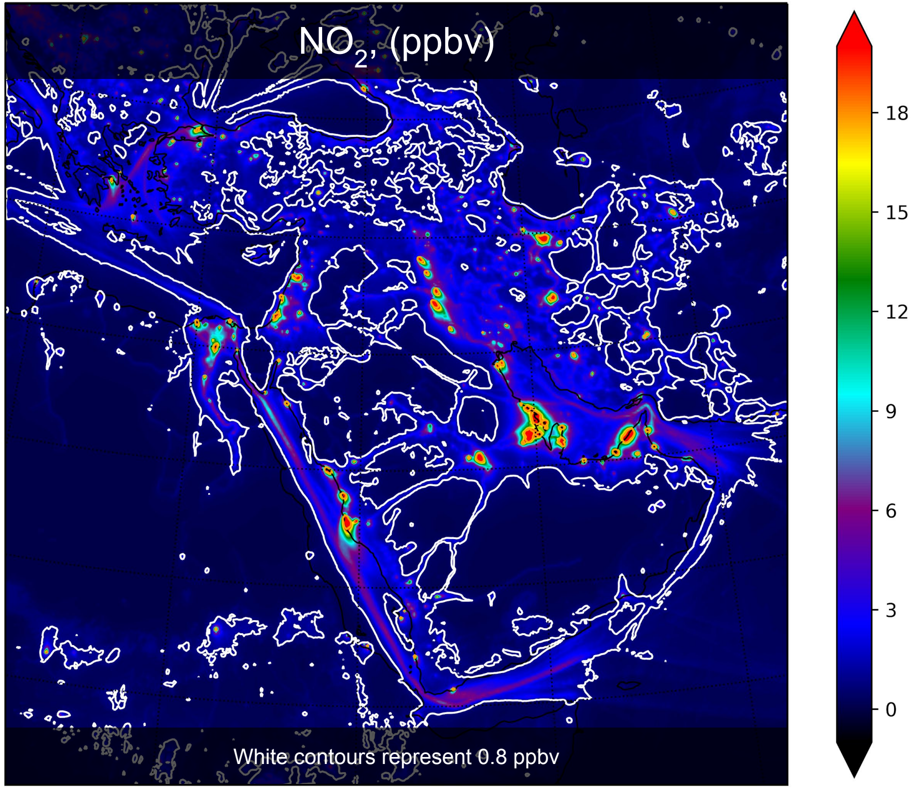
Health protection limit: 50-60 ppbv for 8 hours or ~80 ppbv for 1 hour

NO_2 limits

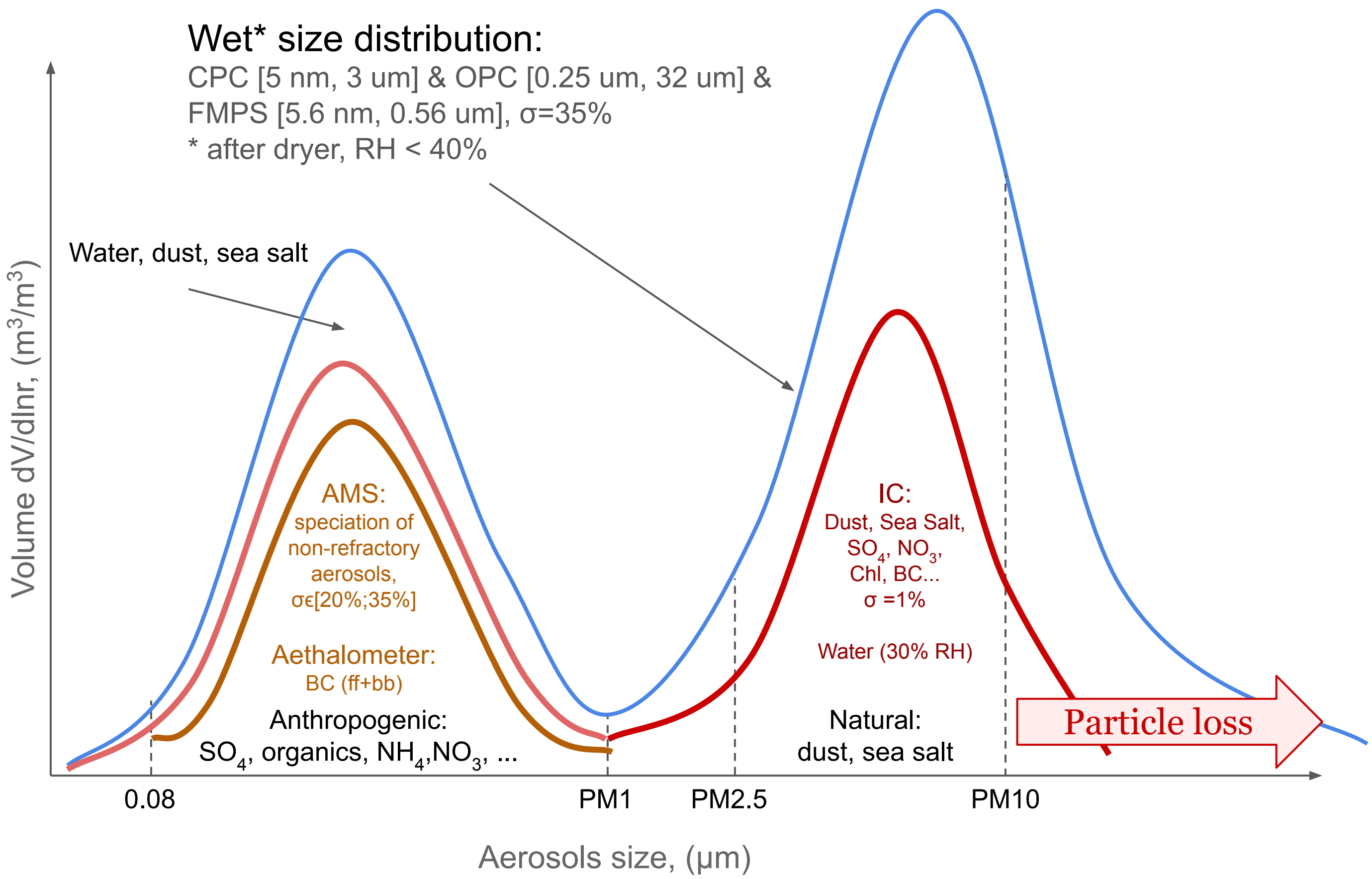
Outdated WHO guideline: 40 ug/m^3 or 21.25 ppbv

New Chowdhury et al., 2021: 0.8 ppbv (WHO adopted this summer)



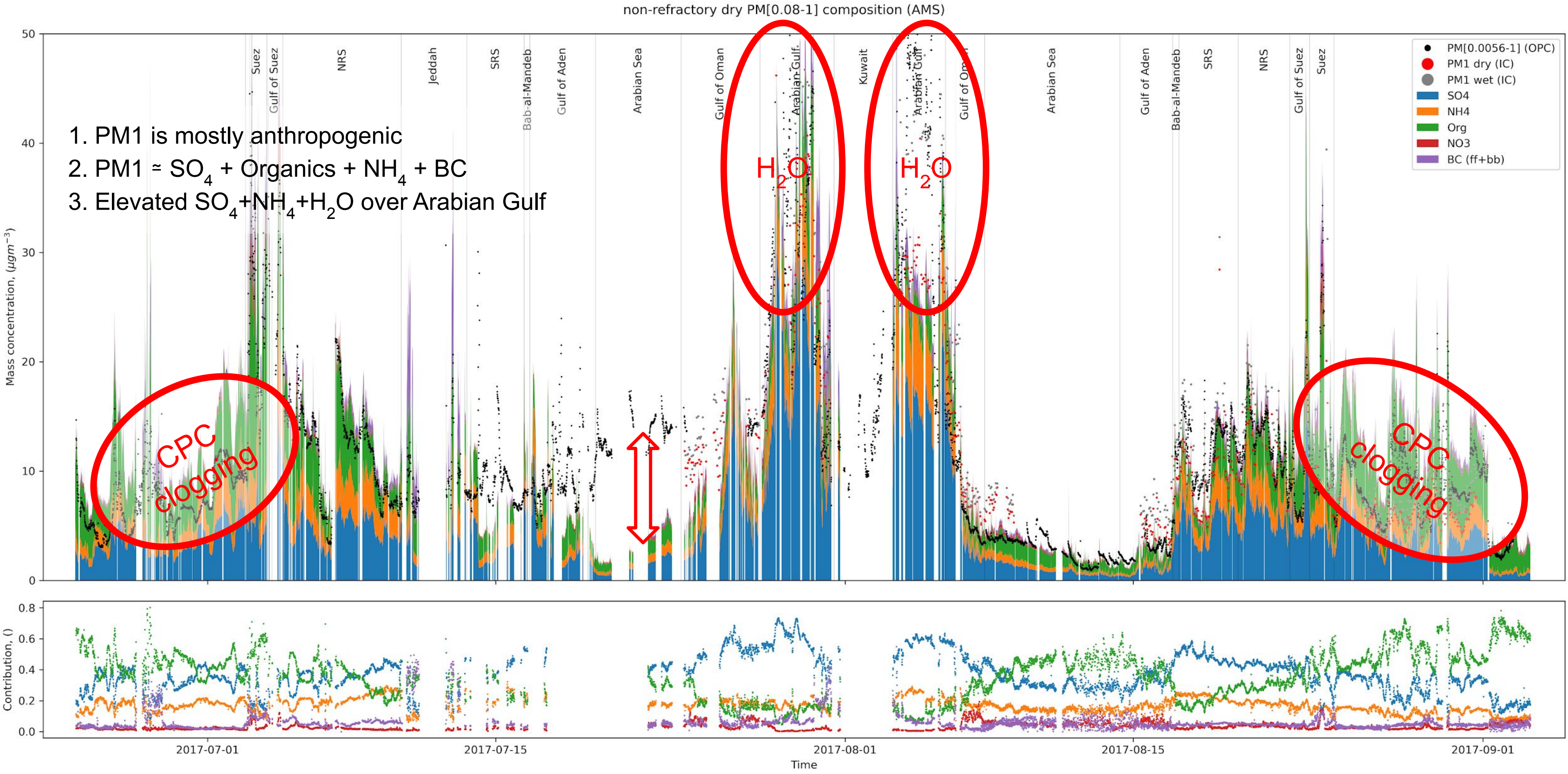


Aerosols: the comparison concept

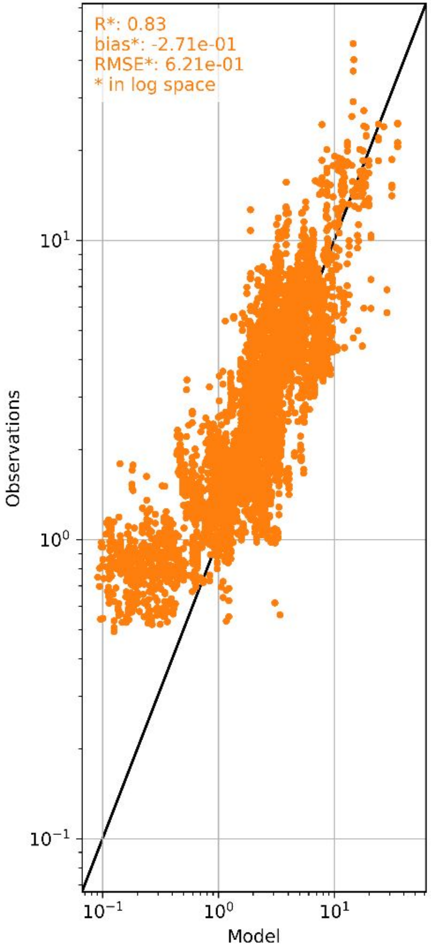


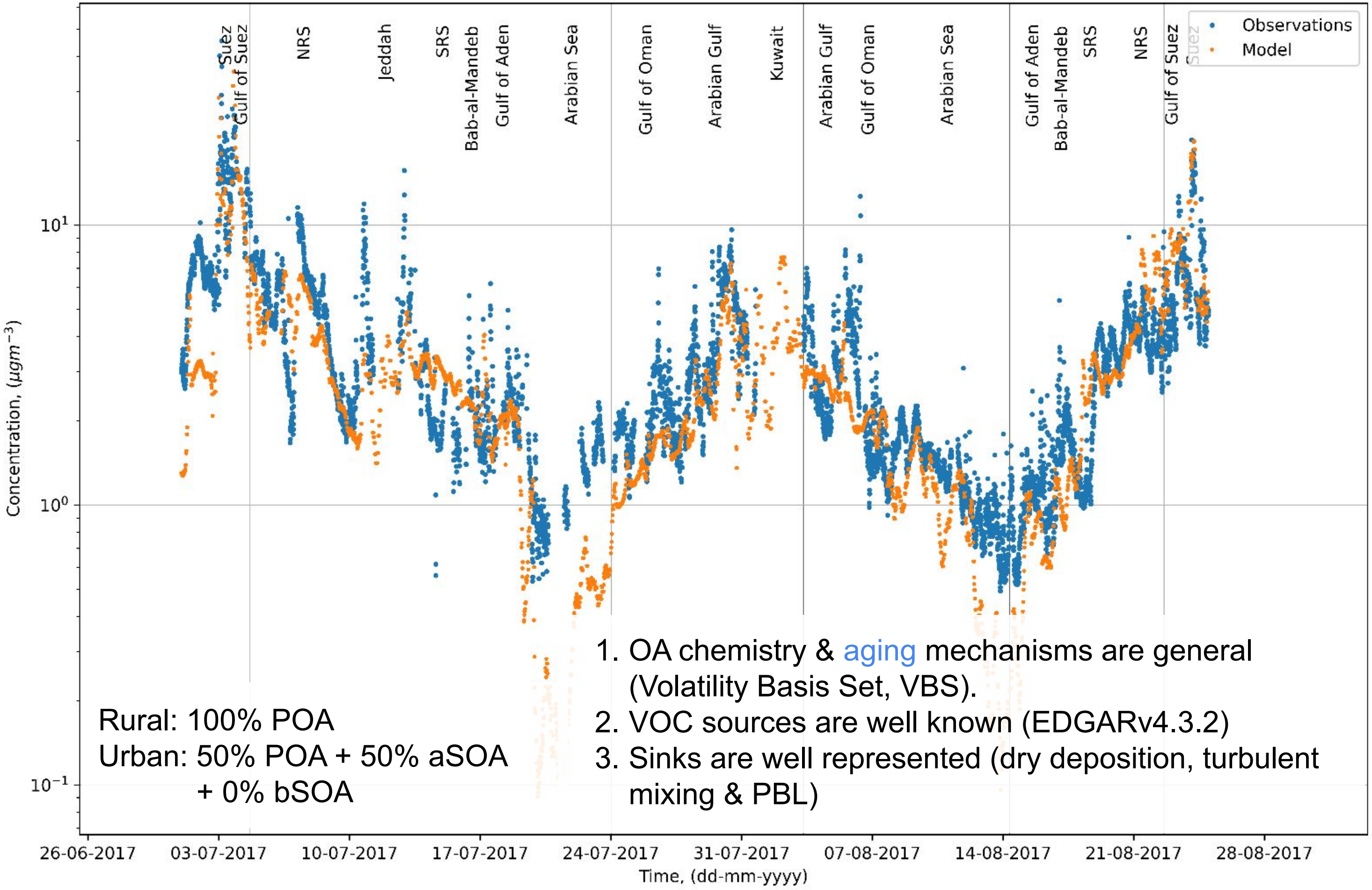
AMS = Aerosol Mass Spectrometer
IC = Ion Chromatography

Non-refractory dry PM[0.08-1] in observations (AMS)



Primary and Secondary Organic Aerosols

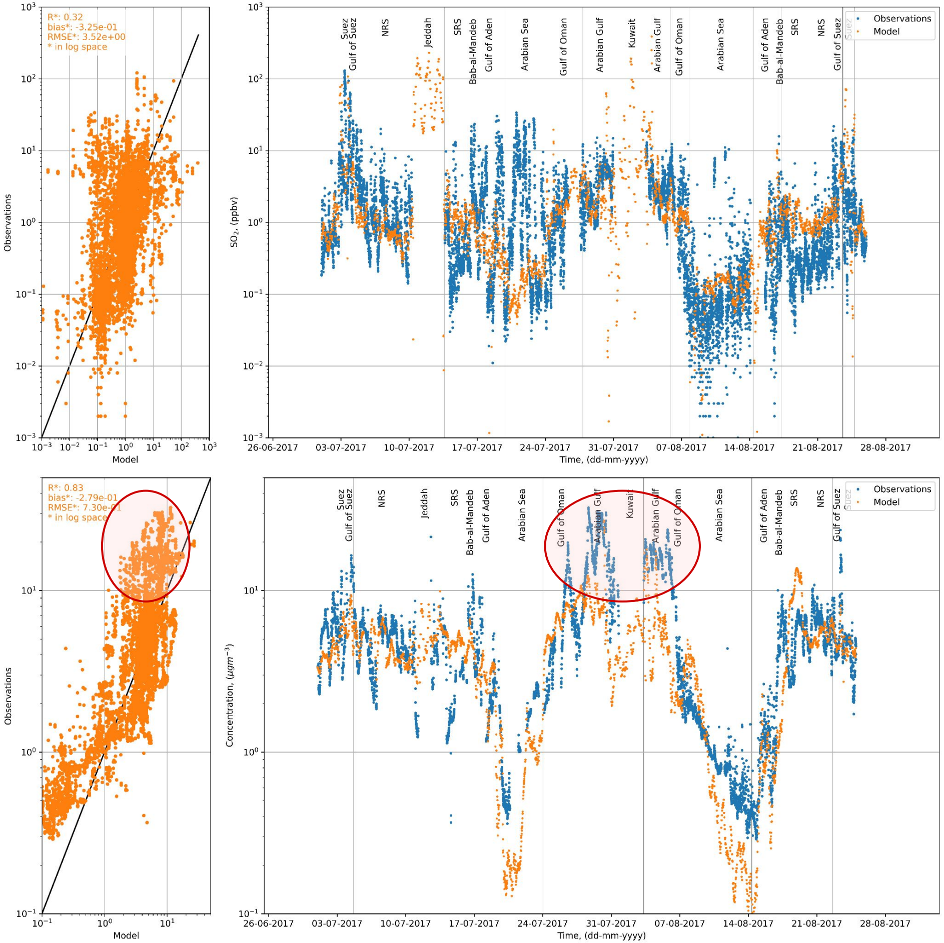




Rural: 100% POA
Urban: 50% POA + 50% aSOA
+ 0% bSOA

1. OA chemistry & aging mechanisms are general (Volatility Basis Set, VBS).
2. VOC sources are well known (EDGARv4.3.2)
3. Sinks are well represented (dry deposition, turbulent mixing & PBL)

Sulfate chemistry



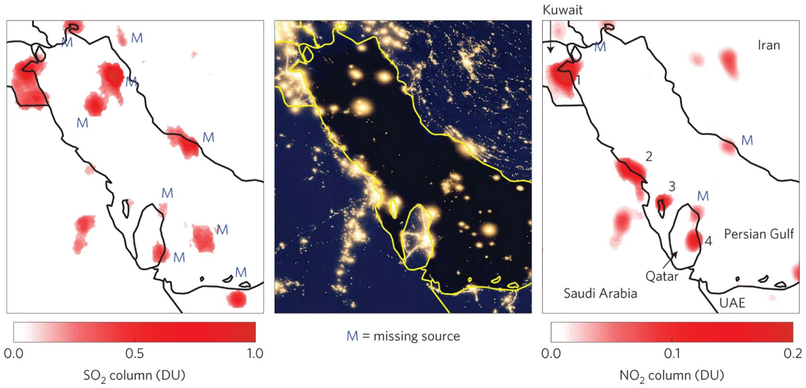
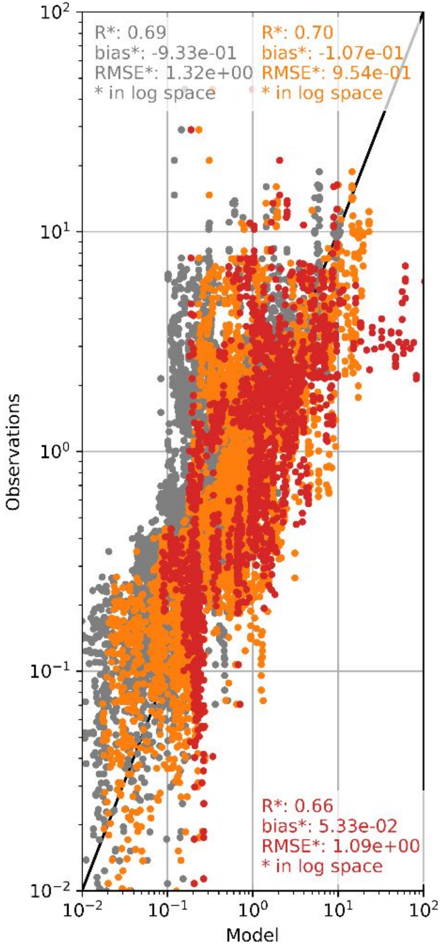
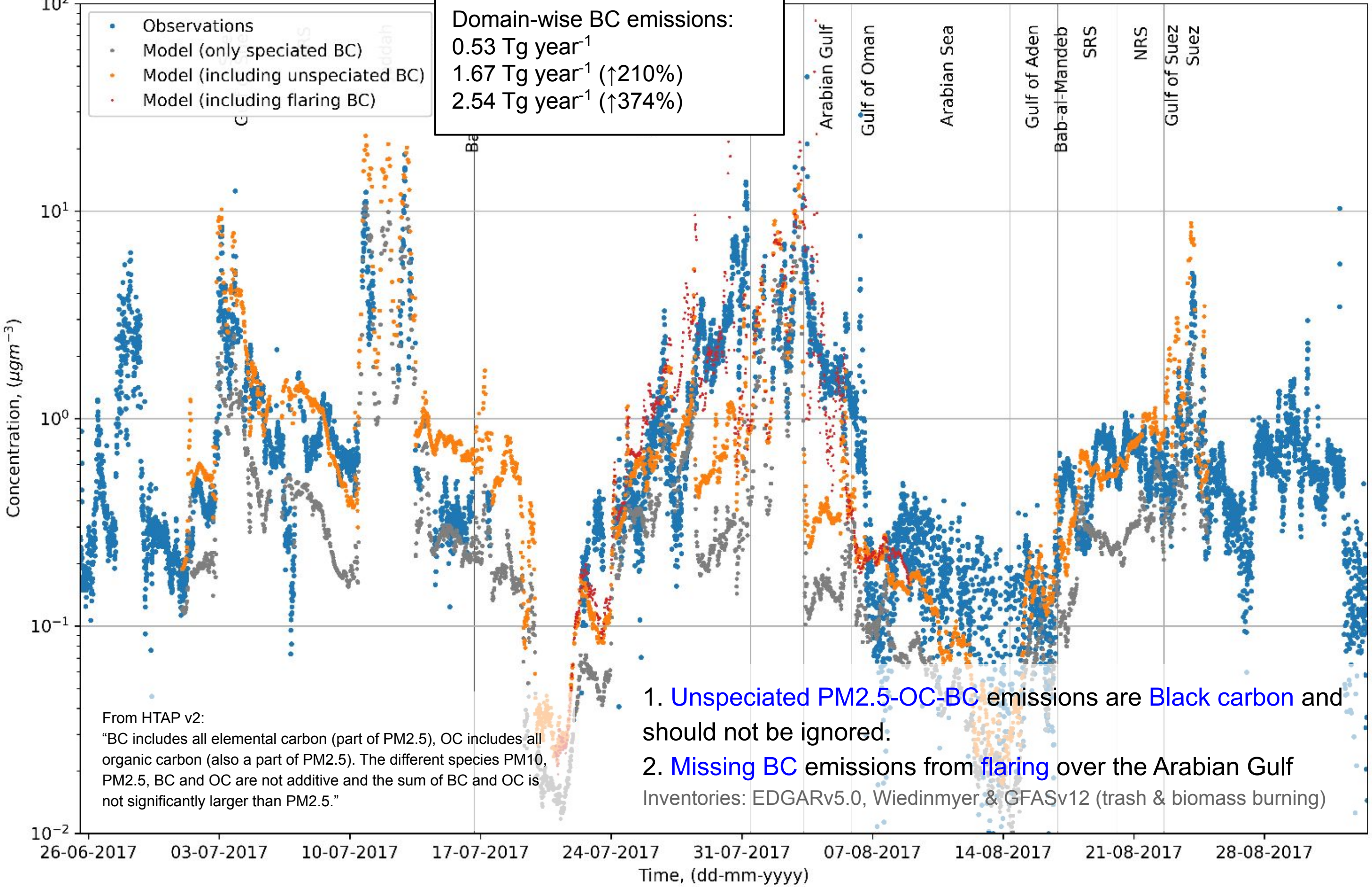


Figure 2 in McLinden et al., 2016

- OMI-HTAP accounts for the missing SO_2 point sources (>30 kt/year) from flaring (Liu et al., 2018, Fioletov et al., 2016, Ukhov et al., 2020)
- Additionally ~50% should be emitted as SO_4 to account for the fast SO_2 oxidation. Possible mechanism is the ozonolysis of alkenes producing Criegee intermediate, which then accelerate SO_2 oxidation.

Black carbon





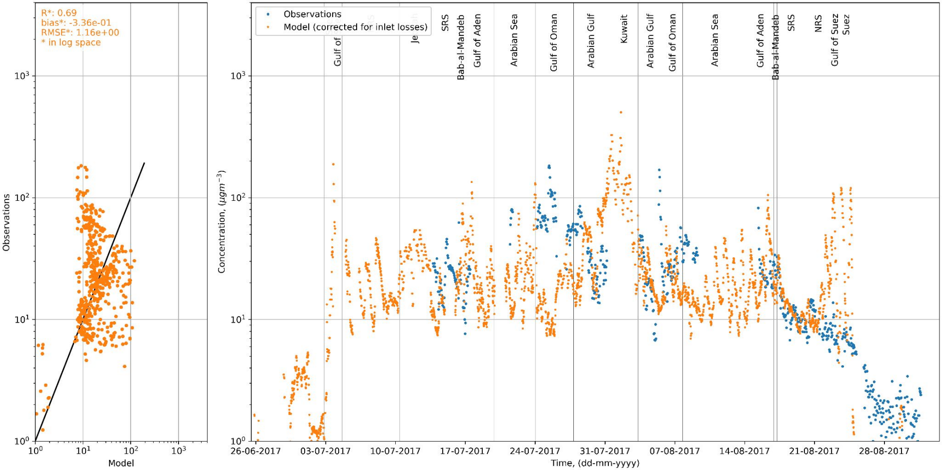
Domain-wise BC emissions:
0.53 Tg year^{-1}
1.67 Tg year^{-1} (↑210%)
2.54 Tg year^{-1} (↑374%)

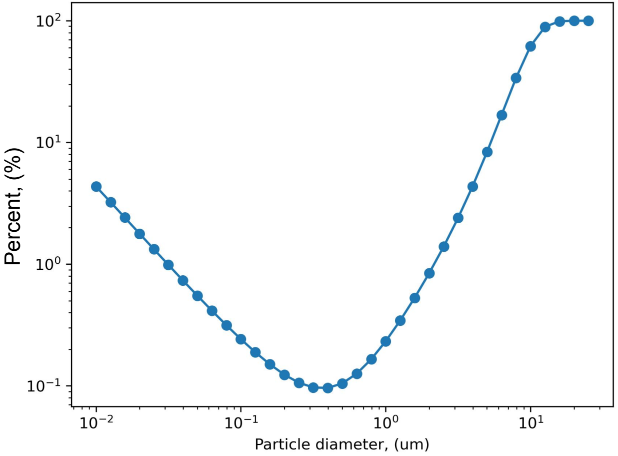
From HTAP v2:
"BC includes all elemental carbon (part of PM2.5), OC includes all organic carbon (also a part of PM2.5). The different species PM10, PM2.5, BC and OC are not additive and the sum of BC and OC is not significantly larger than PM2.5."

1. Unspeciated PM2.5-OC-BC emissions are Black carbon and should not be ignored.
2. Missing BC emissions from flaring over the Arabian Gulf

Inventories: EDGARv5.0, Wiedinmyer & GFASv12 (trash & biomass burning)

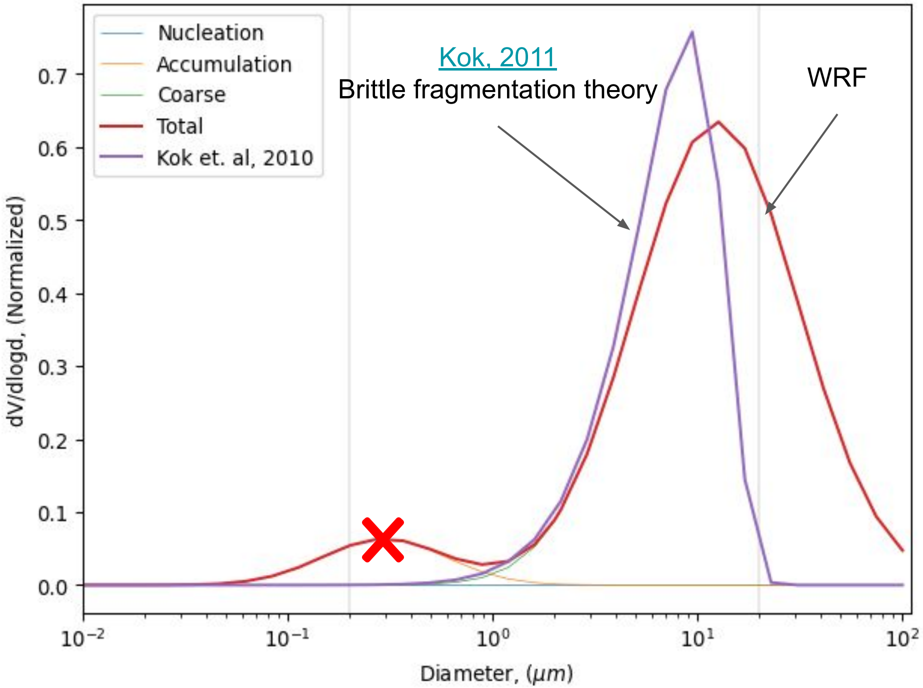
Natural dust





Emitted dust size distribution

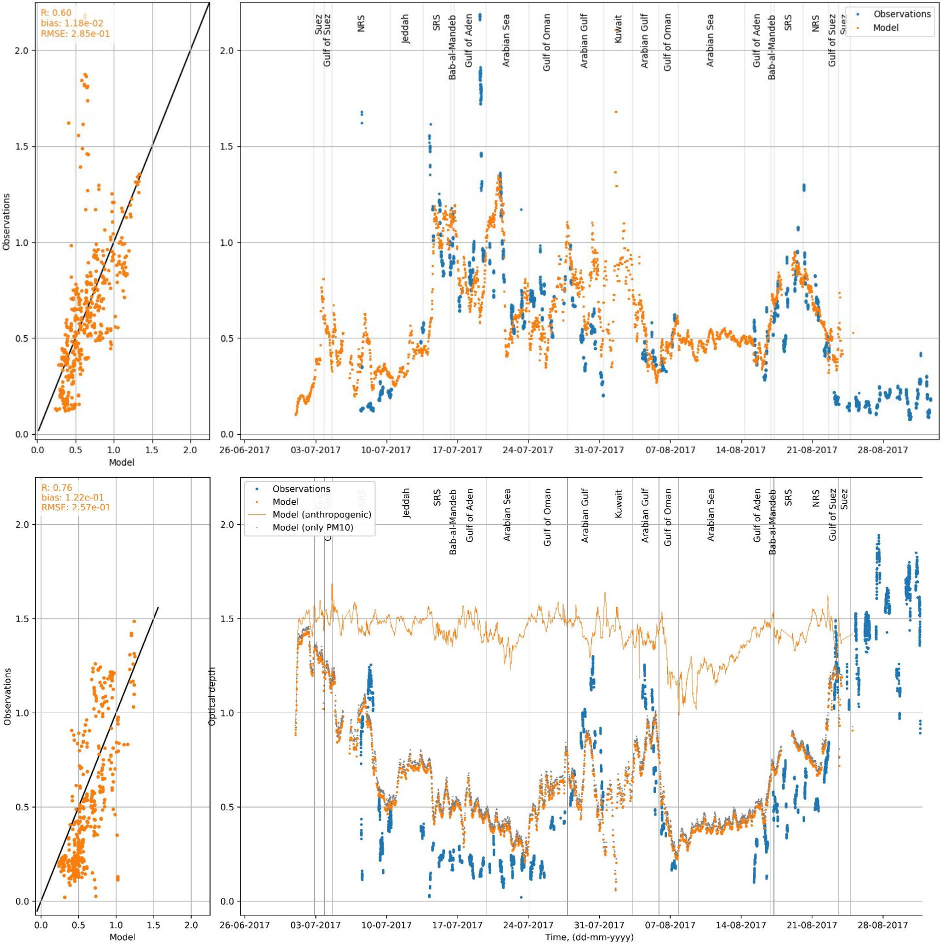
Normalized to 1 over [0.2-20 um]



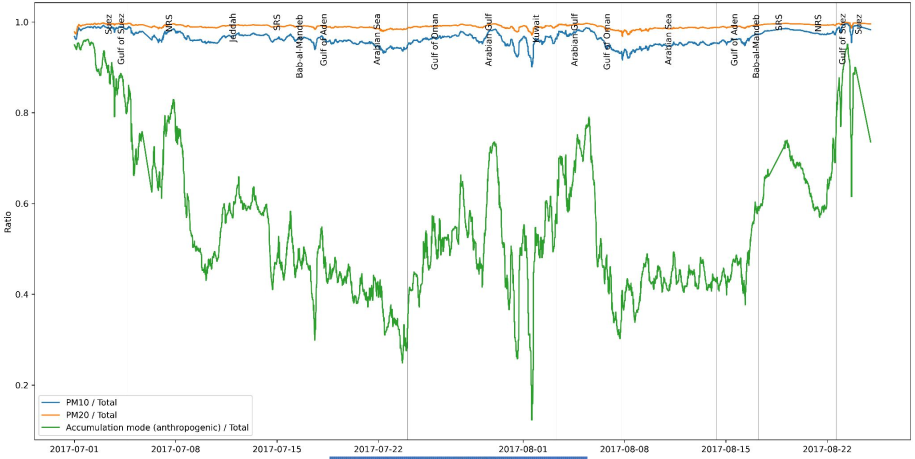
- Emitted dust size distribution is unimodal (coarse) and consistent with the only theoretical size distribution (Kok, 2011).
- Dust contributes to PM1 & PM2.5 through the left tail of the coarse mode (not from the accumulation mode)
- Tuning dust emissions via Aeronet AOD is only valid after constraining the anthropogenic aerosols.

Note: dust emission factor C is 0.65 (down from 1).

Optical constraints



AOD fractions



- Anthropogenic (accumulation mode) aerosols explain at least ~50% of the visible column AOD.
- Thus, they exert radiative forcing on par with natural aerosols (mineral dust).

Note: WRF-Chem (MADE) miscalculates the AOD (low by a factor of 2).

Health effects of air pollution in the Middle East

Country	Death rate (all causes)			Excess mortality due to COVID-19	Excess mortality due to PM2.5			Excess mortality due to O3		
	mean	low	high	mean	mean	low	high	mean	low	high
Bahrain	269	231	312	18.0%	10.7%	6.5%	18.2%	1.2%	0.9%	1.5%
Egypt	572	483	673	1.7%	12.8%	7.6%	21.9%	2.0%	1.6%	2.6%
Iraq	480	404	569	6.3%	10.7%	6.1%	19.1%	0.9%	0.7%	1.0%
Israel	502	493	510	9.0%	4.9%	3.4%	7.0%	2.1%	1.6%	2.9%
Kuwait	218	195	242	15.1%	13.3%	9.4%	19.1%	2.8%	2.3%	3.5%
Lebanon	659	601	722	10.2%	10.0%	5.9%	17.2%	1.5%	1.1%	2.1%
Oman	291	276	307	16.1%	10.9%	6.9%	17.0%	1.3%	1.0%	1.7%
Qatar	148	120	182	8.2%	8.6%	4.5%	15.9%	0.8%	0.6%	1.1%
Saudi Arabia	356	299	428	4.0%	10.1%	5.8%	17.5%	1.9%	1.6%	2.2%
Syria	737	629	870	0.9%	9.1%	4.9%	17.2%	1.5%	1.1%	1.9%
United Arab Emirates	282	217	361	4.2%	9.1%	4.4%	19.4%	2.8%	2.4%	3.3%
Yemen	574	486	684	0.5%	7.3%	3.5%	15.5%	1.4%	1.0%	1.8%
USA	860	861	858	13.0%	3.0%	2.1%	4.5%	2.1%	1.5%	2.7%
Germany	1103	1114	1092	5.8%	3.7%	2.2%	5.1%	0.7%	0.5%	0.9%

Excess mortality calculations (Sourangsu Chowdhury @ MPIC) using the hazard ratio functions of PM2.5 (Chowdhury et al., 2020, Murray et al., 2020, Lelieveld et al., 2019) and assuming the exposure to the simulated PM2.5 fields (mean July-August 2017).

Mortality statistics are available from http://ghdx.healthdata.org/gbd-results-tool. Global Burden of Disease Study 2019 (GBD 2019) Results. Seattle, United States: Institute for Health Metrics and Evaluation (IHME), 2020.

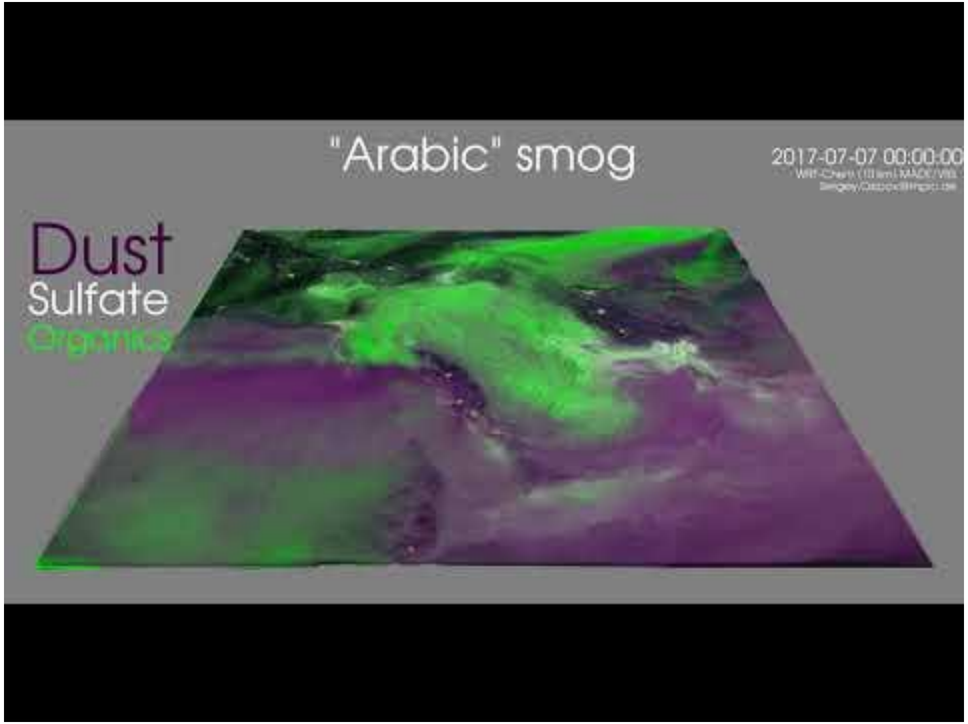
The COVID-19 data were obtained from https://www.statista.com on 4 September 2021.

Incidence of asthma in children and adolescents due to ambient NO_2 (Chowdhury et al., 2021).

Conclusions:

- Anthropogenic emissions in the Middle East have profound influence on the air quality and climate.
    - PM2.5 & O_3 are attributable to ~10% of the excess mortality (~35 cases per 100.000 per year), analogous to mortality due to COVID-19.
    - Anthropogenic aerosols explain >50% of the visible column AOD.

    Within the marine boundary layer and around Arabian Peninsula:
    - Accumulation mode (PM1) is anthropogenic (SO_4, Organics, NH_4, BC).
    - Coarse mode (PM10 & TSP) is natural (dust and sea salt).
- Emissions inventories are inhomogeneous and inconsistent.
    - Missing emissions from flaring (SO_2, BC, HCHO and others; mostly over Arabian Gulf) have to be included from gas flaring volume and species yield considerations (McLinden et al, 2016).
    - Unspeciated PM2.5 emissions (PM2.5-OC-BC) are black carbon.
    - Emissions recipe: CAMS-GLOB-SHIP v2.1 (ship traffic) + EDGAR v4.3.2 / HTAPv2 (only VOCs) + EDGAR v5.0 (without VOCs, industrial SO_2, ship traffic) + OMI-HTAP (only SO_2) + GFASv12 & Wiedinmyer (biomass & trash burning) + Van Damme et al., 2018 (IASI NH4) + Bourtsoukidis et al., 2020 (NMHCs).


"Arabic" smog
2017-07-07 00:00:00
Dust
Sulfate
Organics