Jet Propulsion Laboratory
California Institute of Technology

Global tropospheric ozone responses to reduced NOx emissions linked to the COVID-19 world-wide lockdowns

Science Advances, 2021

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NASA Tracks COVID-19's Atmospheric Fingerprint (several media releases by NASA HQ)

Environmental policy to reduce human health risk from air pollution
Human activity and technology
COVID-19 natural experiment
Air pollutant emissions (NOx etc)
Complex chemical mechanisms
Air pollution level (Ozone, PM2.5)
??
Obser-vables
Implications for effective policy making
Human health & Climate
??
Can be inferred
Sinuses
Windpipe (trachea)
Lungs

MOMO-Chem (Multi-mOdel Multi-cOnstituent Chemical) Data Assimilation System

MLS

TES

OMI

MOPITT

AIRS

SCIAMACHY

GOME-2

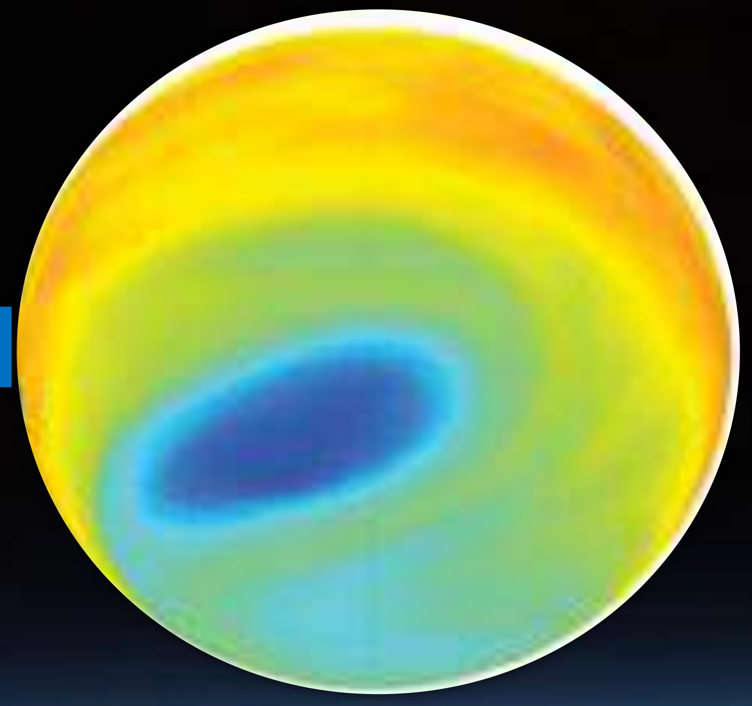
TROPOMI

Satellite Observations Assimilated in MOMO-Chem

Satellite

(O_3, CO, NO_2, HNO_3, CO)

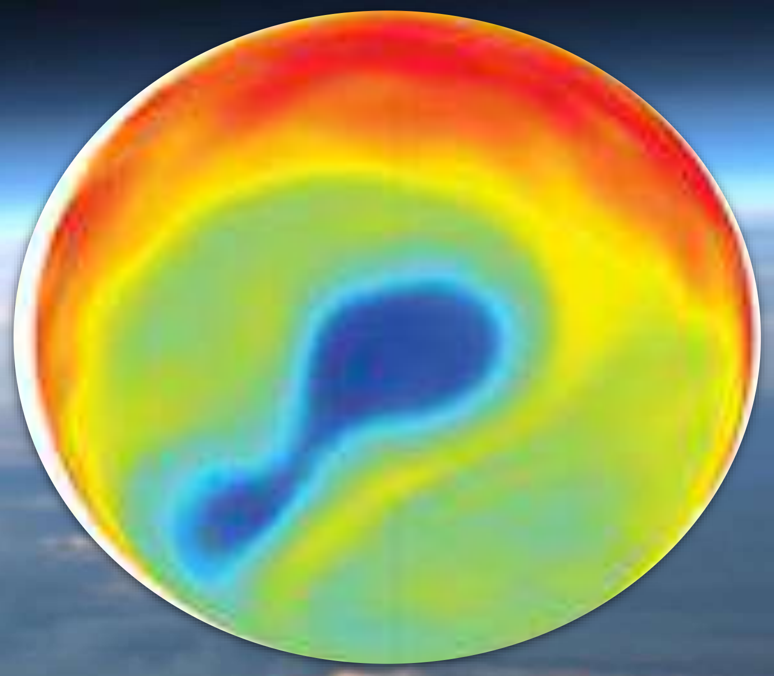
Data Assimilation



Model

(4 models)

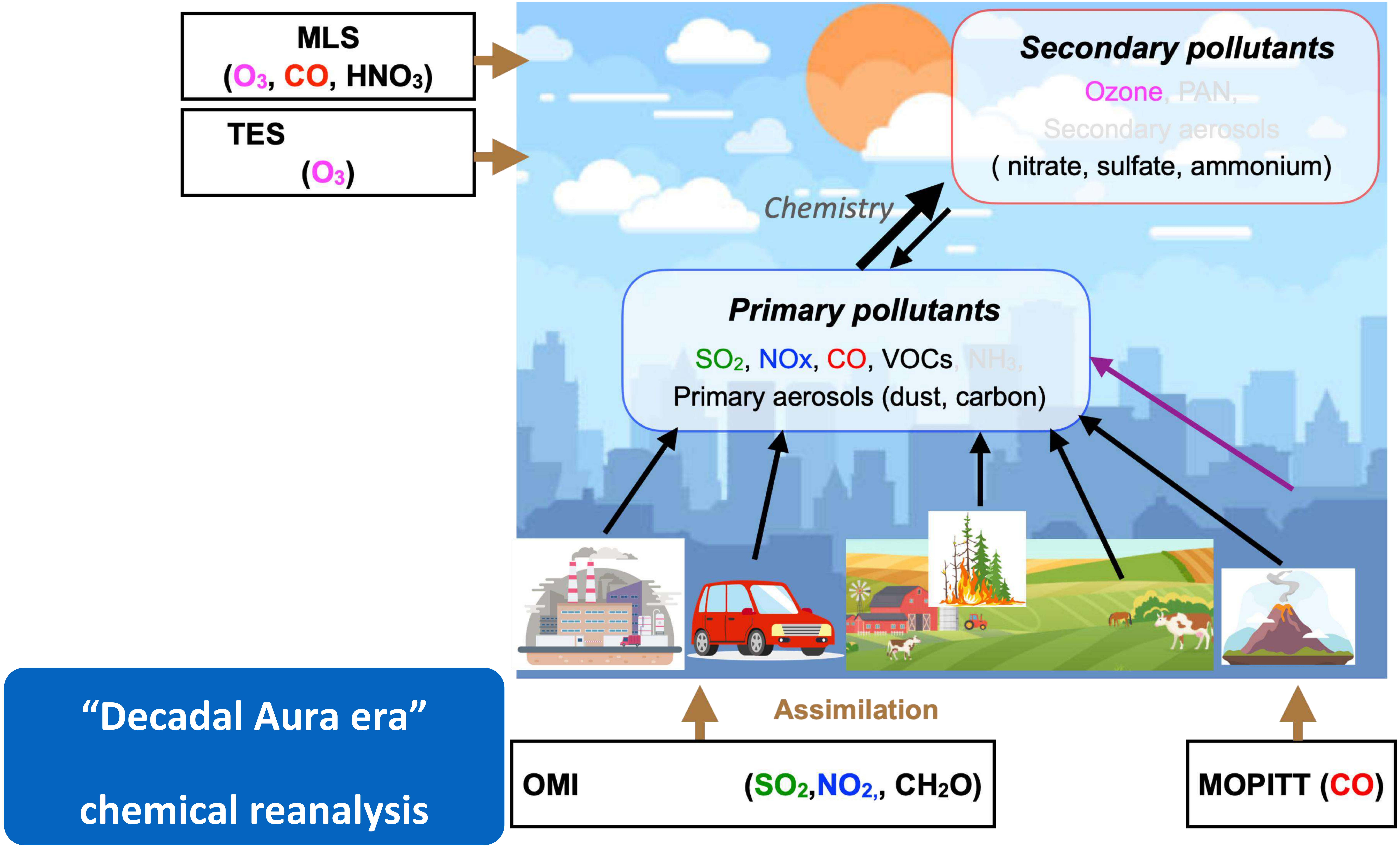
Models Used for Assimilation



Validation against in-situ & aircraft measurements

Tropospheric Chemical Reanalysis

- 17 years (2005-present), two-hourly, global, surface to lower stratosphere chemical concentrations of 35 species, including O_3, NOx, HNO_3, PAN, OH, SO_2, VOCs, Aerosols
- Anthropogenic, biogenic, biomass burning, and lightning emissions (NOx, CO, SO_2)
- Various science applications, focusing on attributions, including validation of NASA satellite products
- Able to support OSSE activities in support of mission formulation



MLS
(O3, CO, HNO3)
TES
(O3)
Secondary pollutants
Ozone, PAN,
Secondary aerosols
(nitrate, sulfate, ammonium)
Chemistry
Primary pollutants
SO2, NOx, CO, VOCs, NH3,
Primary aerosols (dust, carbon)
Assimilation
OMI
(SO2,NO2,, CH2O)
MOPITT (CO)
"Decadal Aura era"
chemical reanalysis

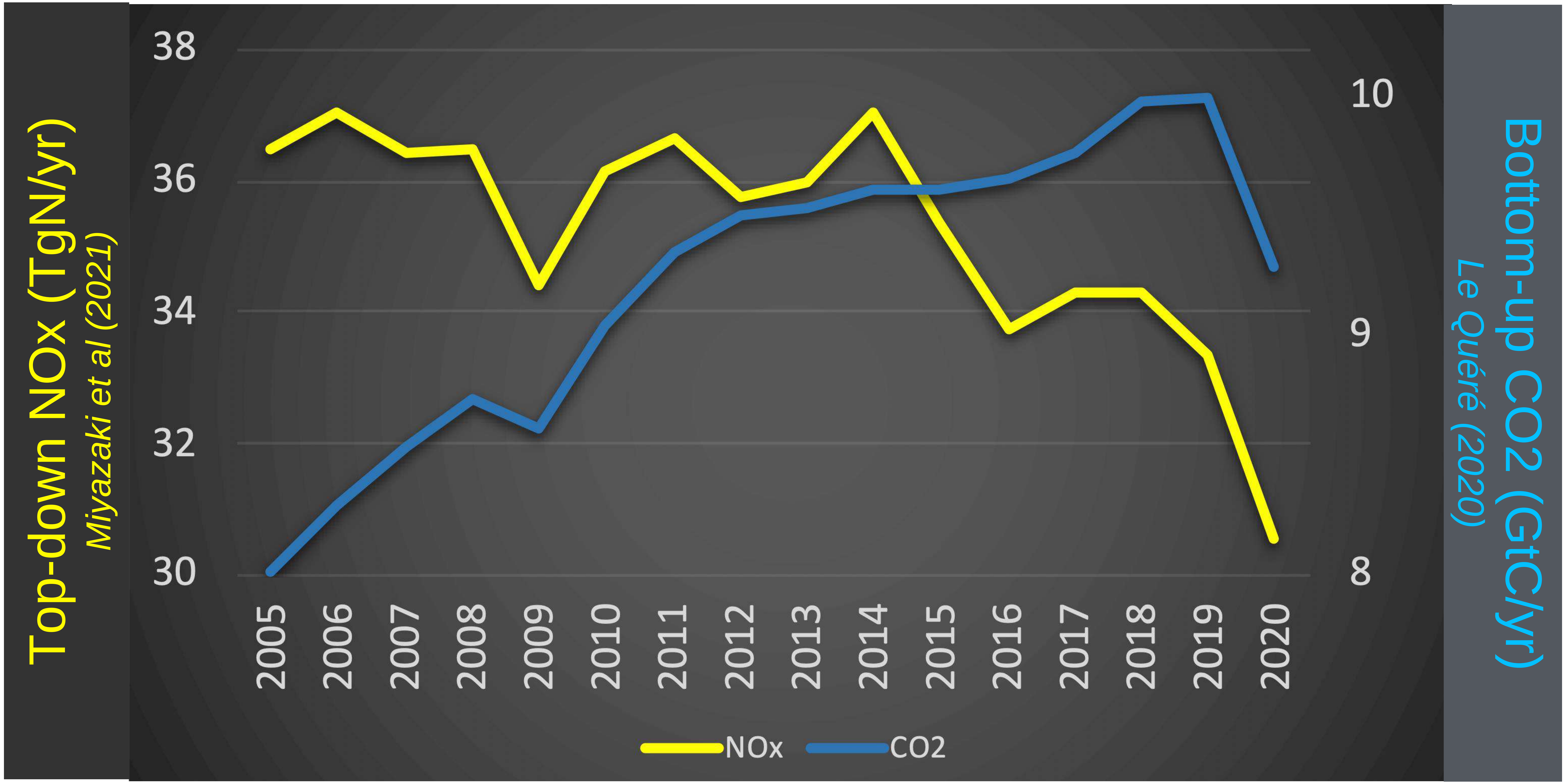
MLS
(O3, CO, HNO3)
TES, AIRS/OMI
(O3)
Long-lived GHGs
Oxidation capacity (OH)
↓
CH4
AQ-GHG co-emissions
↓
CO2
“Decadal Aura era”
“New satellite era”
chemical reanalysis
Secondary pollutants
Ozone, PAN,
Secondary aerosols
(nitrate, sulfate, ammonium)
Chemistry
Validation
Primary pollutants
SO2, NOx, CO, VOCs, NH3,
Primary aerosols (dust, carbon)
VIIRS
(AOD)
CrIS
(O3,PAN)
OMPS
(SO2,NO2)
Assimilation
OMI, TROPOMI (SO2,NO2,, CH2O)
CrIS (NH
(CO)
OMI vs TROPOMI NO2 DA
Poster by Sekiya et al.,

Global anthropogenic emission reductions in 2020: 7% (CO_2) 8% (NOx)

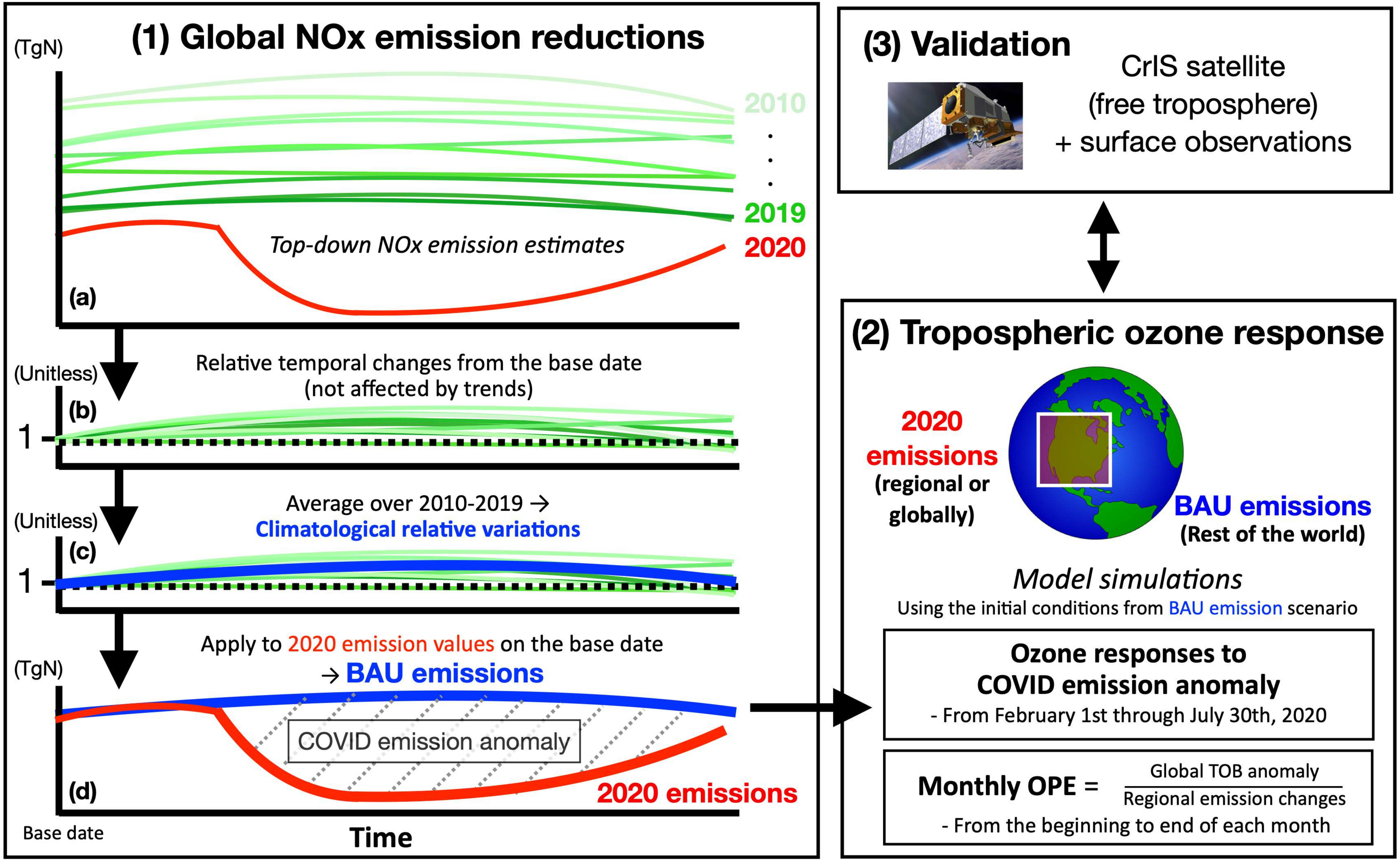
Miyazaki et al.
2020 GRL
2021 Science Advances

Laughner et al.
2021 PNAS

Jiang et al.
2020 ACP



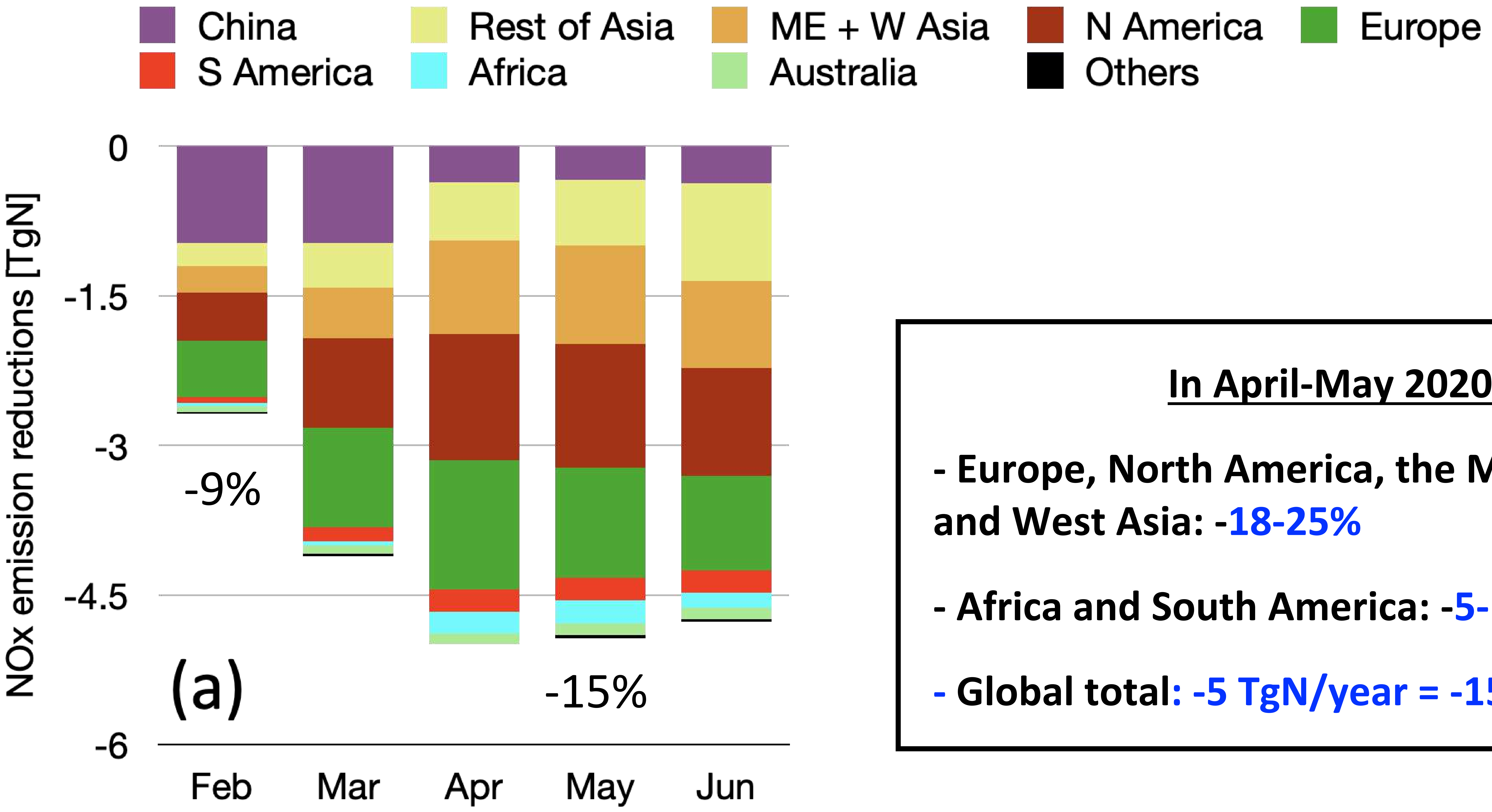
1. Emissions (NOx, SO2, CO) → **2. Concentrations** → **3. Health and climate Impacts**



(1) Global NOx emission reductions
(TgN)
2010
2019
2020
Top-down NOx emission estimates
(a)
(Unitless)
Relative temporal changes from the base date
(not affected by trends)
(b)
1
(Unitless)
Average over 2010-2019 →
Climatological relative variations
(c)
1
(TgN)
Apply to 2020 emission values on the base date
→ BAU emissions
COVID emission anomaly
(d)
2020 emissions
Base date
Time
(3) Validation
CrIS satellite
(free troposphere)
+ surface observations
(2) Tropospheric ozone response
2020
emissions
(regional or
globally)
BAU emissions
(Rest of the world)
Model simulations
Using the initial conditions from BAU emission scenario
Ozone responses to
COVID emission anomaly
- From February 1st through July 30th, 2020
Monthly OPE = Global TOB anomaly / Regional emission changes
- From the beginning to end of each month


Stringency Index
100
80
60
40
20
0
Feb 2020
Mar 2020
Apr 2020
May 2020
Jun 2020
Jul 2020
Feb 10 2020
NOx Anomaly, kgN/m²s
-0.15
-0.075
0.0
0.075
0.15
-0.2
-0.1
0.0
0.1
0.2
-0.3
-0.15
0.0
0.15
0.3
United States
Italy
China

Estimated NOx emissions

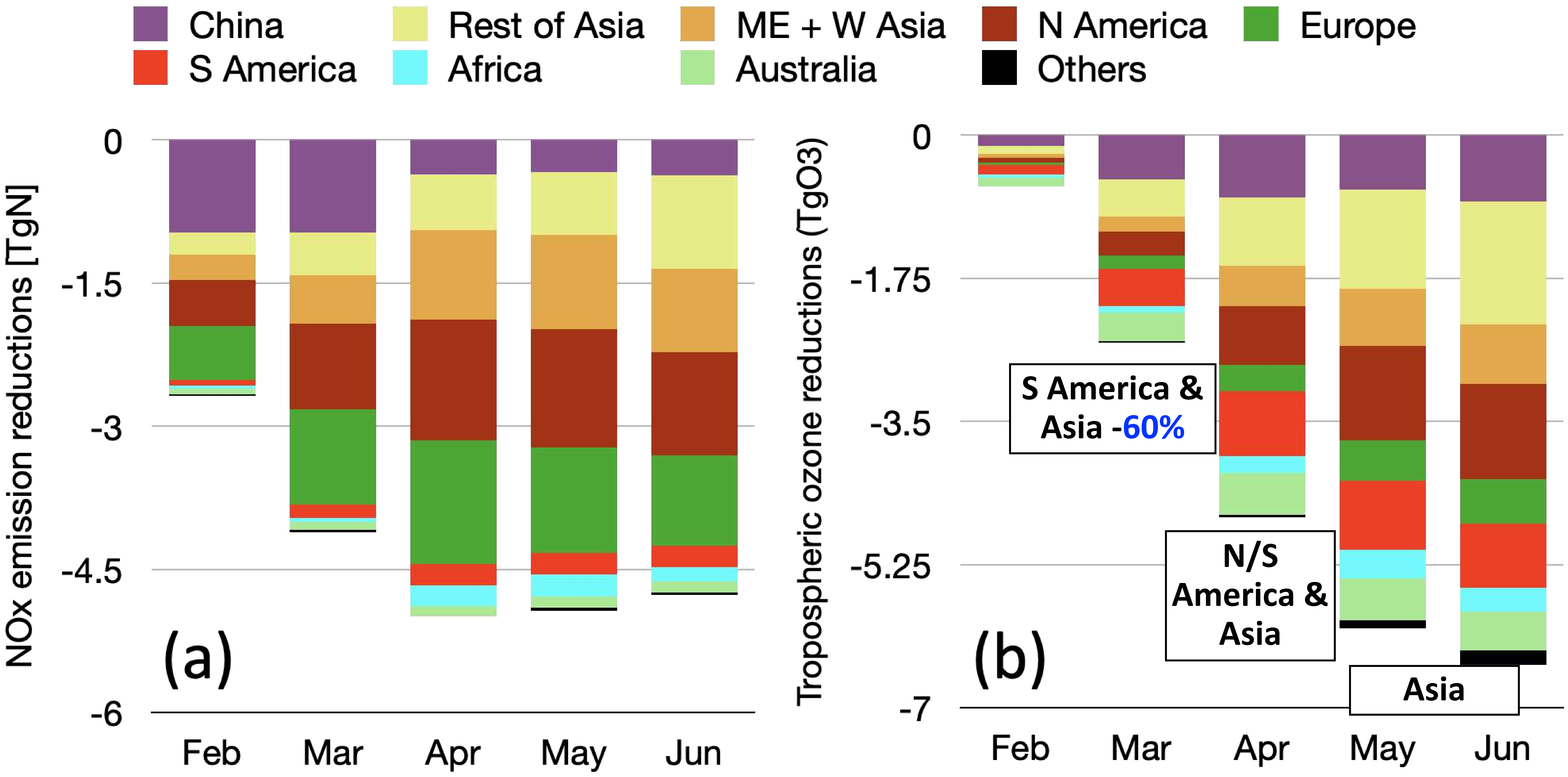


1. Emissions (NOx)

In April-May 2020

- **Europe, North America, the Middle East and West Asia: -18-25%**
- **Africa and South America: -5-10%**
- **Global total: -5 TgN/year = -15 %**

Global ozone response



1. Emissions (NOx)

2. Concentrations (ozone)

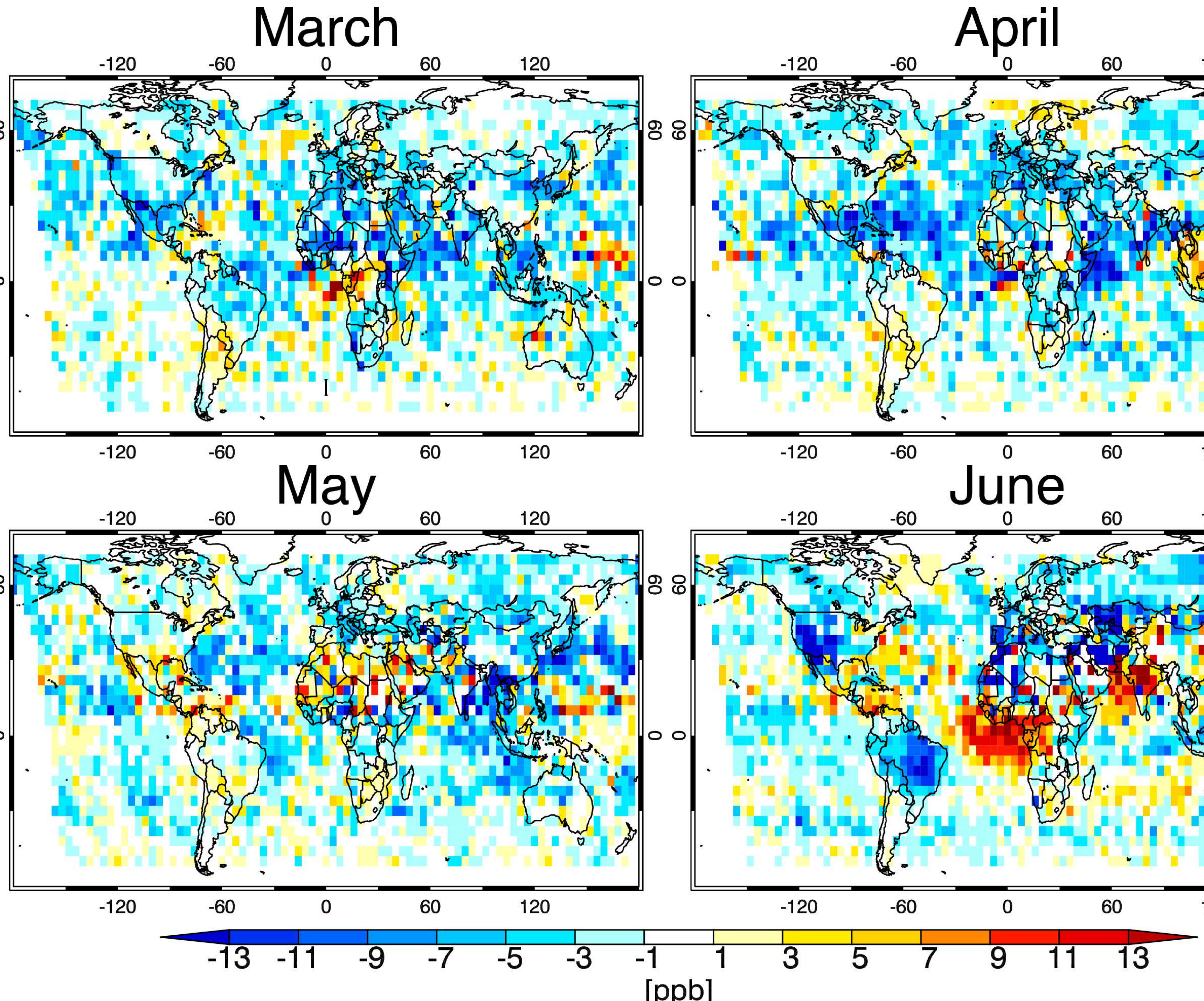
Reduced global TOB decreased by 6 TgO3 (2%). This drop is 15 times more rapid than what has been viewed as achievable through even aggressive emissions reductions considered by IPCC. Important implications for ozone RF.

Global ozone response: Comparisons against CrIS satellite

CrIS (JPL TROPESS) ozone 700 hPa: 2020 minus 2019

2. Concentrations

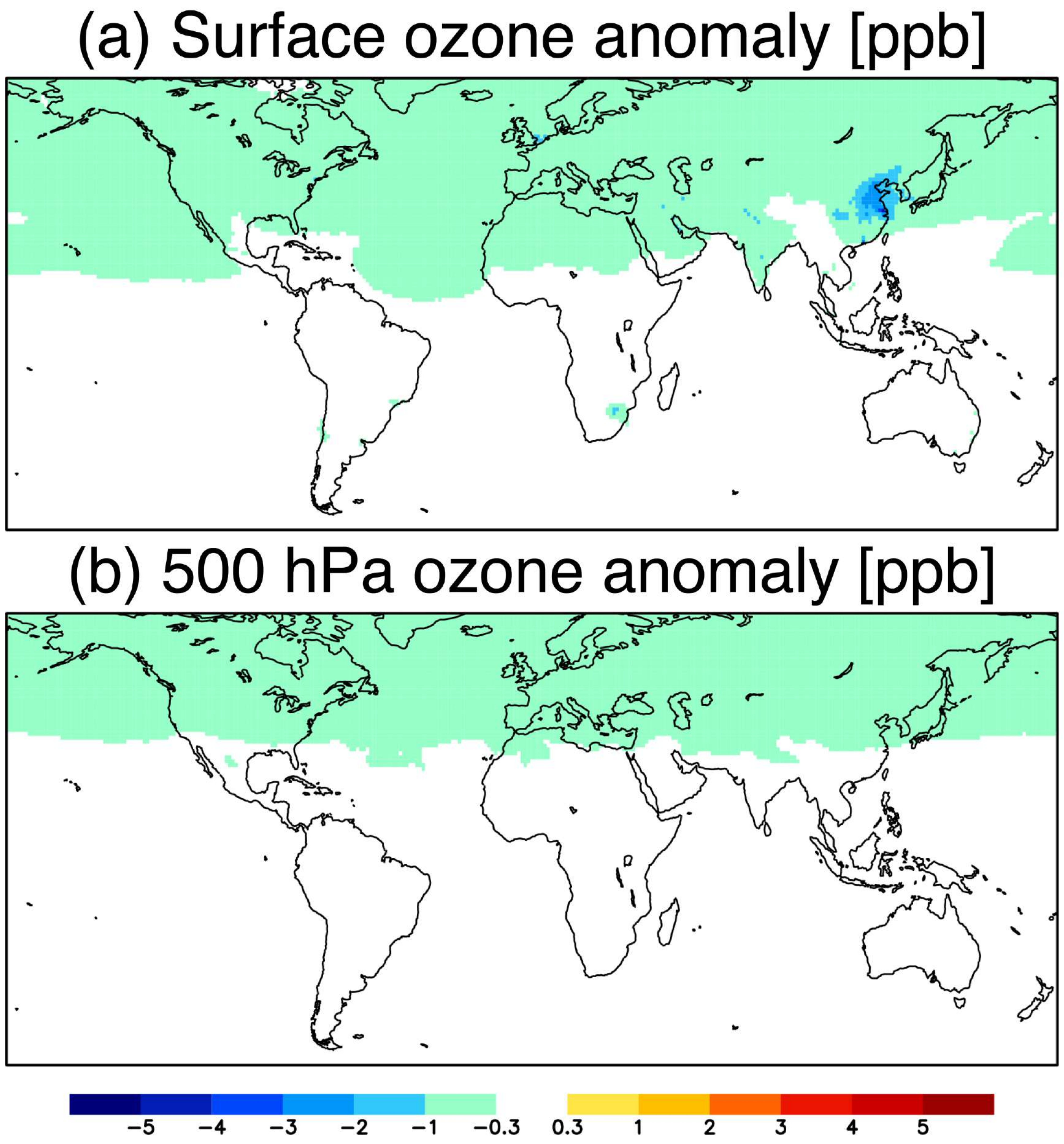
tropess

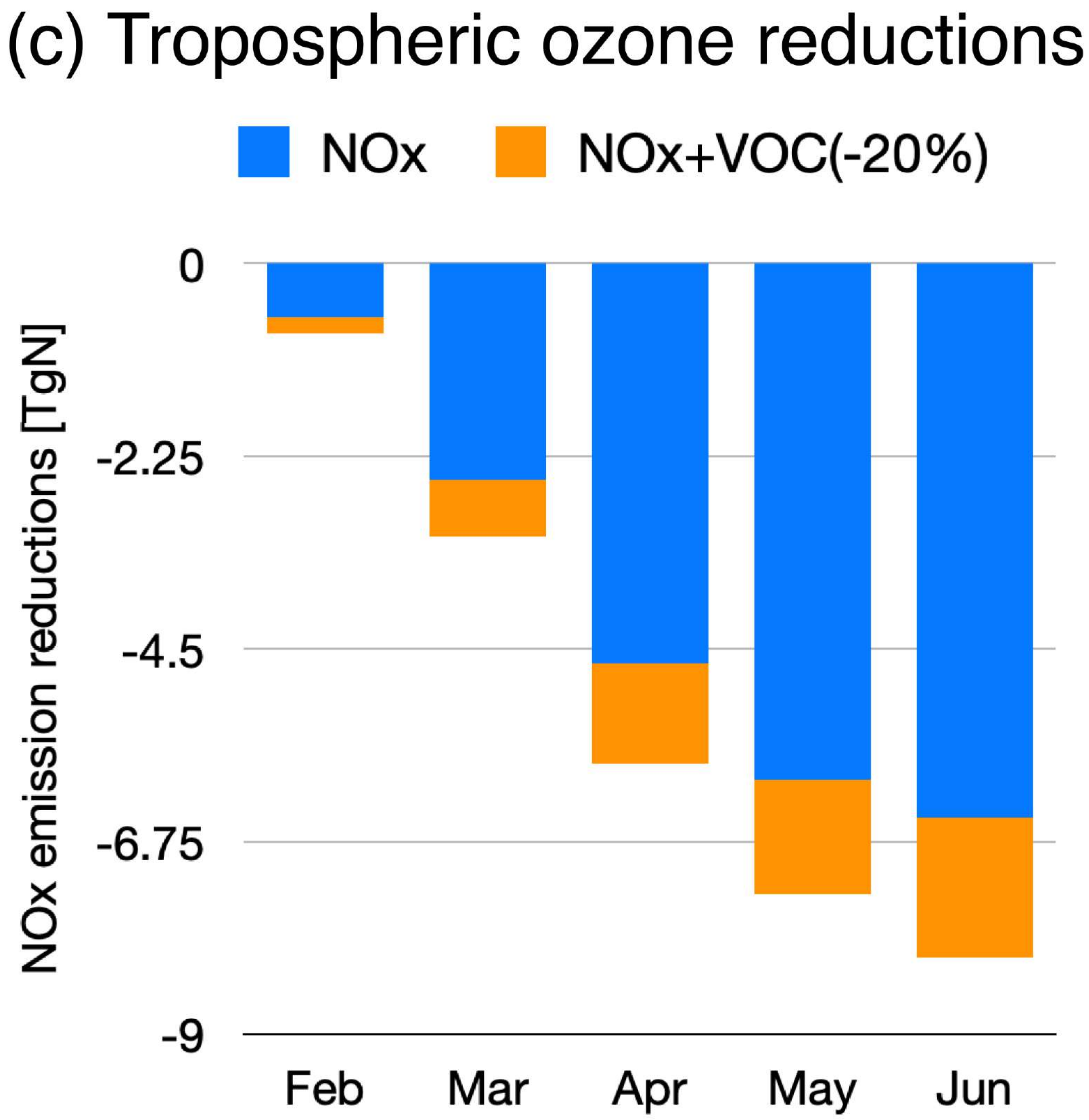


where and when the lockdowns occurred is very important in determining the impact on atmospheric composition

Feb 01 2020
Ozone Anomaly, United States
-6 -5 -4 -3 -2 -1 0
parts per billion
Ozone Anomaly, Non-China Asia
-6 -5 -4 -3 -2 -1 0
parts per billion
200 mb
400 mb
600 mb
800 mb
1000 mb

Global ozone response due to VOC emission reductions

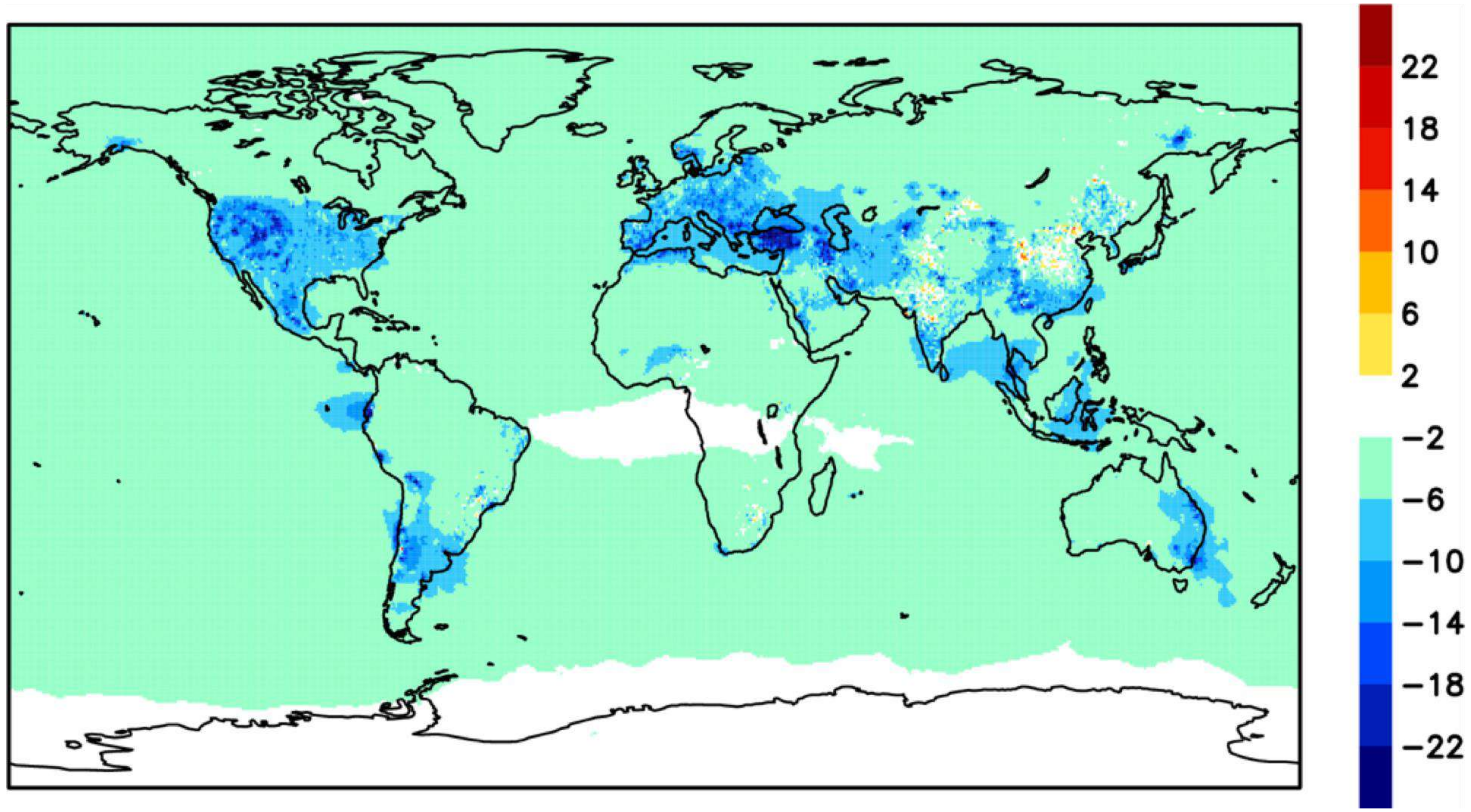




Additional 22-26 % reduction in global TOB

Tropospheric OH and CH4 anomaly

OH tropospheric mean (%)



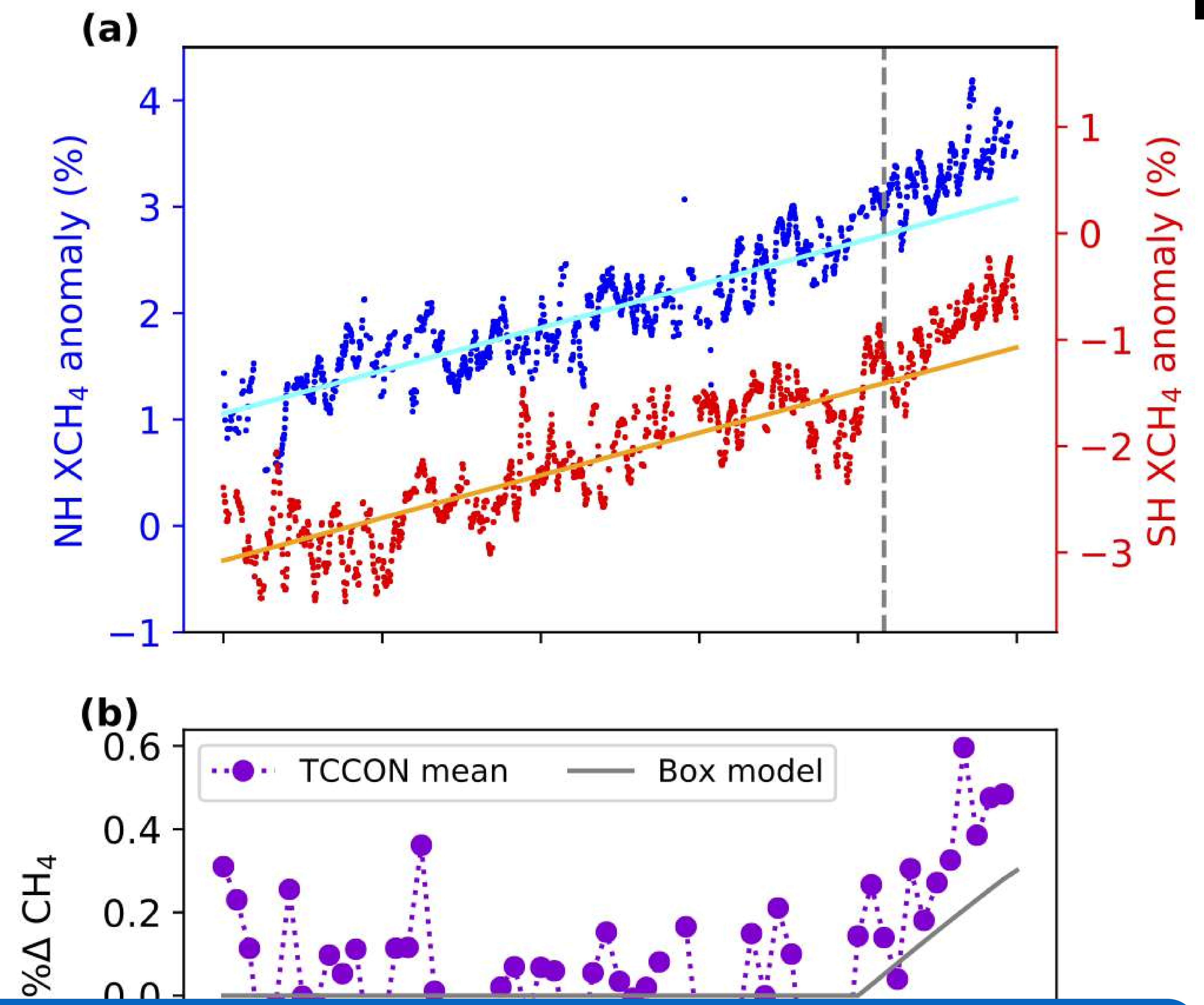
The 4% reduction in the tropospheric global mean OH would increase CH_4 lifetime by 4 months.

→ *the broad impacts on tropospheric chemistry*

2. Concentrations

3. Climate Impacts

Miyazaki et al., Sci. Adv. 2021; Laughner et at., PNAS 2021



Total climate impacts of COVID:

O_3 (Sci Adv. 2021; PNAS 2021), CH_4 (in prep.), Secondary aerosols (to be submitted), CO_2 (CMIP)

Summary

- Anthropogenic NOx emissions dropped by at least 15% globally and 18-25% regionally in April and May 2020, which led to < 5 ppb decreases in FT ozone and a 2% reduction in TOB, consistent with independent satellite observations.
- Our results show that COVID-19 mitigation led to a clear and global atmospheric signature that altered atmospheric oxidative capacity and climate radiative forcing and can be used to inform policies that co-benefit air quality and climate.
- New LEO and GEO measurements and multi-spectral retrievals provide much-improved spatial and temporal resolution and coverage. They should lead to greater usefulness of satellite measurements for climate and air quality applications in conjunction with the chemical reanalysis, for instance, to better isolate sources and attribute sectors and their influences on ozone at daily scales (Miyazaki et al., 2022 & in review).