西湖大學
WESTLAKE UNIVERSITY

Trace Compositions of the Atmosphere

from global climate change to regional air pollution

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July 1, 2020

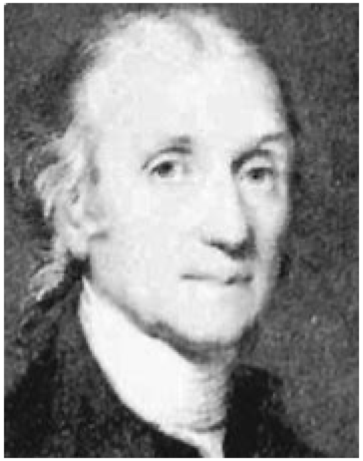

A blanket of air surrounding Earth
Wind, rain, cloud, lightning, hurricane
Climate, Air quality

Composition of the air

TABLE 10-1. Average composition of dry air (Seinfeld and Pandis 2016).

Gas	Parts per million by volume (ppmv)
N_2	781 000
O_2	209 000
Ar	9340
CO_2[a]	406
Ne	18
He	5.2
CH_4[b]	1.85
H_2	0.58
N_2O[c]	0.33
CO	0.1
O_3 (troposphere)	0.01–0.10
O_3 (stratosphere)	0.5–10.0
Non-methane hydrocarbons	0.005–0.02
Halocarbons	0.001
Nitrogen oxides (NO_y)	0.000 01–0.2

[a] Dlugokencky and Tans (2018).
[b] Dlugokencky (2018).
[c] NOAA (2018).



Henry Cavendish
1731-1810

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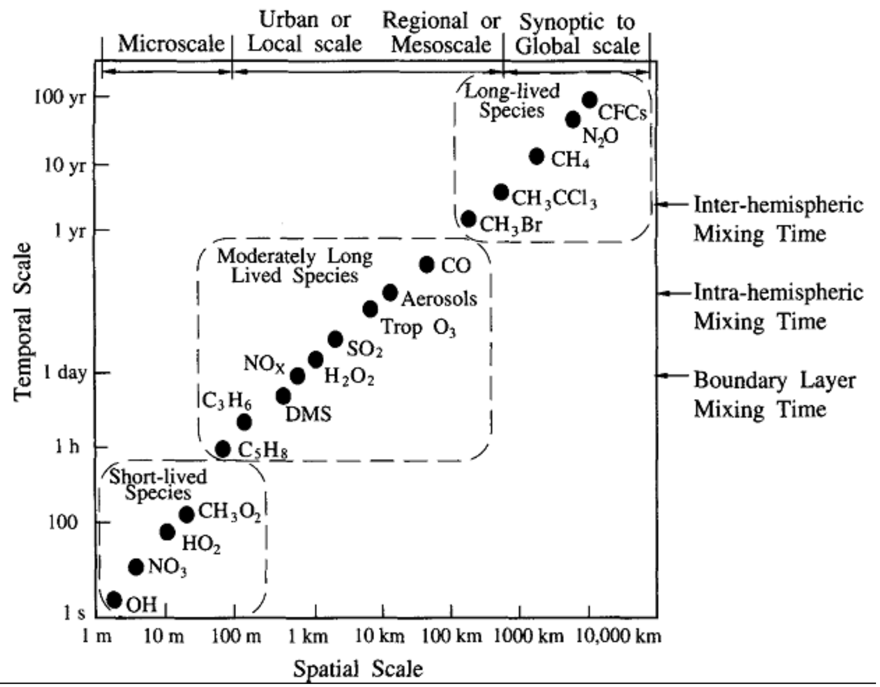
[c] NOAA (2018).

Chemically and radiatively interesting trace compositions

Understand their spatial & temporal distributions

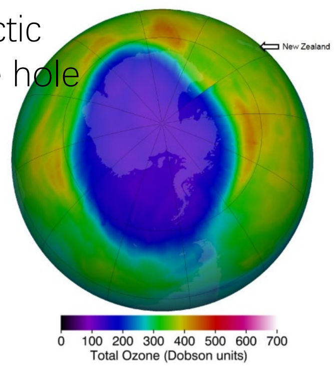
Spatial & temporal scales of trace gases



Seinfeld and Pandis, 2016

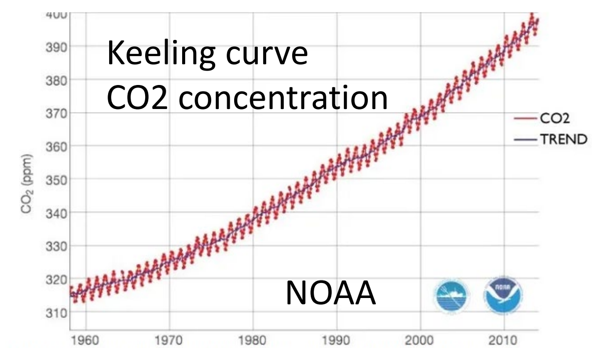
Spatial distribution

Antarctic ozone hole



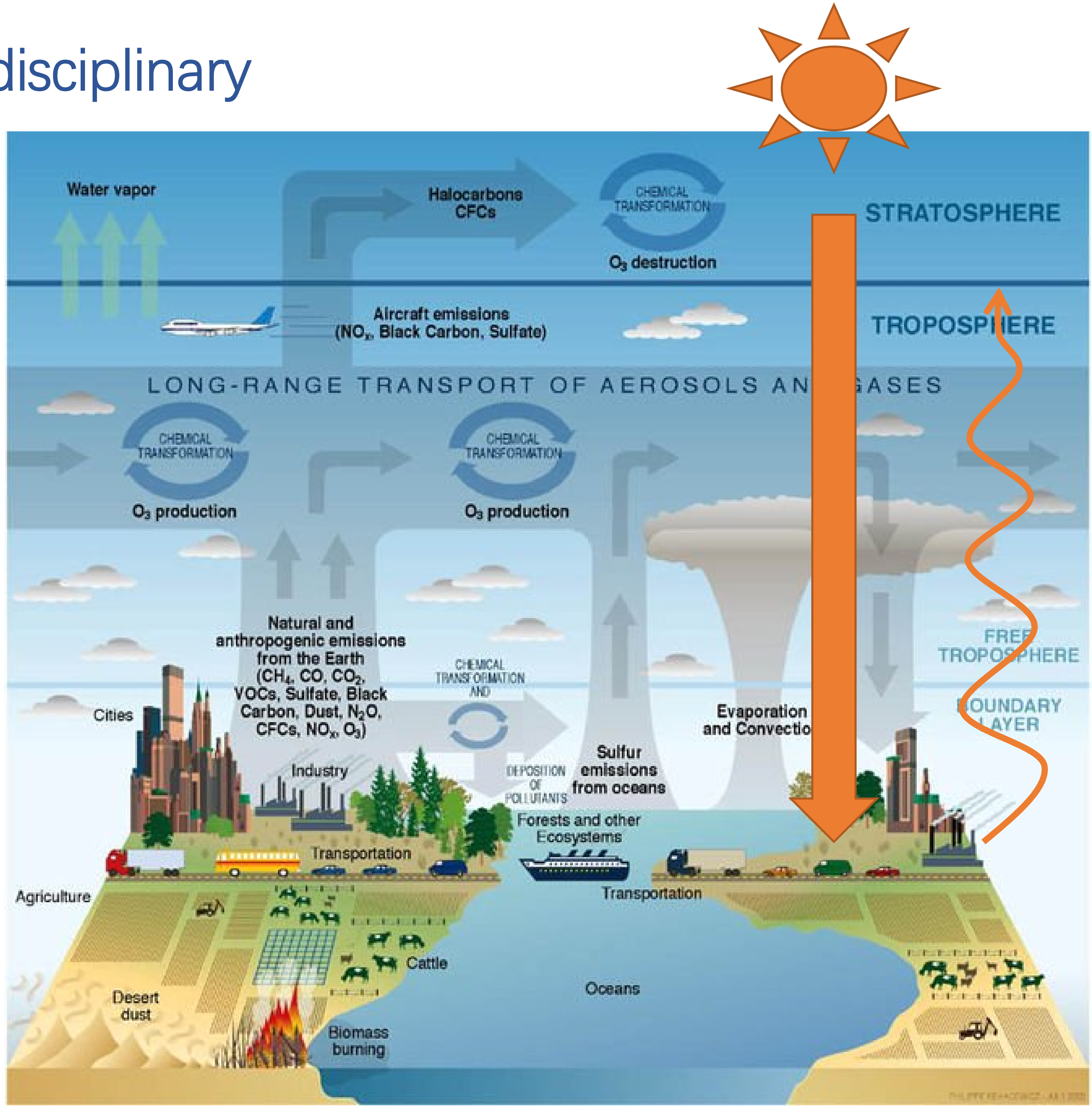
NASA

Temporal changes

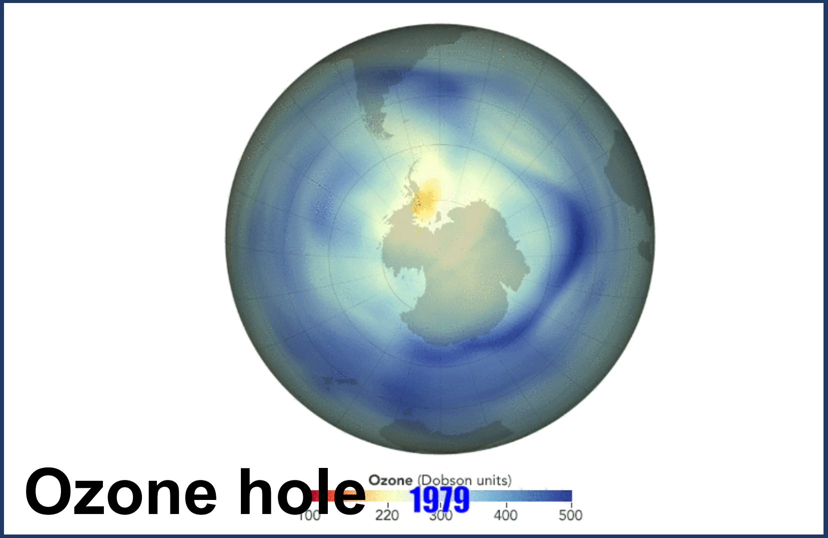


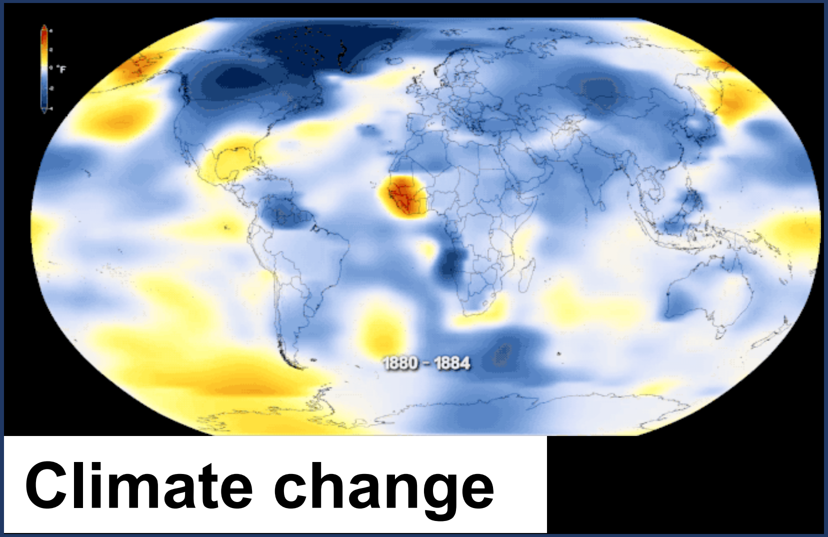
The Keeling curve shows levels of carbon dioxide at Mauna Loa in Hawaii. *NOAA Earth System Research Laboratory/Scripps Institute Of Oceanography*

Transdisciplinary



Problem driven

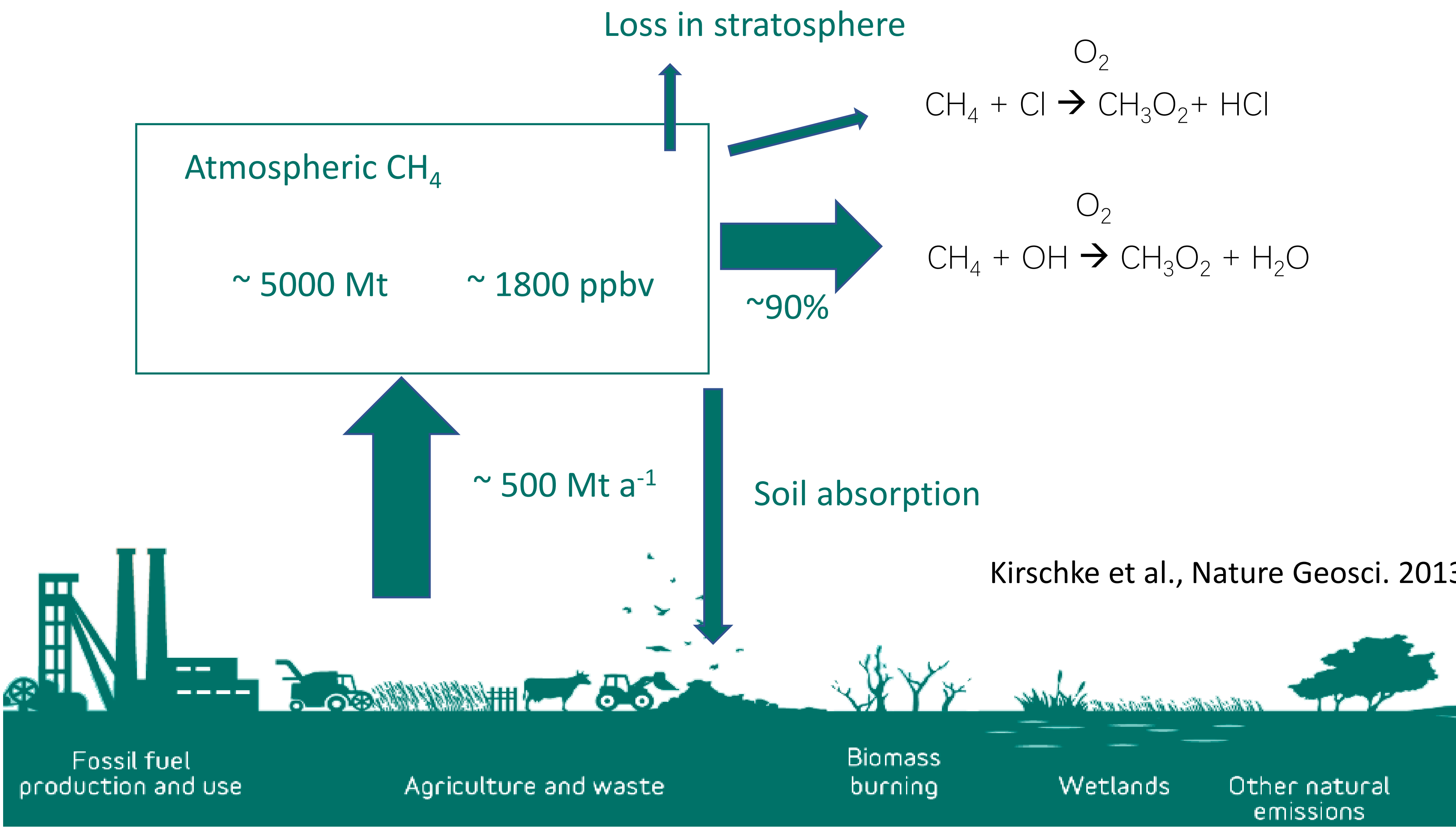





Greenhouse Gas: Methane


Regional air pollution
(surface O_3, $PM_{2.5}$)

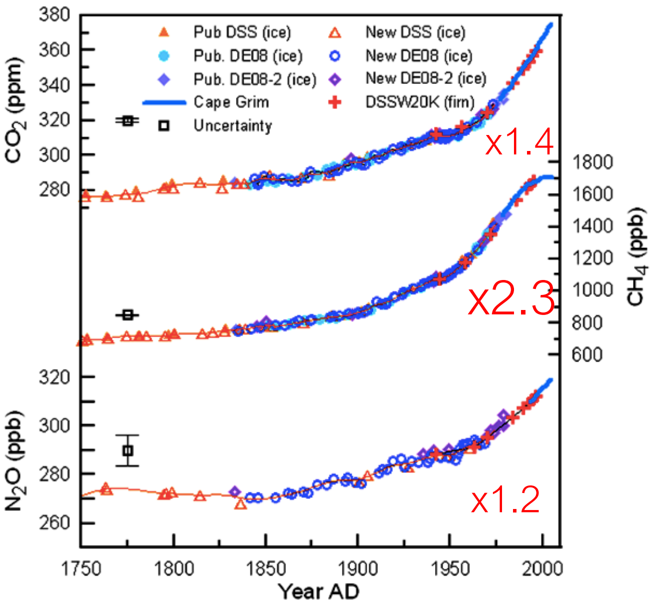
Greenhouse gas – Methane (CH_4)



Kirschke et al., Nature Geosci. 2013

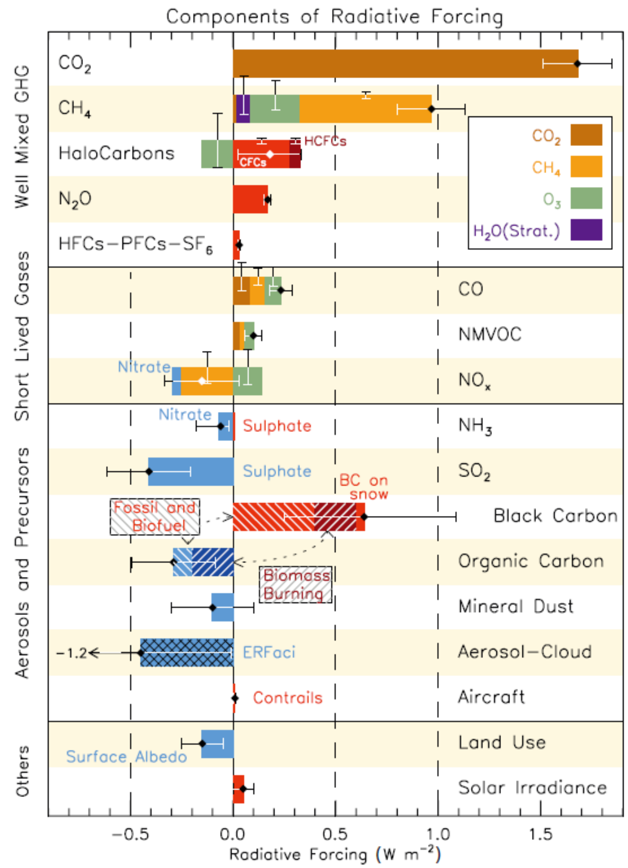
Potent greenhouse gas - Methane

Ice core record



MacFarling Meure et al., 2006

Climate effects since industrialization

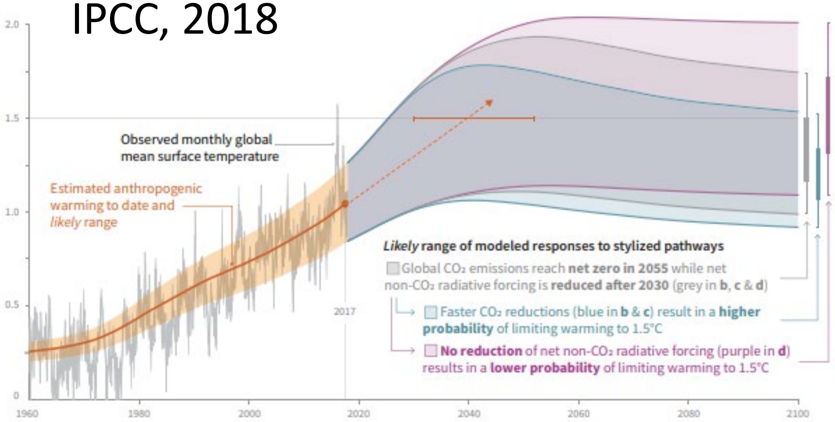


IPCC assessment report 5, 2013

Why it is important to study methane?

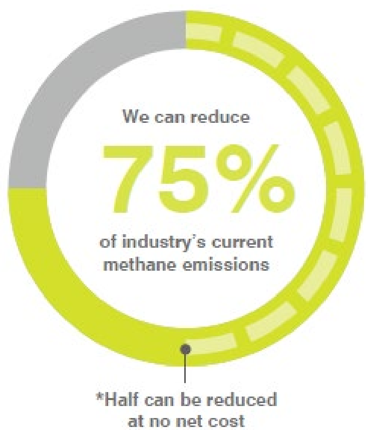
Necessary supplement to controlling CO_2 to meet climate goal

IPCC, 2018



Relative low-hanging fruit

- oil/gas industry makes money
- existing legal structure

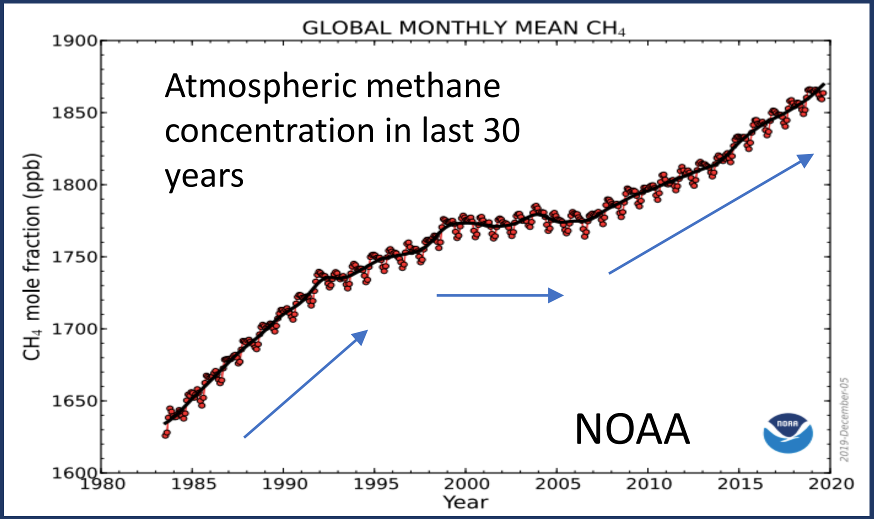


International Energy Agency

OIL AND GAS CLIMATE INITIATIVE

Knowledge gap

1. Understanding global methane budget and its changes



↑ wetland/rice emissions ($^{13}CH_4$)

Schaefer et al., 2016, Science

Nisbet et al., 2016, Global Biogeochem. Cycles

↑ oil/gas emissions (ethane)

Rice et al., 2016, PNAS
Hausmann et al., 2016, Atmos. Chem. Phys.

No significant trend in the U.S.
Lan et al., 2019, Geophys. Res. Lett

↓ fire emissions ($^{13}CH_4$ + CO)

Worden et al., 2017, Nature Communications

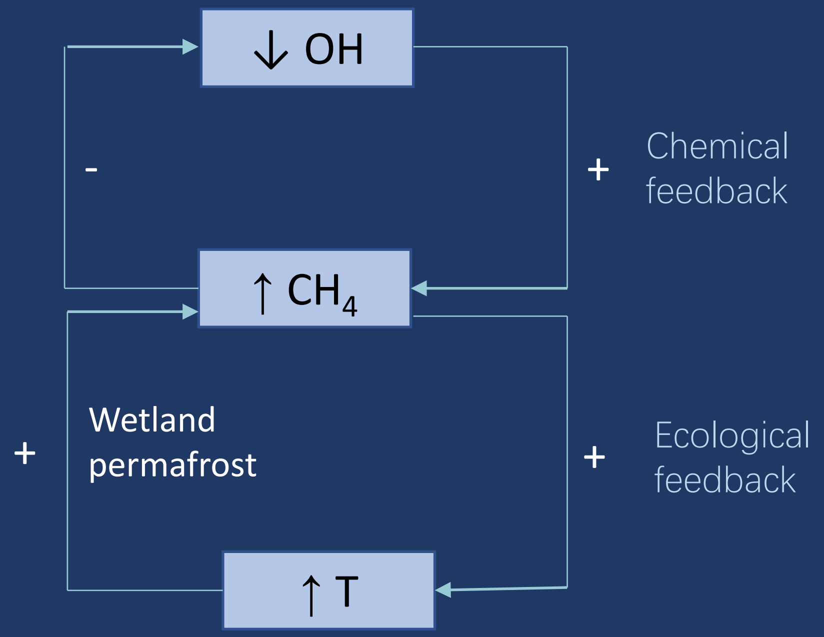
↓ decreasing sink by OH (CH_3CCl_3)

Rigby et al., 2017, PNAS
Turner et al., 2017, PNAS

Knowledge gap

1. Understanding global methane budget and its changes

Potential positive climate feedback involving CH_4



Knowledge gap

2. Information for actions

Paris agreement

National determined contributions (NDCs)

Important to have a monitoring platform to track, validate the implementation of NDCs

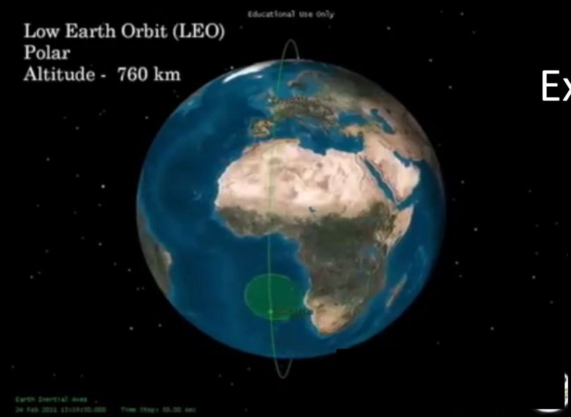
OIL AND GAS CLIMATE INITIATIVE

Identify hotspots at facility level

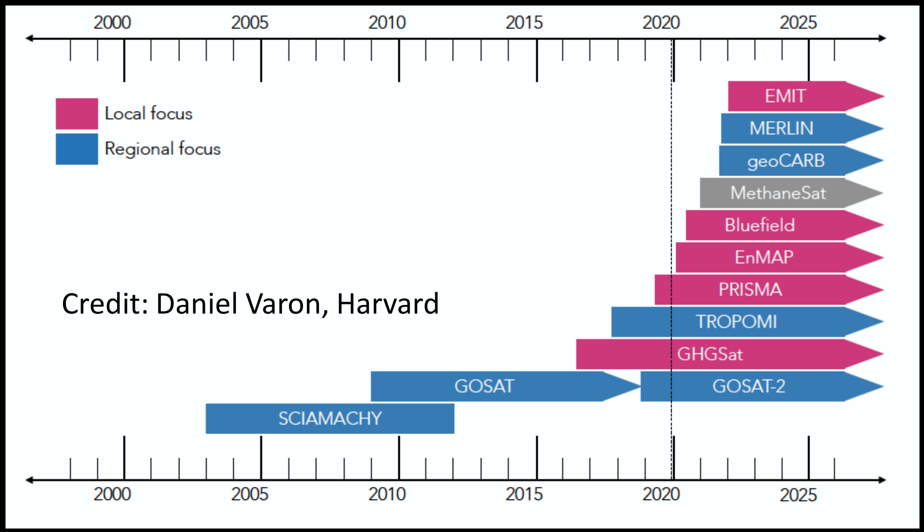
Detection & monitoring system that informs the operators where to look

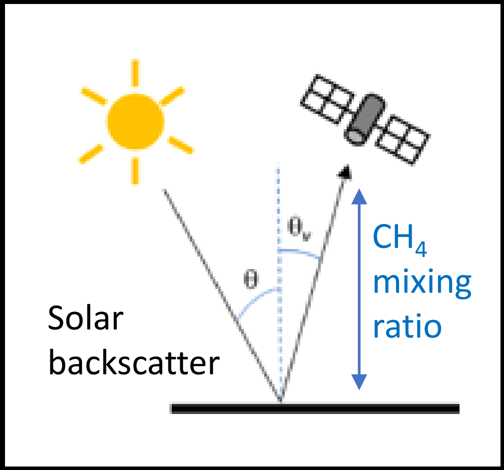

EDF
ENVIRONMENTAL
DEFENSE FUND

Satellite-based observations: solution?



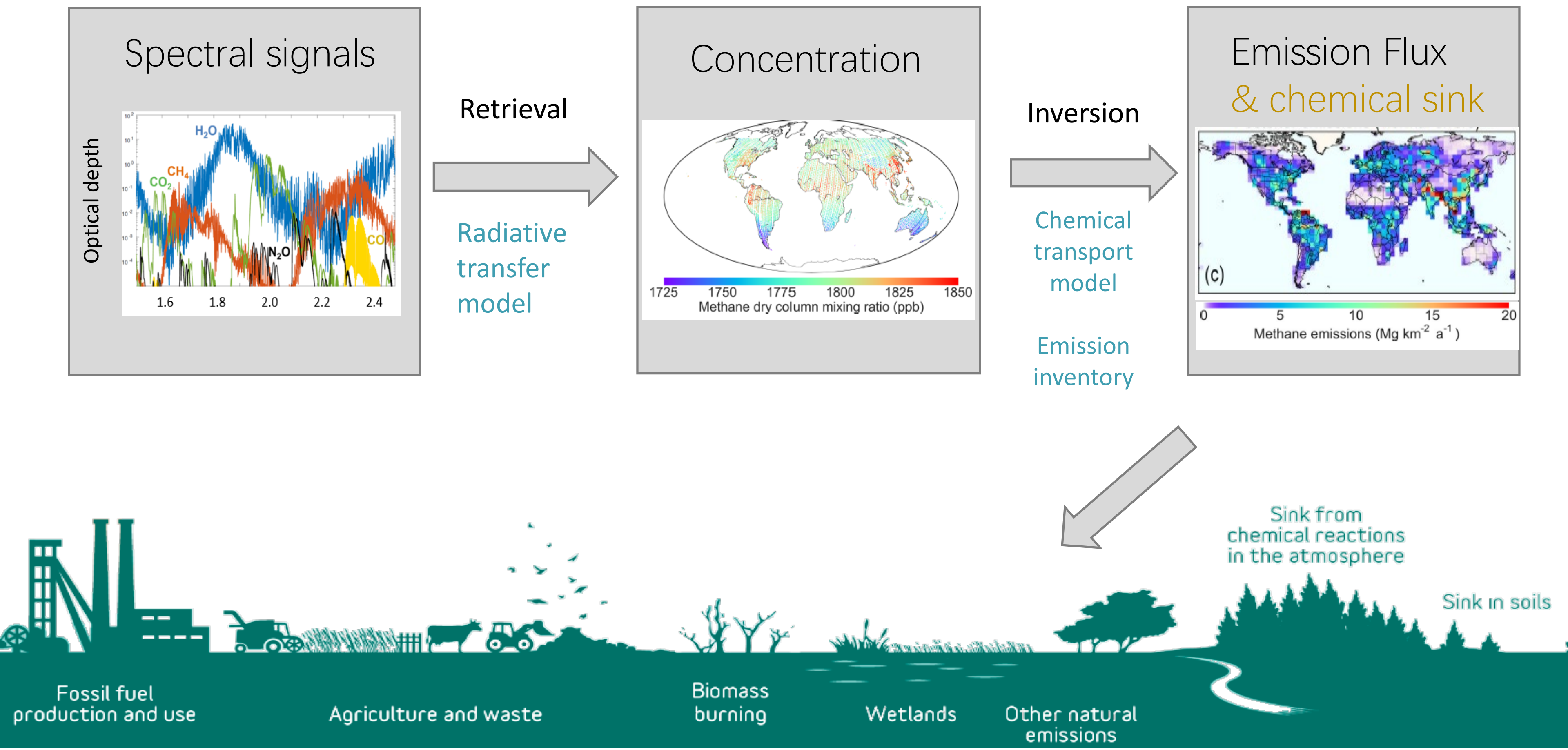
Existing and planned satellite for CH4 measurements





Jacob et al., 2016

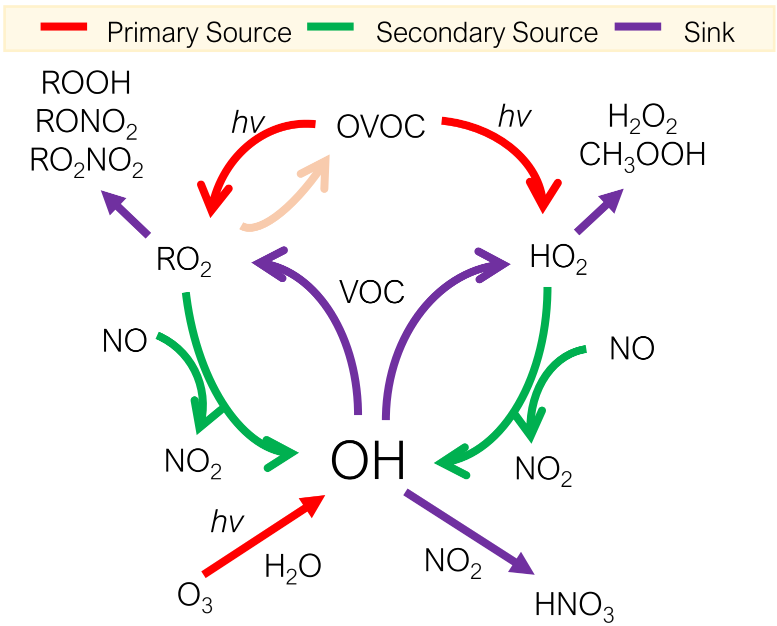
Monitor methane emissions from space



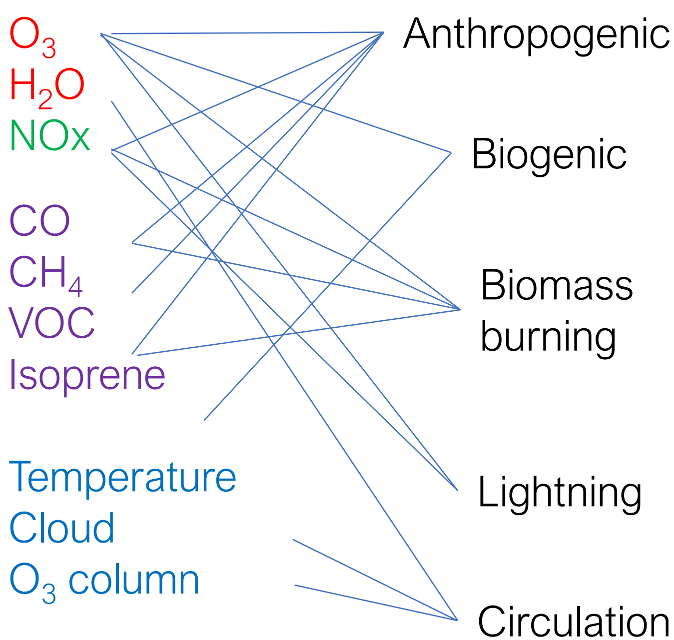
Turner et al., 2015; Zhang et al., 2018; Maasakkers et al., 2019; Zhang et al., in prep; Lu et al., in prep

Hydroxyl radical (OH): most important oxidant in the air

Central role of OH in
O_3-NO_x-VOC photochemistry



Chemicals and factors controlling
global OH concentration



Monitor hydroxyl radical concentration from space ?

Surface measurements

Sparse measurements & lack of source information

→ Methylchloroform (CH_3CCl_3) — Prinn et al., Science, 2001; Montzka et al., Science, 2011

Hydroflurocarbons — Liang et al., JGR, 2017

^{14}CO — Manning et al., 2005, Nature; Murray et al., 2019, IGC9

Satellite measurements

Insensitive to global temporal changes

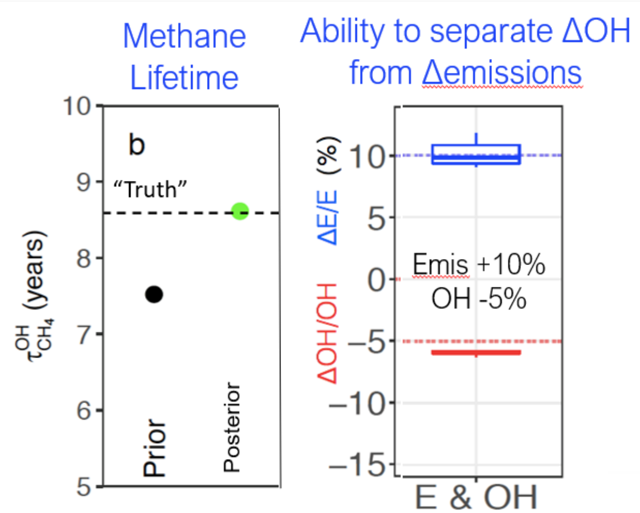
CO — Gaubert et al., GRL, 2017

HCHO over remote ocean — Wolfe et al. PNAS, 2019

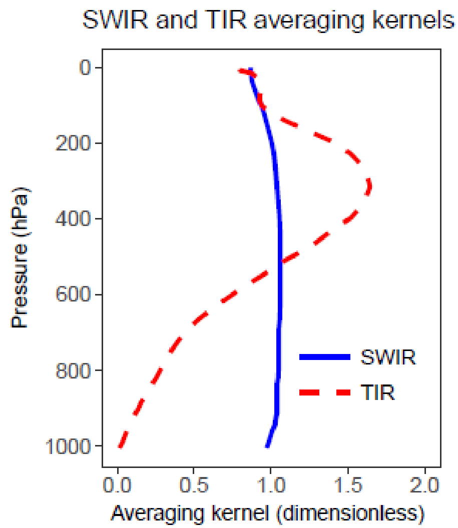
→ CH_4 — Zhang et al. ACP, 2018

Monitor hydroxyl radical concentration from space

Global OH concentration can be inferred from satellite methane observations



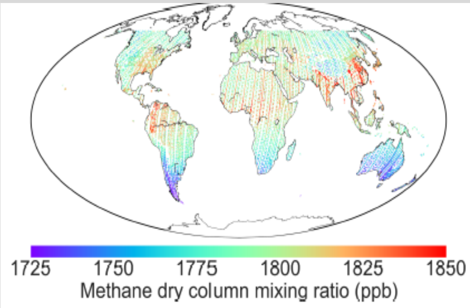
Two-band methane observations enhance the detectability



Zhang et al., 2018

Monitor methane emissions from space

Concentration

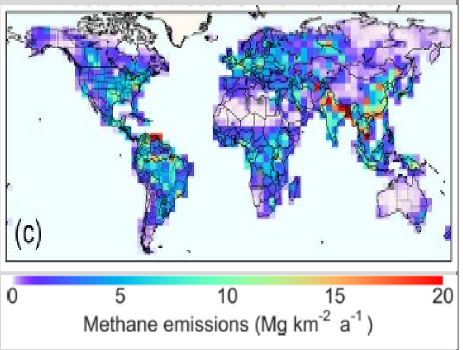


Inversion

Chemical transport model

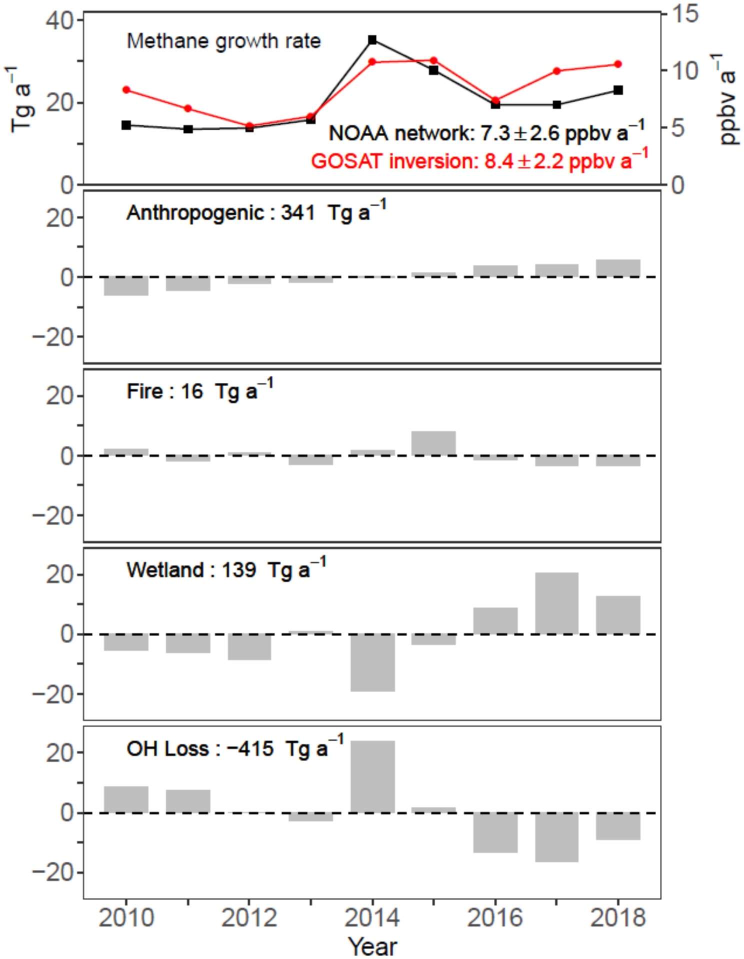
Emission inventory

Emission Flux
& chemical sink

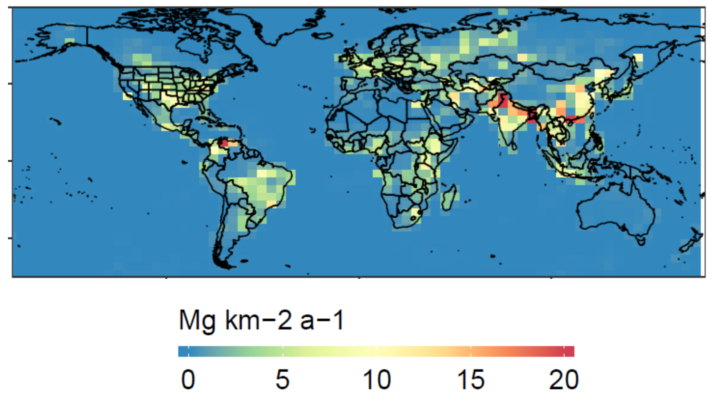


Global methane budget analysis

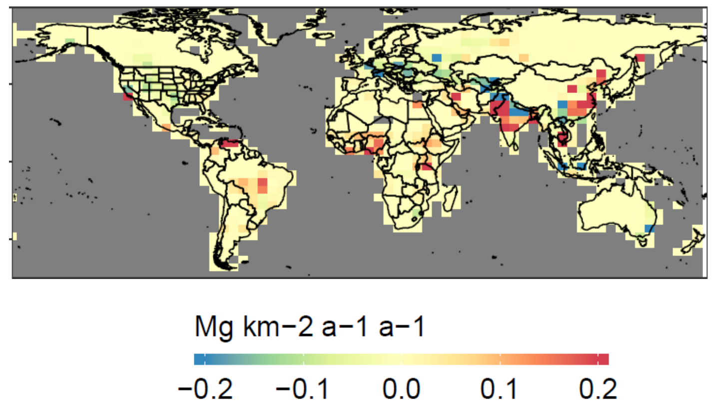
Budget attribution



Anthropogenic emissions



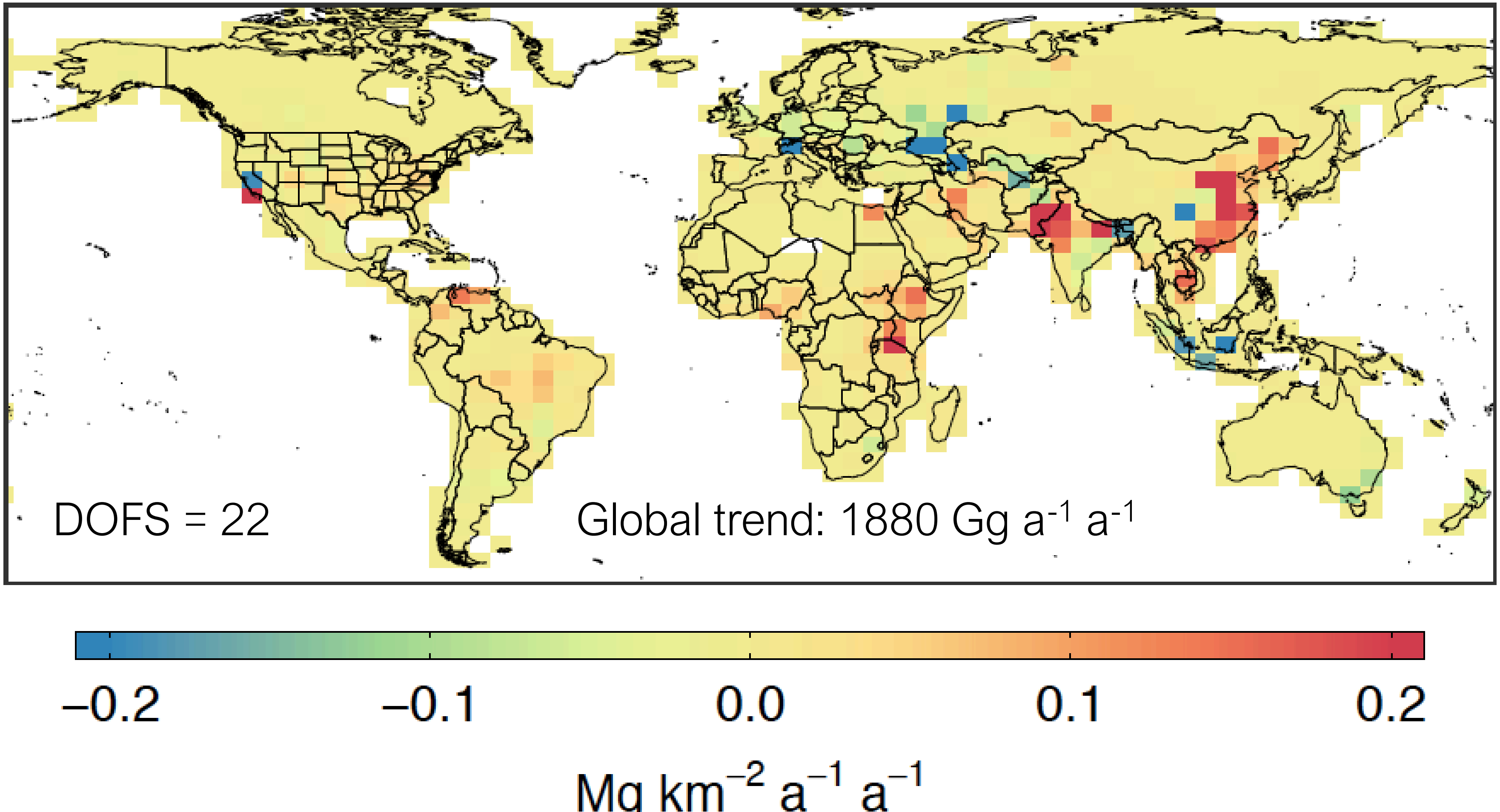
Anthropogenic emission trends



Zhang et al., in prep

Changes in anthropogenic methane emissions

Linear trends of anthropogenic emissions during 2010-2016



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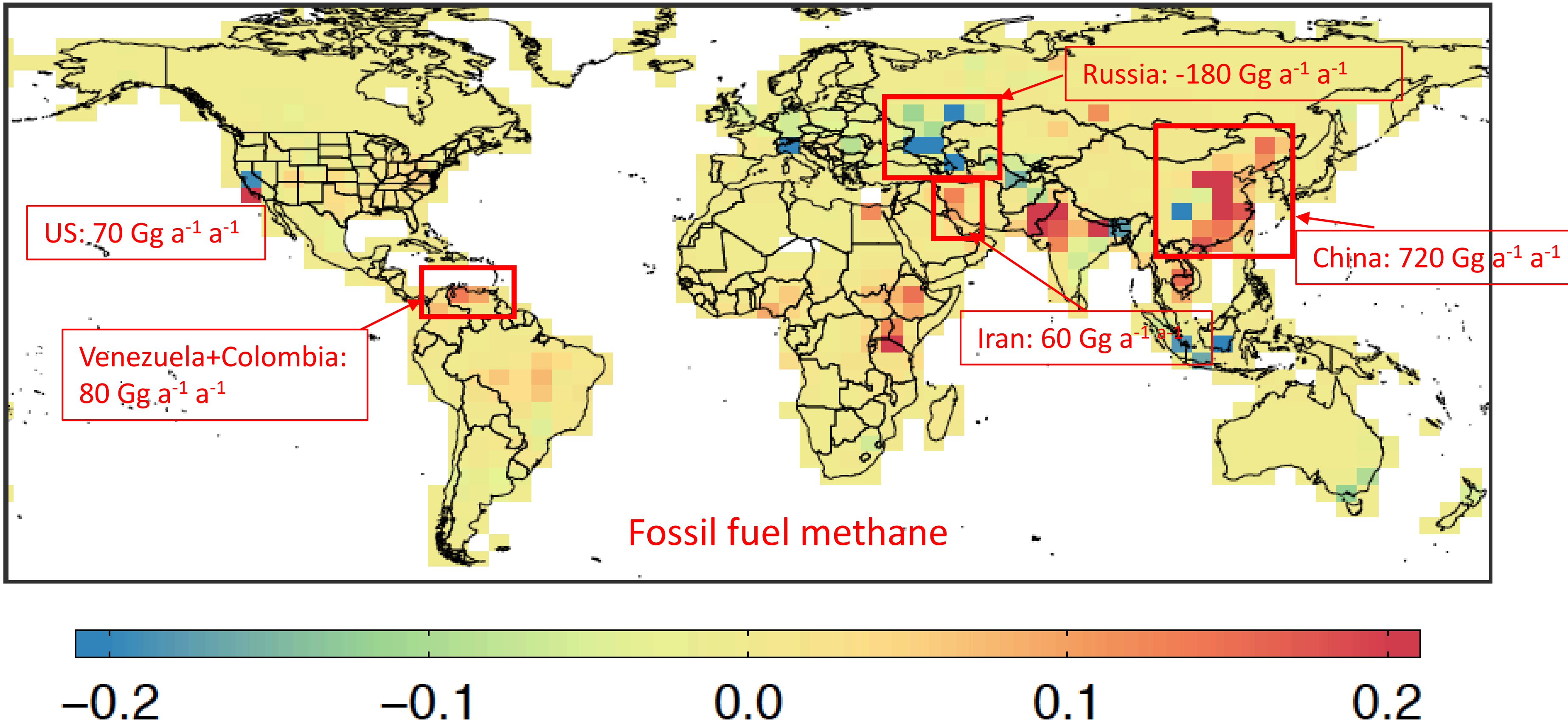

Global trend: 1880 Gg a^{-1} a^{-1}

Mg km^{-2} a^{-1} a^{-1}

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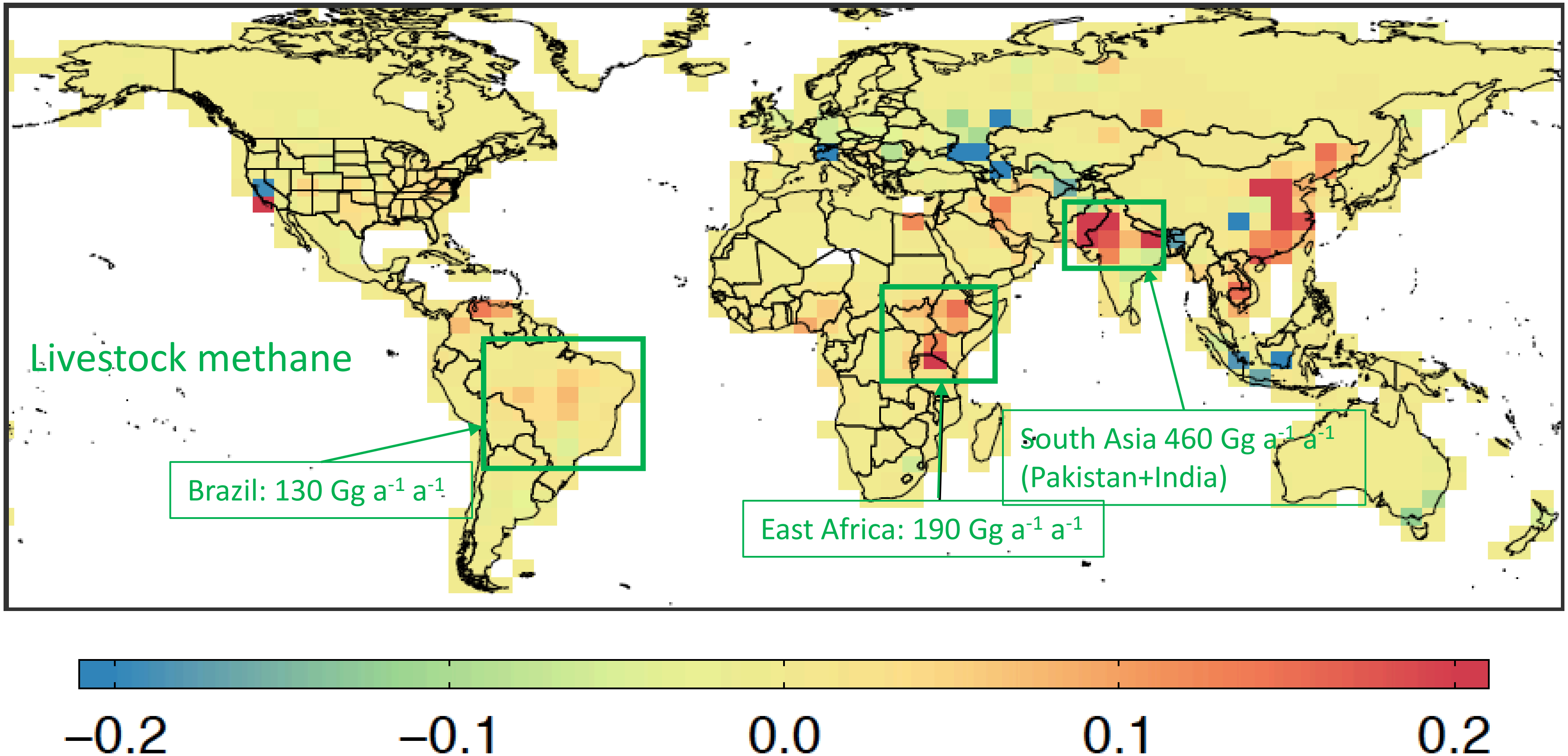

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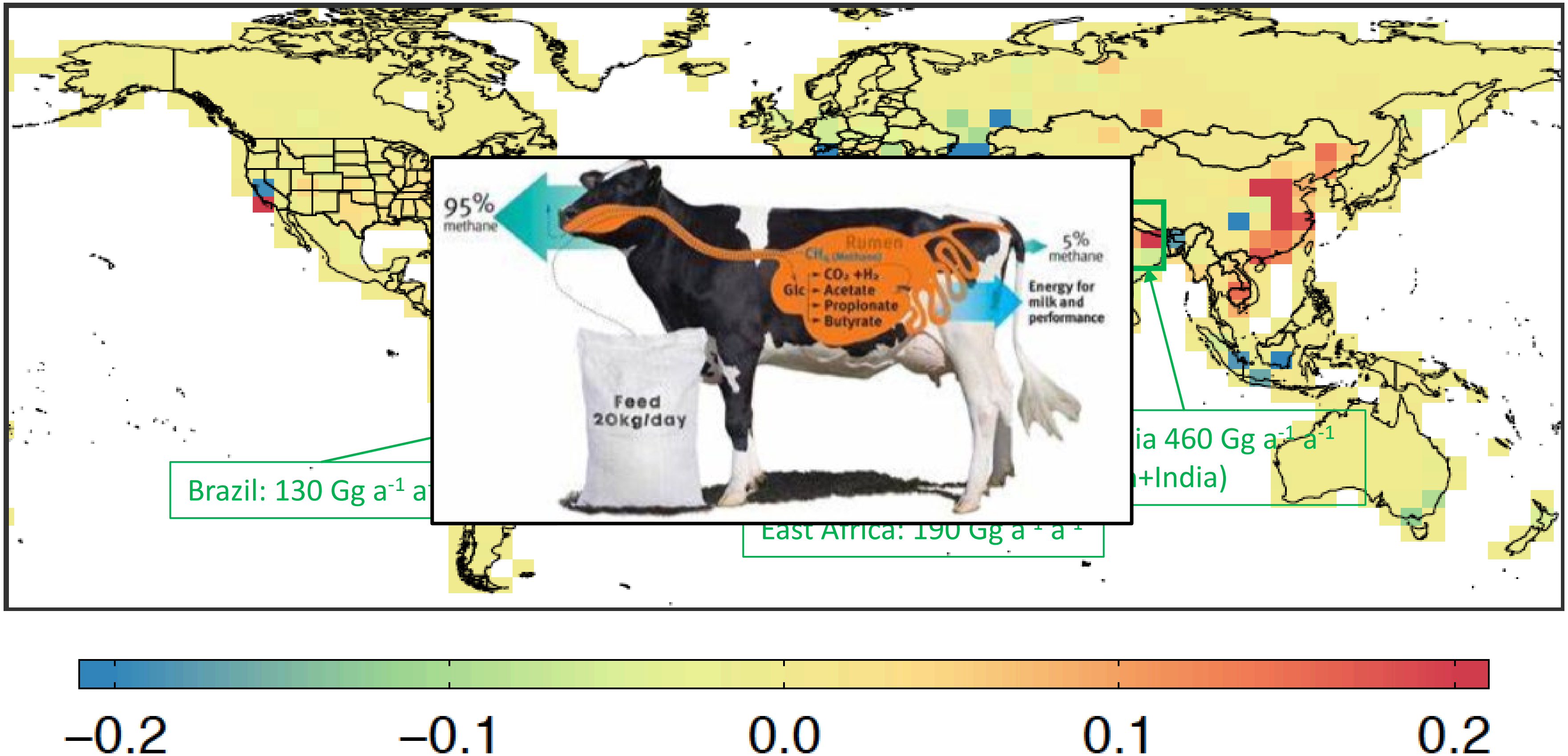
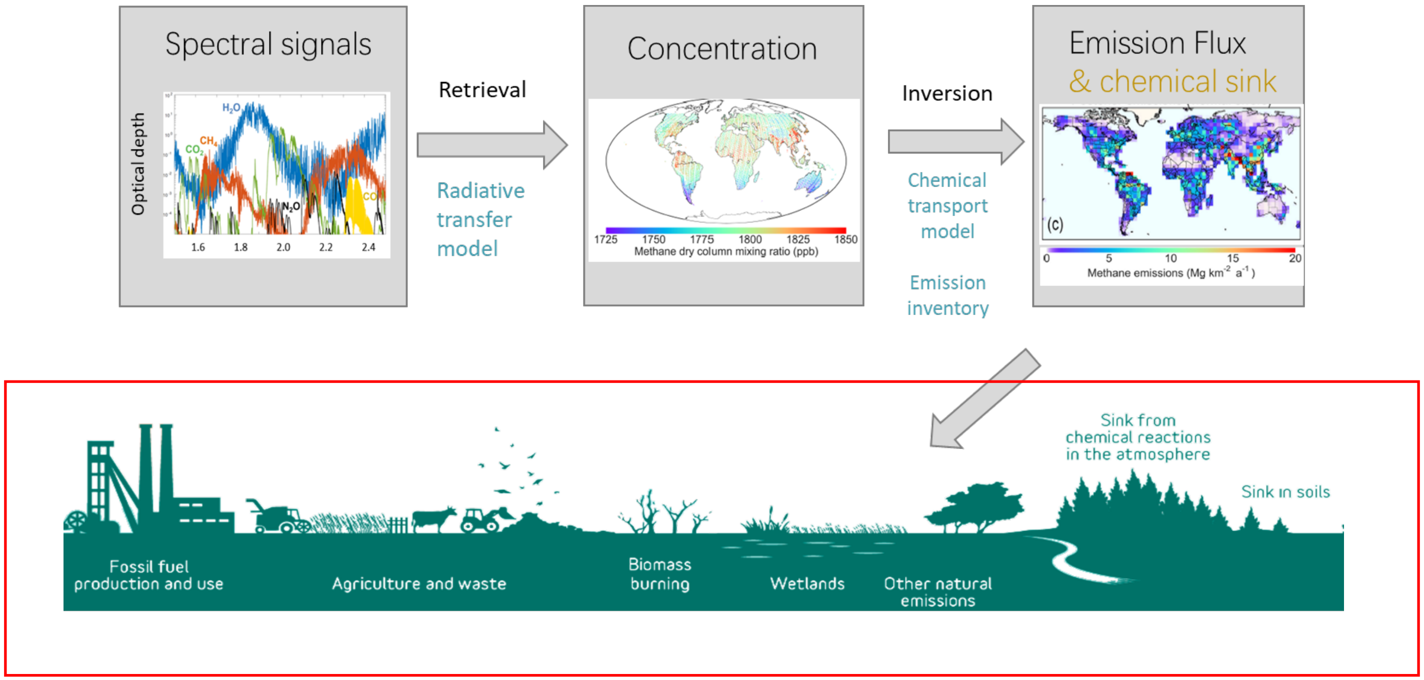


Global trend: 1880 Gg a^{-1} a^{-1}

Mg km^{-2} a^{-1} a^{-1}

What next?

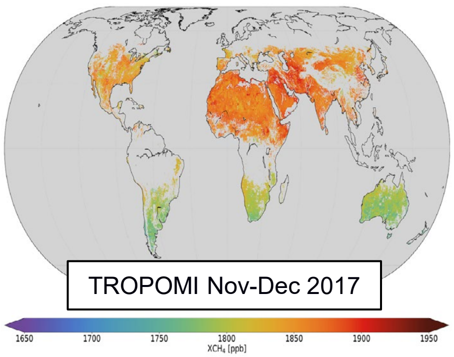
Use the constraints provided by satellite observations to improve our understanding of each budget terms



Information for actions

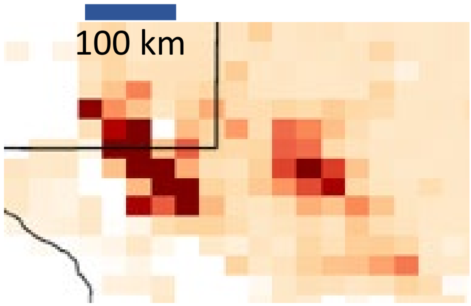
- Efficiently assimilate huge amount of satellite data
- Provide information relevant to government and operators

Global/national scale



~1000 km

Regional/basin scale



~10 km

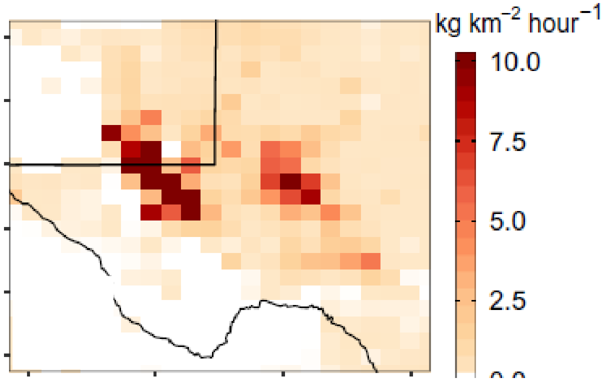
Permian basin

5.5×10^5 m^3 a^{-1} crude oil
3.2×10^8 m^3 a^{-1} natural gas

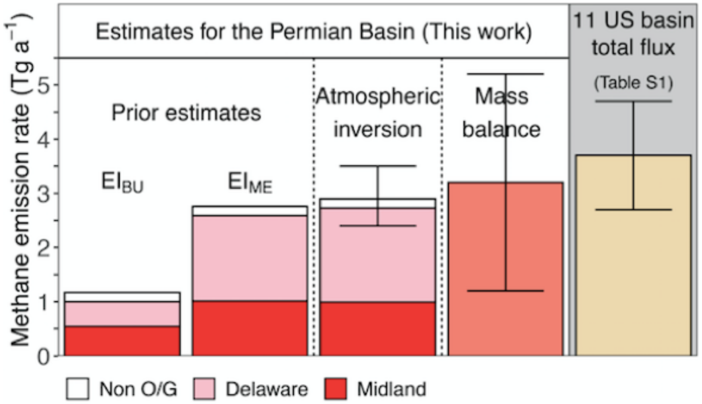
150,000 oil/gas wells

Largest methane emitting oil/gas basin in U.S.

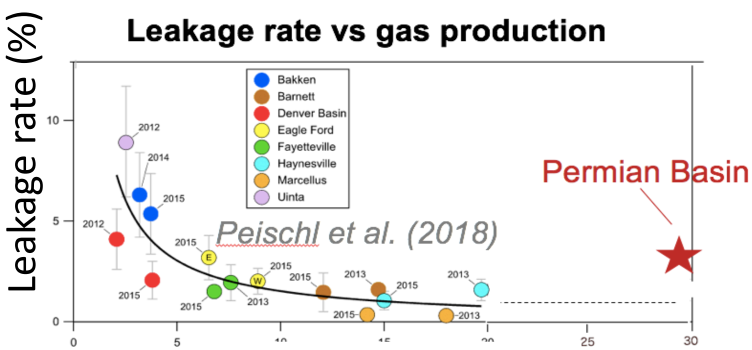
Spatial distributions



Comparable to 11 basins combined



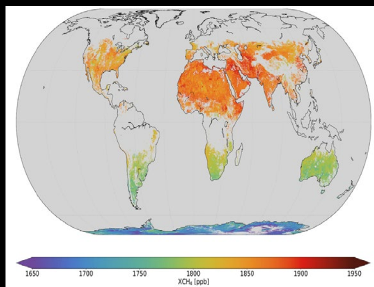
High leakage rate indicates lag in natural gas infrastructure



Zhang et al., Science Advances, 2020

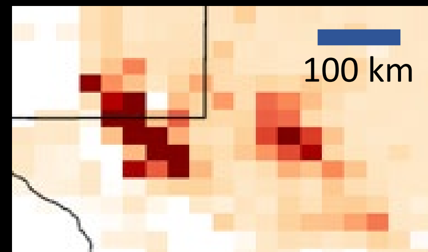
Next: Actionable environmental monitoring data

Global/national scale



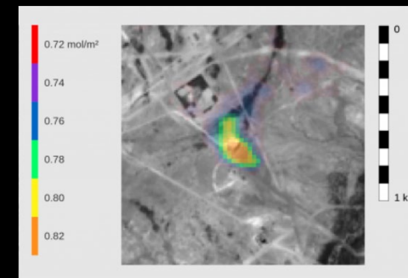
~1000 km

Regional/basin scale



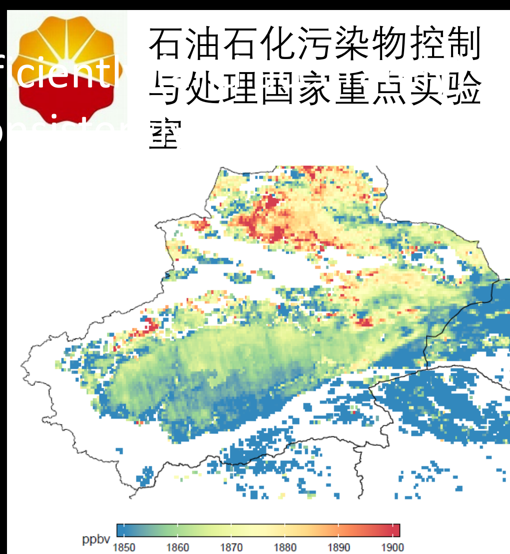
~10 km

Facility scale



~100 m

- Eff rocess large amount of satellite data
- Co e sources of information



Summary: greenhouse gas methane

Analysis of satellite observations of CH_4 are set to provide

- Valuable constraints to understand the global balance of methane concentration
- Useful information to inform actions to flight climate change

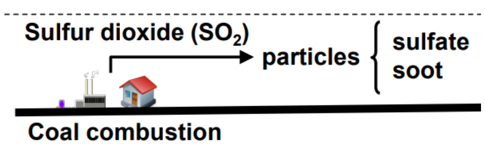

Greenhouse Gas: Methane


Regional air pollution
(surface O_3, $PM_{2.5}$)

Air pollution

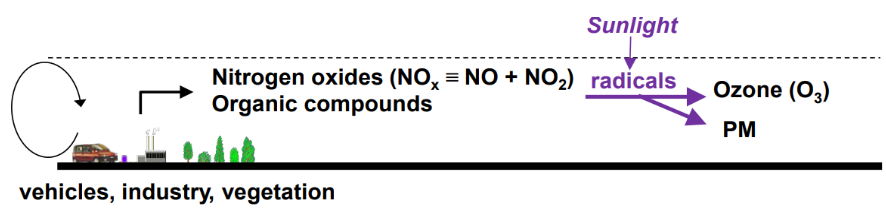
London fog (PM2.5)

“Killer fog” of December 1952 caused 10,000 deaths in 4 days



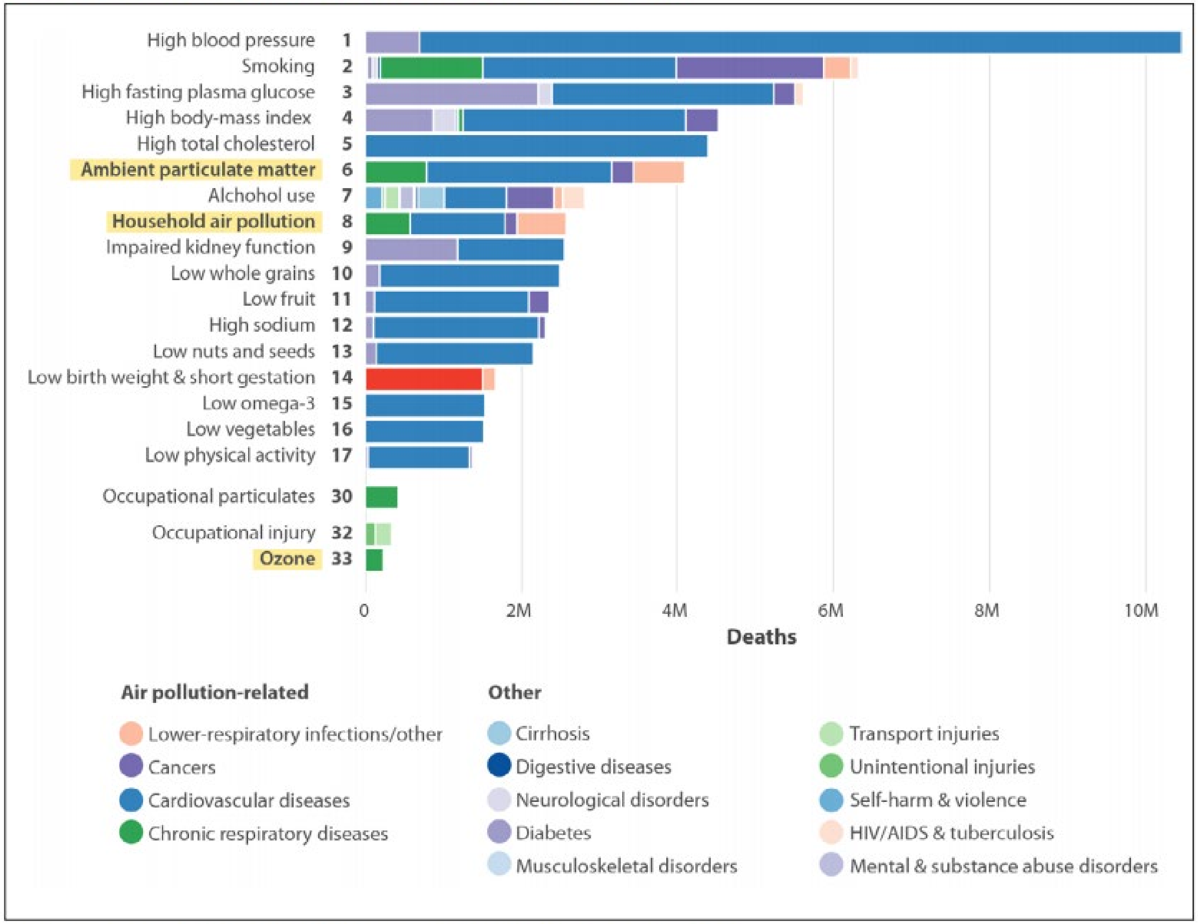
Los Angeles smog (ozone)

~ 1970’s



Air pollution

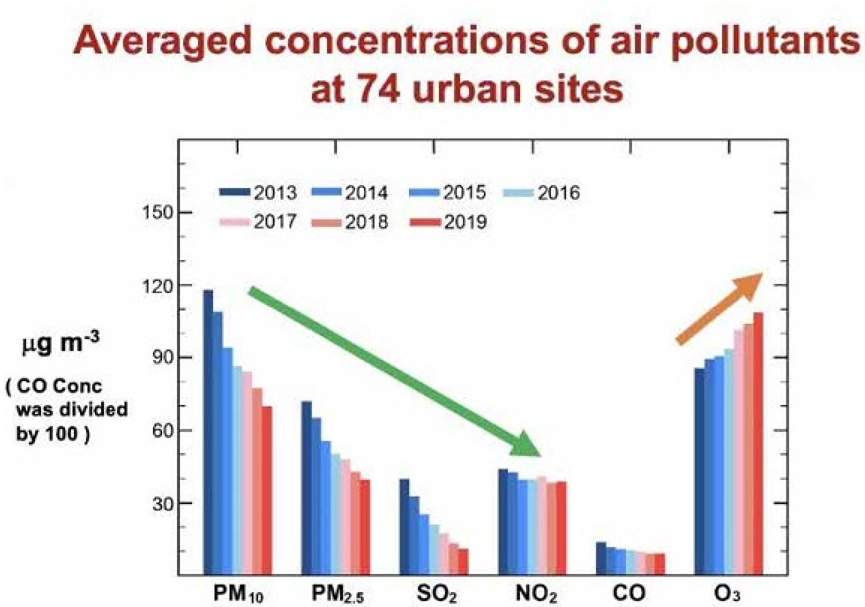
Figure 1. Global ranking of risk factors by total number of deaths from all causes for all ages and both sexes in 2016.



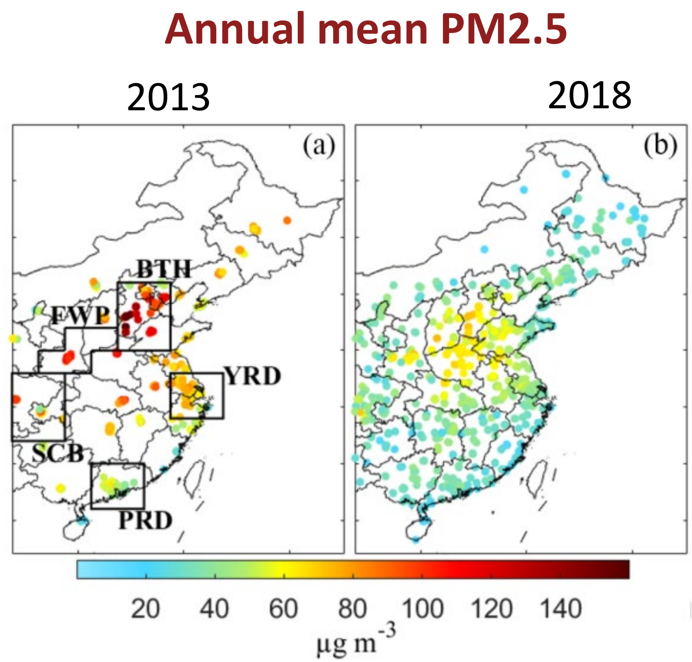
Explore the rankings further at the IHME/GBD Compare site.

Health effects institute, 2018

Regional air pollution in China



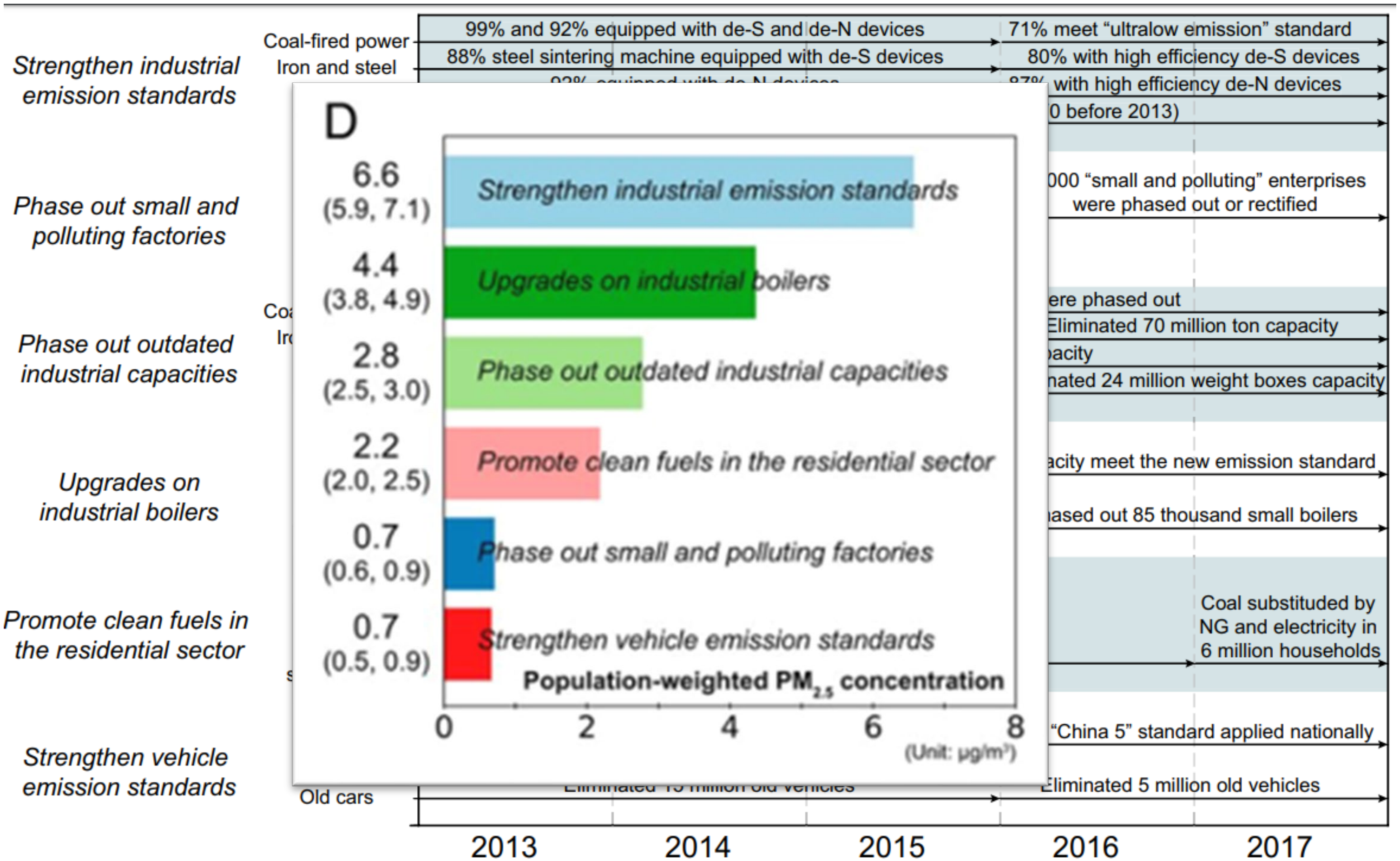
Hong Liao, NUIST



Zhai et al., Atmos. Chem. Phys. 2019

- What are effective measures that led to the reduction in pollution?
- What should we do to further reduce PM2.5?
- Why ozone is increasing?

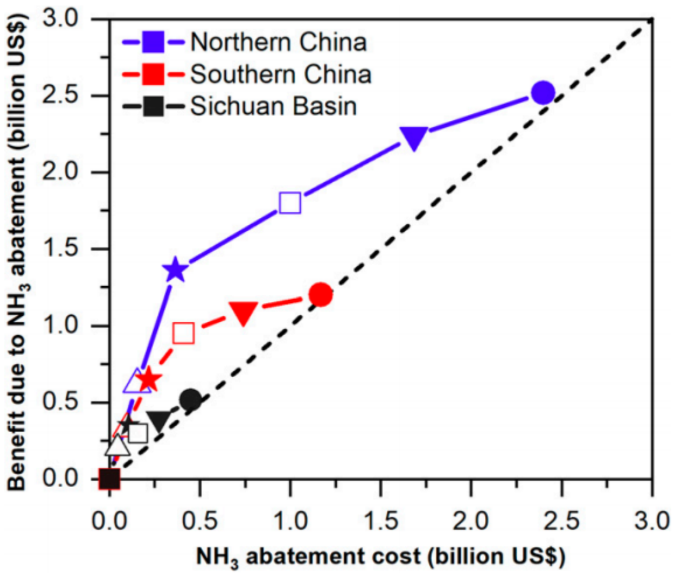
Measures taken since 2013



Q. Zhang et al., PNAS, 2019

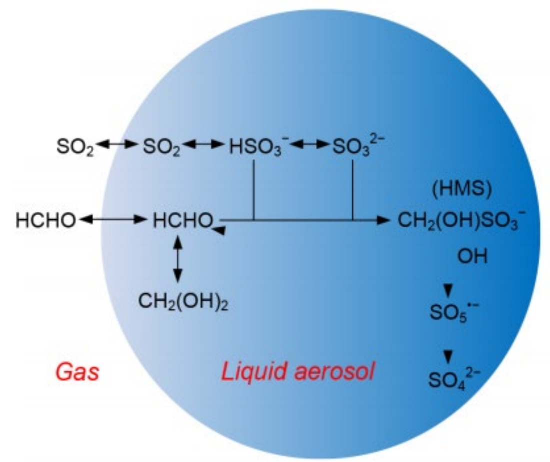
What is the pathway forward for PM2.5

Control ammonia emissions to further reduce PM2.5



Liu et al., PNAS, 2019
Zheng et al., Geophys. Res. Lett., 2019

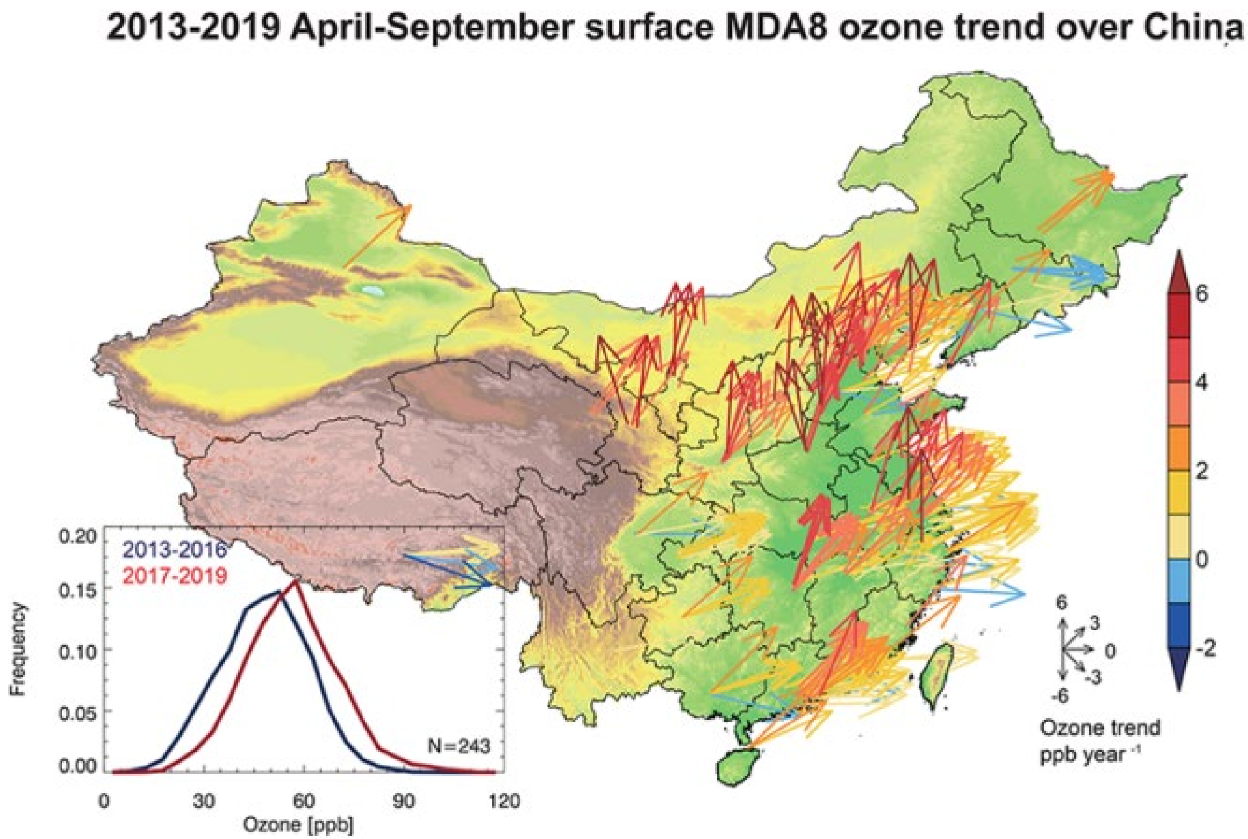
Novel mechanisms for secondary particle formation



hydroxymethanesulfonate (HMS)

Song et al., Atmos. Chem. Phys., 2019
Moch et al., Geophys. Res. Lett., 2019
Ma et al., Atmos. Chem. Phys., 2020

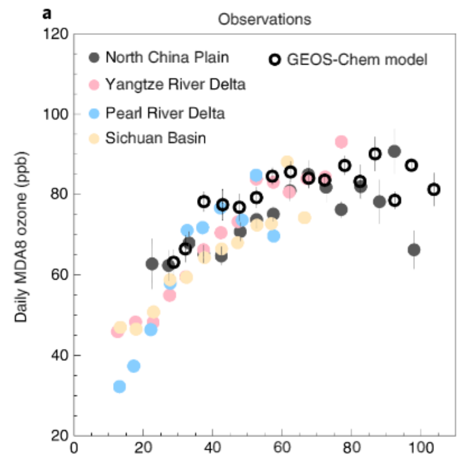
Ozone getting worse. Why?



Lu et al., 2020

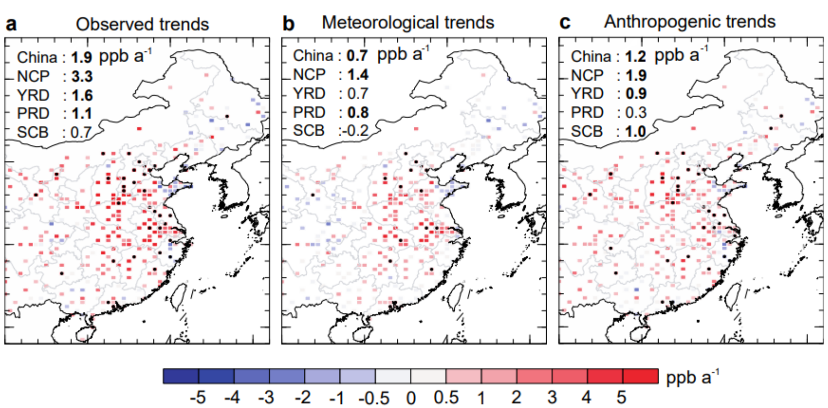
Ozone getting worse. Why?

Interaction between pollutants



PM2.5 suppresses radicals in the air

Interaction with meteorology

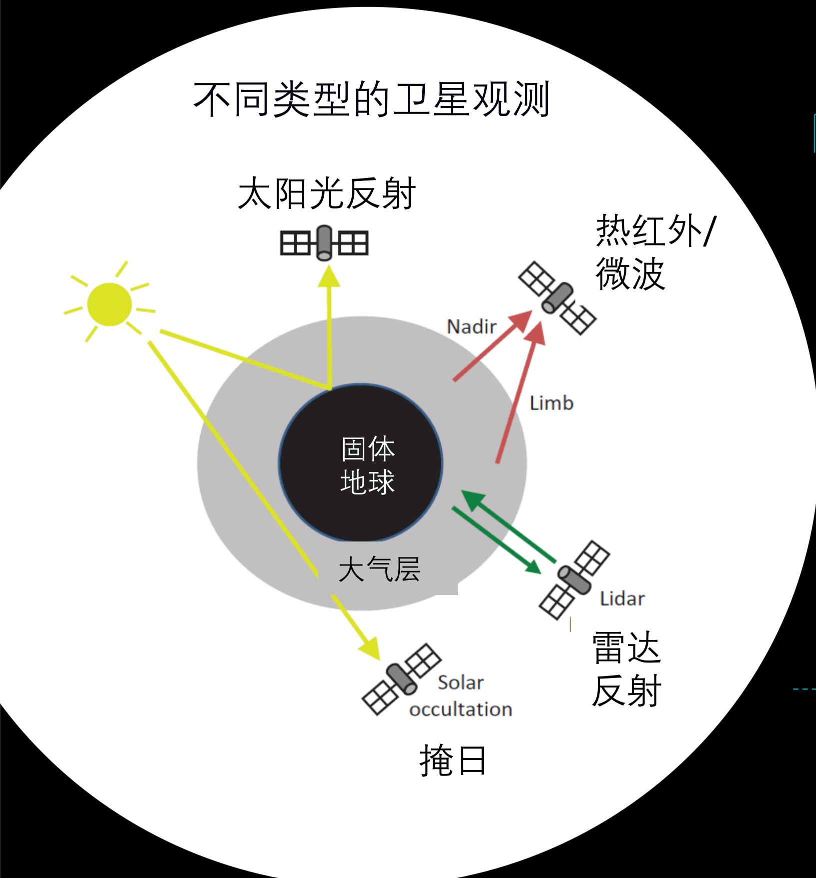


Li et al., PNAS, 2019
Li et al., Nature Geosci., 2019
Li et al., Atmos. Chem. Phys, 2020

Summary: regional air pollution

- Air quality in China has improved significantly in last 5 years, as results of strict control measures
- Ozone concentrations have been increasing, likely because interactions with other pollutants and meteorology
- NH3 control has been proposed to reduce PM2.5 in next 5 years
- Scientific studies help elucidate pathways to further improvement

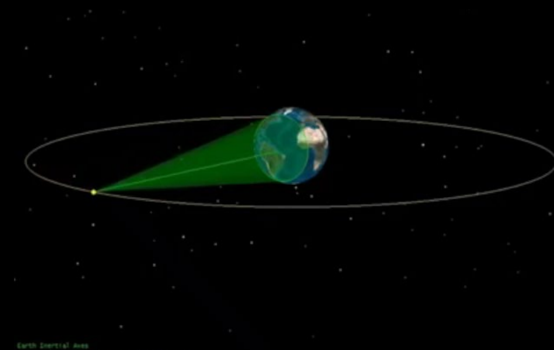
卫星环境监测的独特优势



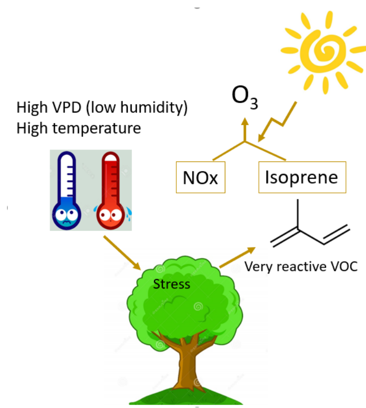
覆盖范围广

极轨轨道 500-1000 km 高度

地球同步轨道 36,000 km 高度



Coupling: pollution and climate



Zhang and Wang, 2017

Zhang et al., 2018