西湖大學 WESTLAKE UNIVERSITY

基于卫星观测的大气甲烷排放估算

从全球趋势到区域热点

张 羽 中

中国大气环境科学与技术大会 2020.12.8

致 谢

Harvard
Daniel Jacob, Jianxiong Sheng, Xiao Lu, Tia Scarpelli, Daniel Varon, Lu Shen, Zhen Qu, Hannah Nesser

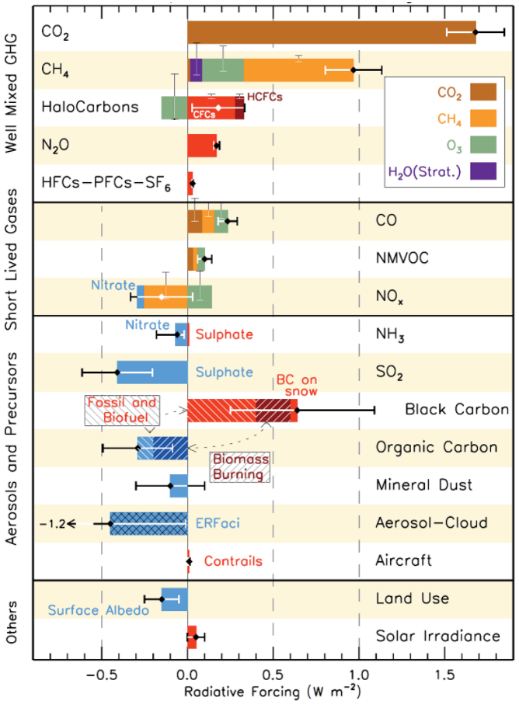
EDF
Ritesh Gautam, Mark Omara, Daniel Zavala-Araiza, David Lyon

JPL John Worden, Anthony Bloom, Shuang Ma

SRON Ilse Aben, Bram Maasakkers, Sudhanshu Pandey

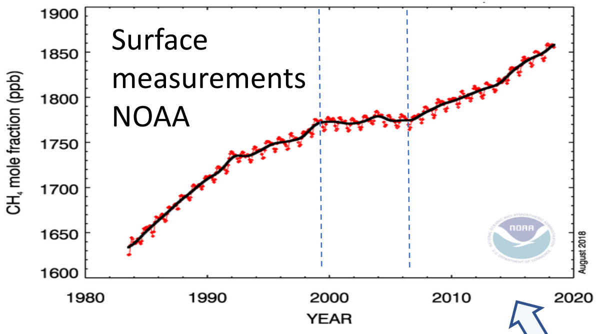
温室气体甲烷

Radiative forcing

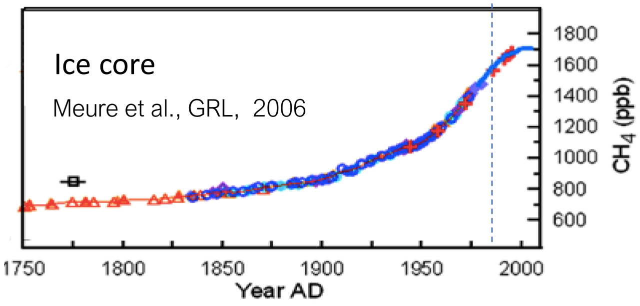


IPCC AR5

Methane concentration in last 35 years



Methane concentration in last 300 years



大气甲烷的源


Wetlands

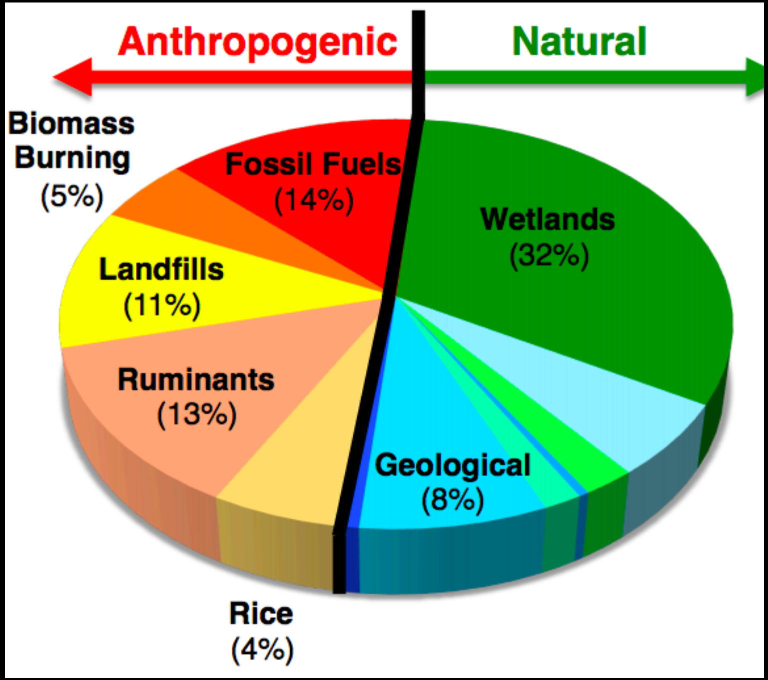

Oil/gas


Landfills,
wastewater

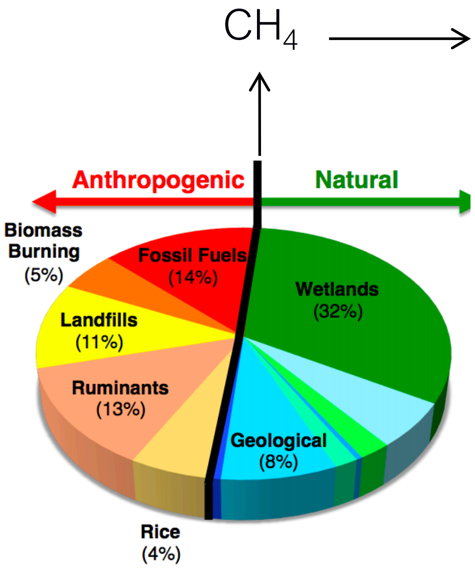

Livestock


Coal mines


Fires


Anthropogenic
Natural
Biomass Burning (5%)
Fossil Fuels (14%)
Wetlands (32%)
Landfills (11%)
Ruminants (13%)
Geological (8%)
Rice (4%)

大气甲烷的汇



源

550 ± 60 Tg a^{-1}

汇

大气寿命约10年

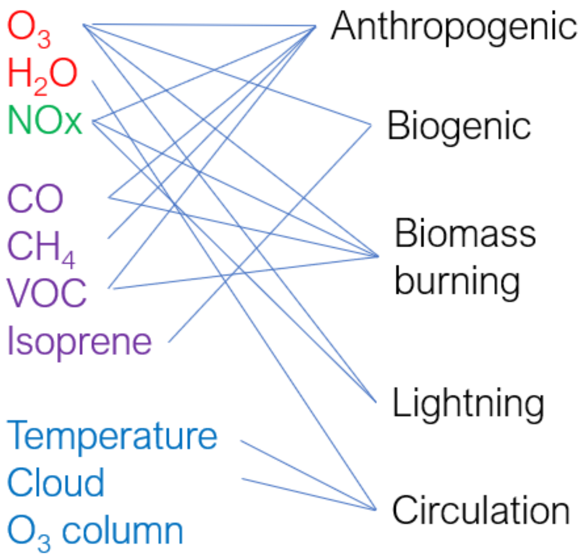
Tropospheric OH
89%

Soil Absorption

Stratospheric Loss

Tropospheric Cl

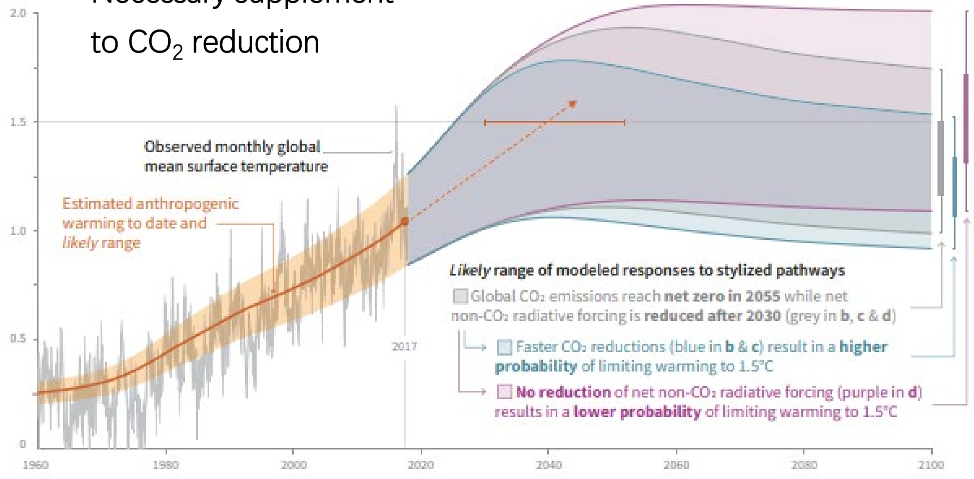
影响OH浓度的因素



甲烷减排的必要性和可行性

必要性

Necessary supplement
to CO_2 reduction

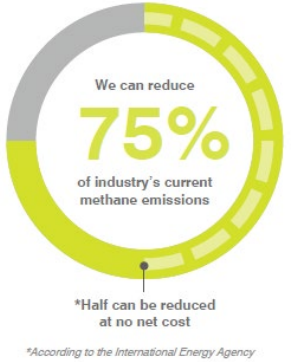


IPCC, 2018

可行性

能源行业甲烷减排有较高的可行性:

- 天然气经济价值
- 已有的技术手段
- 现有的法律架构



Global Methane Initiative	OGCI OIL AND GAS CLIMATE INITIATIVE	METHANE GUIDING PRINCIPLES
政府	油气企业	企业+民间+学术界

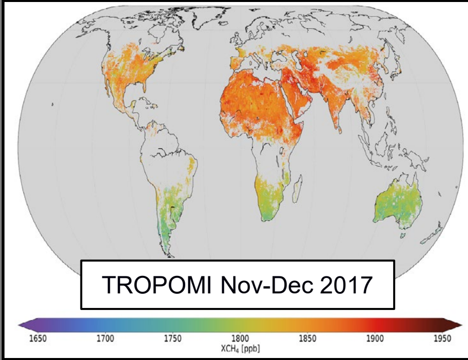
具有挑战的监测需求

全球覆盖
世界每个角落的排放
都贡献气候变化

不同时空尺度信息整合
全球收支、国家盘点、区域/
行业热点、设施维修

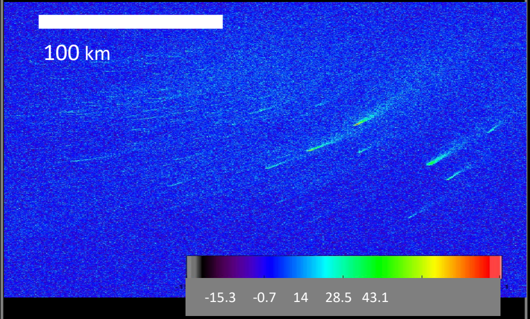
源监测
源数量多、种类多
绝对量较小、但波动很大

国家/全球尺度



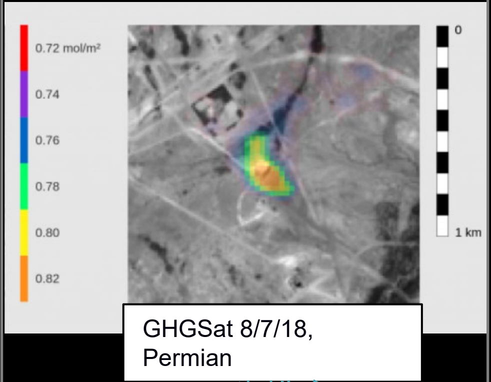
5-10 km 分辨率

区域/盆地尺度



~500-1000 m 分辨率

设施尺度

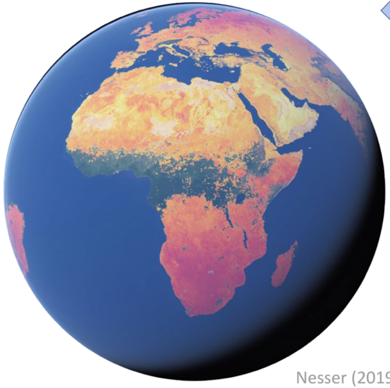


~10 m 分辨率

甲烷的科学问题：从全球到区域到点源

Global/national Scale

- 全球收支
- 气候反馈耦合
- 国家级减排措施的验证

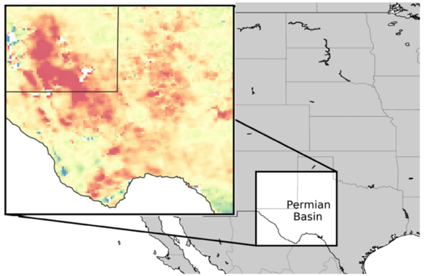


Nesser (2019)

500 km resolution

Regional Scale

- 区域热点的时空分布和影响因素
- 指导点源探测

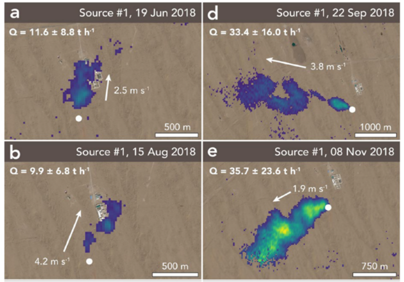


Zhang et al. (2020)

10 km resolution

Facility Scale

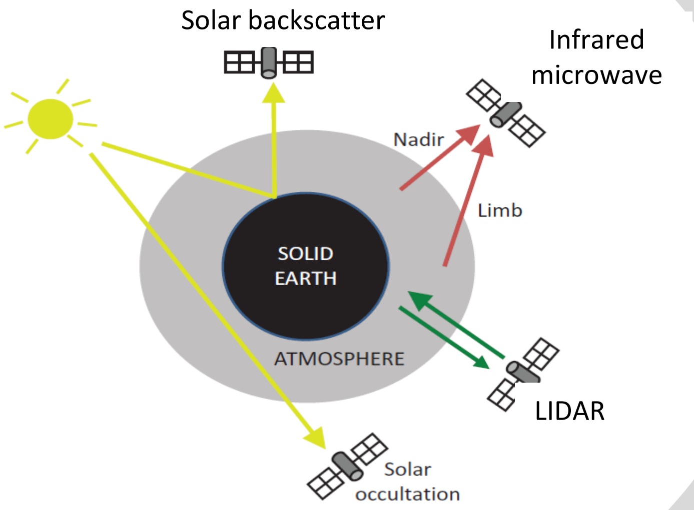
- 探测异常排放
- 为减排措施提供指引：检测、维修…

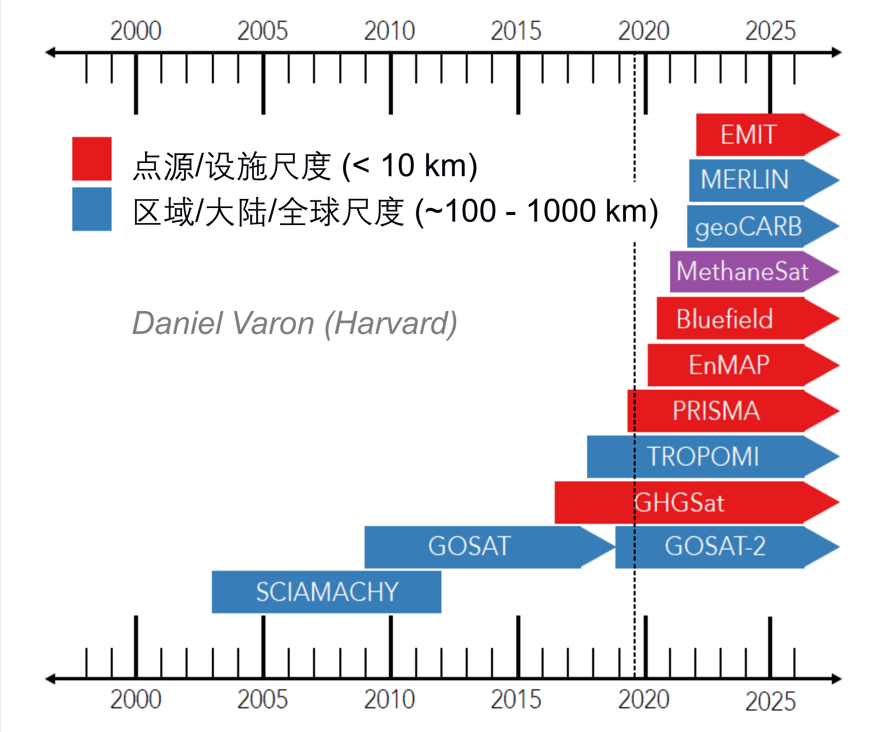


Varon et al. (2019)

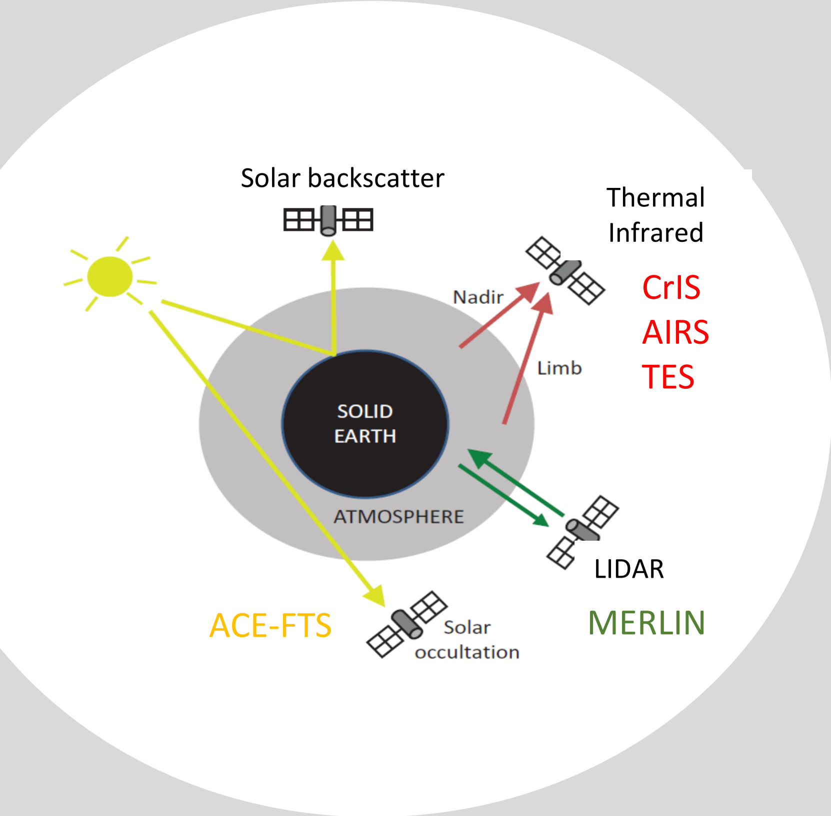
10 m resolution

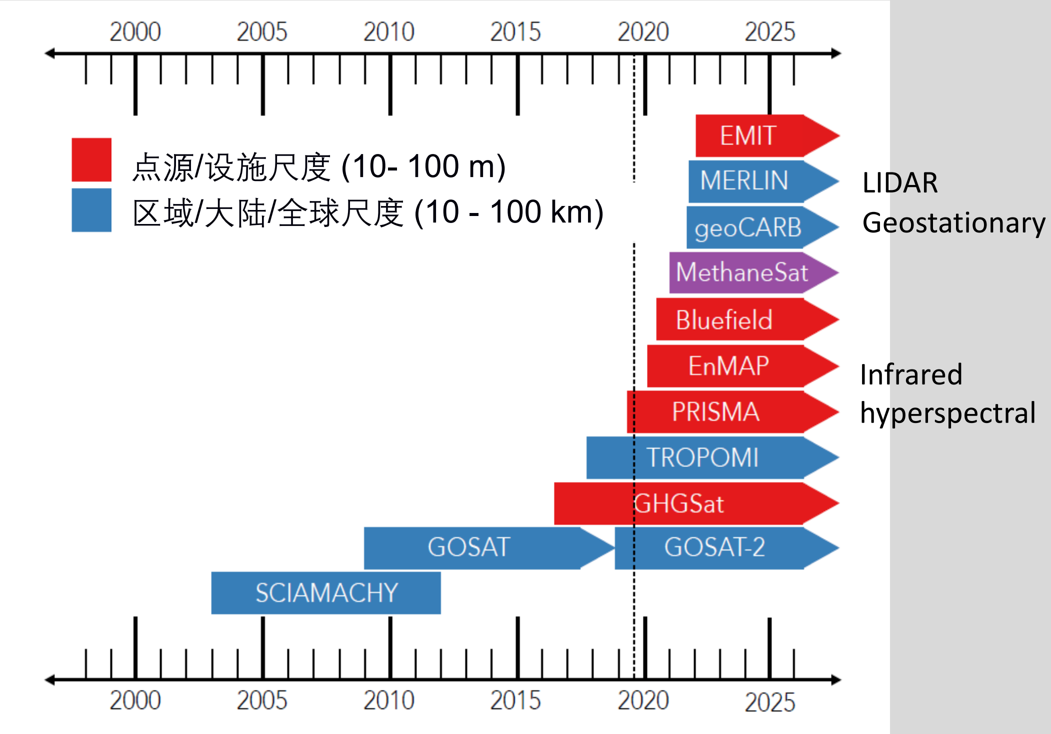
发展迅速的卫星观测能力





迅速发展的卫星观测能力



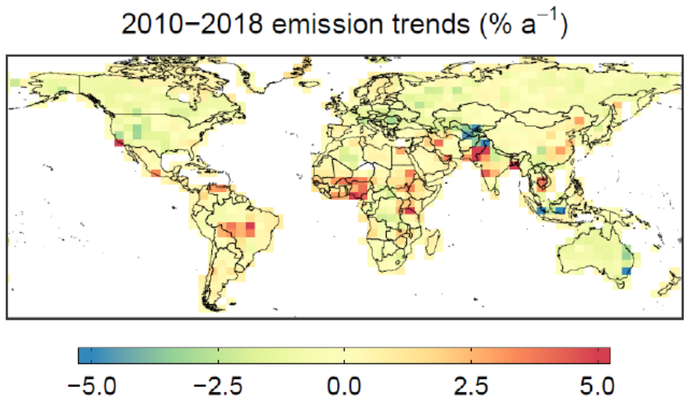


Daniel Varon, Harvard

大气甲烷：从全球收支到区域热点

Global

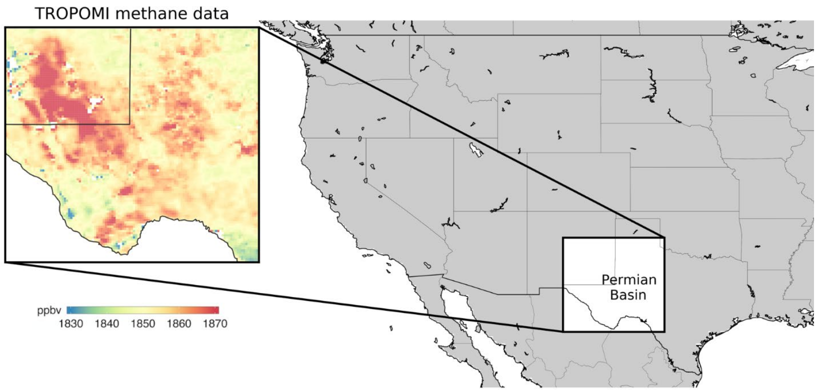
2010-2018全球大气甲烷收支



Zhang et al., 2020; Lu et al., 2020; Maasakkers et al., 2019; Zhang et al., 2018

Regional

美国最大油气盆地甲烷排放量估计



Zhang et al., Sci. Adv., 2020;
Zhang et al., GRL, 2019

什么因素驱动了大气甲烷的浓度变化？

Atmospheric constraints

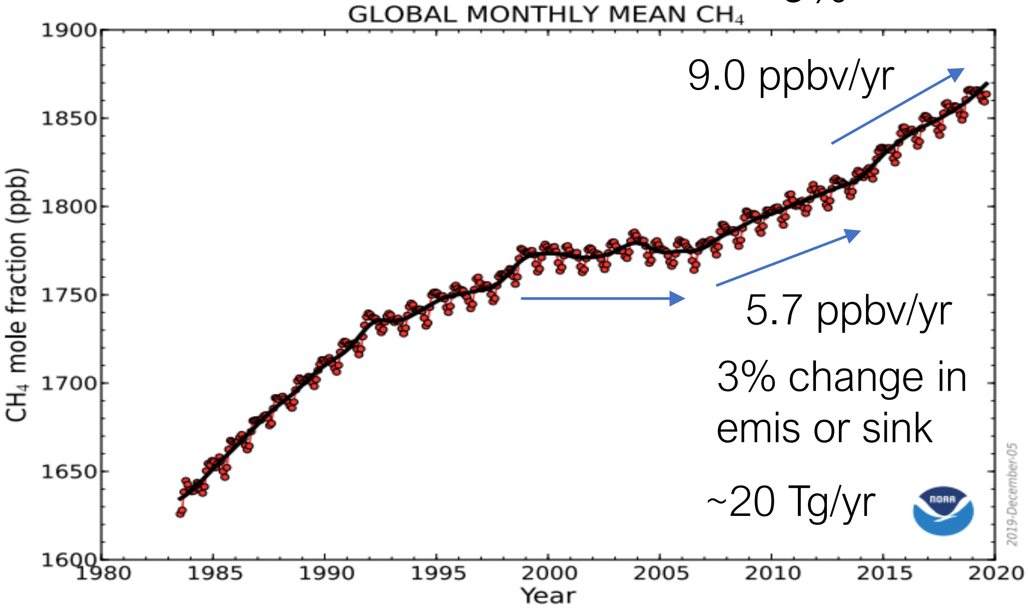
Surface network

Satellite

Ethane

$\delta^{13}CH4$

CH_3CCl_3



5%

9.0 ppbv/yr

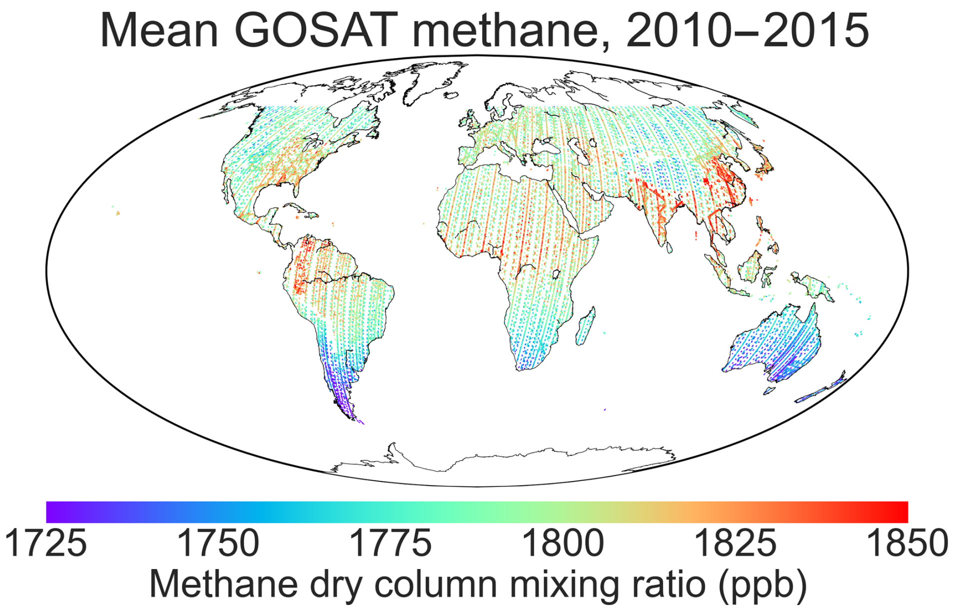
5.7 ppbv/yr

3% change in emis or sink

~20 Tg/yr

覆盖全球的卫星观测是否蕴含更多信息?

GOSAT Satellite



Maasakkers et al., ACP, 2019

卫星数据的反演分析

1. Best available prior information
2. Improved stratospheric bias correction
3. Better treatment for wetland emissions
4. Annual hemispheric OH

Prior Information
- Global fuel emission inventory (Scarpelli et al.)
- GFED4 fire emissions (Liu et al.)
- Seeps (Etiope et al., 2019)
- Soil absorption (Murguia-Flores et al.)

1

Simulated XCH_4
Bias correction: ACE-FTS satellite observations

2

Observations
GOSAT XCH_4 retrievals
2010-2018

CTM simulation
GEOS-Chem v11

Jacobian Matrix

Observation error covariance So

Prior error covariance S_A

Inversion
State vector
- Non-wetland emissions and its linear trend from 2009-2018 on 4x5 grid
- Monthly wetland emissions for 14 subcontinental regions
- Annual hemispheric OH

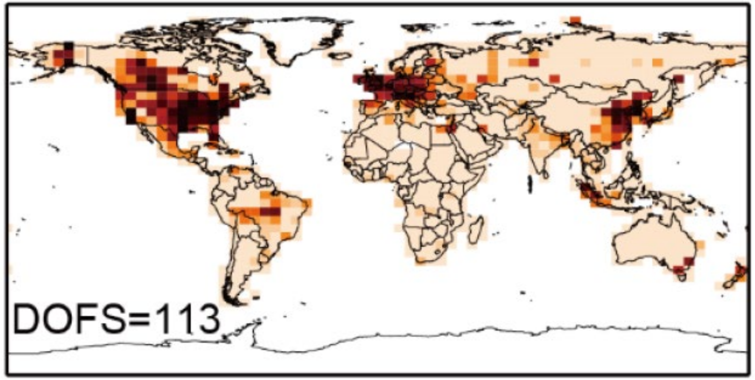
3

4

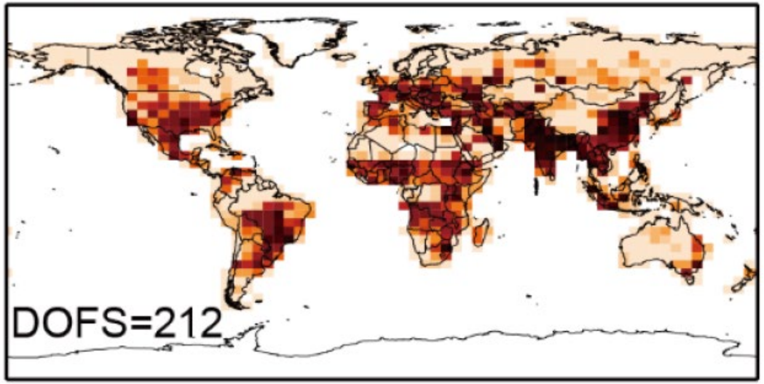
Zhang et al., ACPD, 2020

卫星观测对估算南半球排放尤其重要

观测所蕴含的信息量



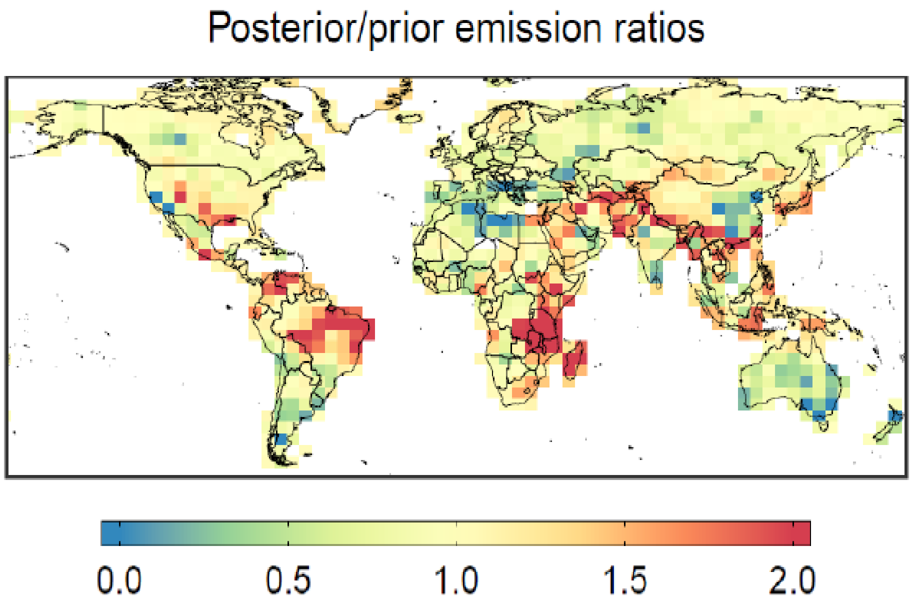
地面站点

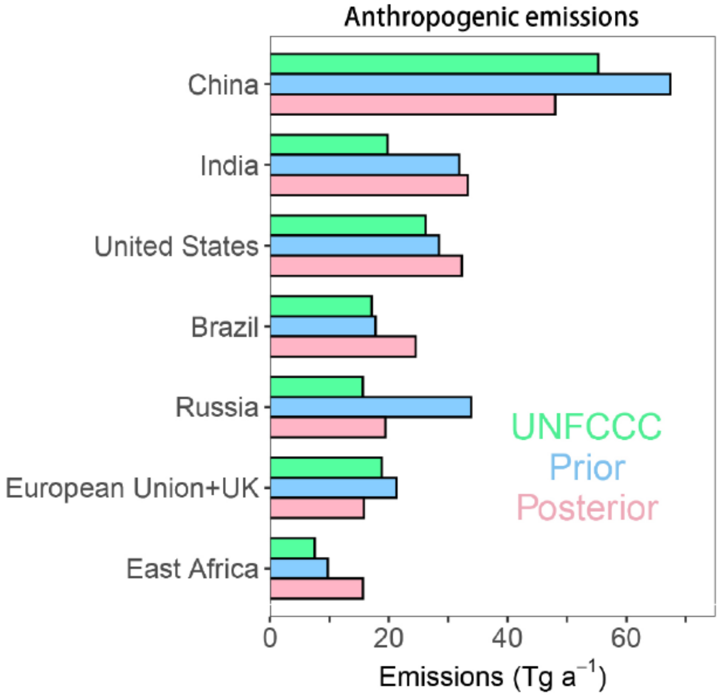


卫星观测

Lu et al., ACPD, 2020

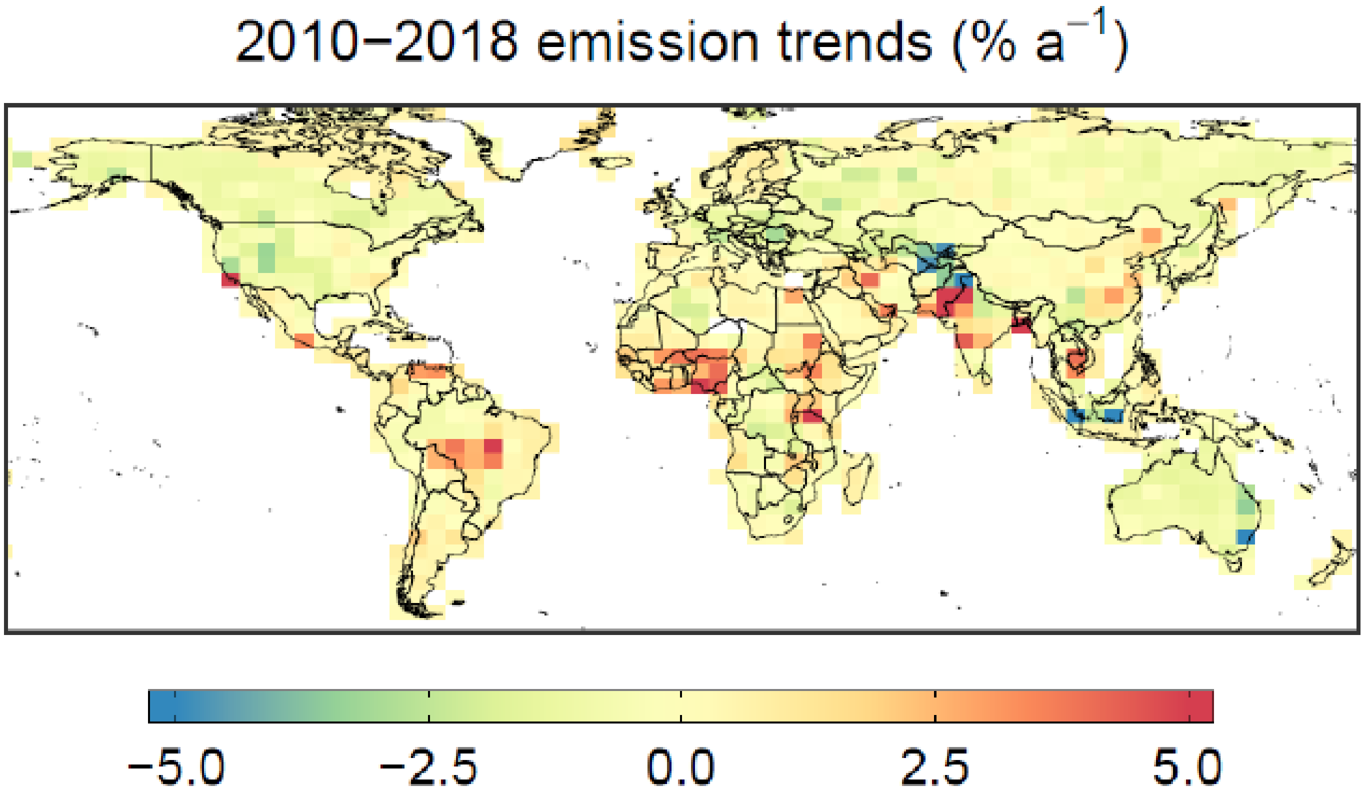
全球2010-2018 GOSAT反演：人为源排放



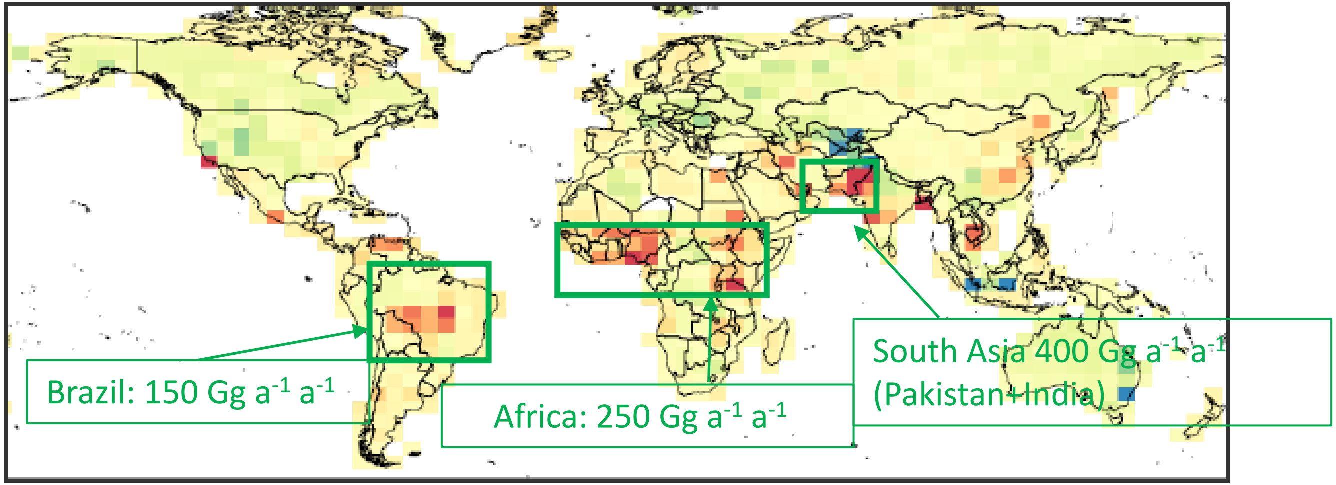


Zhang et al., ACPD, 2020

全球2010-2018 GOSAT反演：人为源排放趋势



Zhang et al., ACPD, 2020



Top 5 counties with fastest growing cattle population

UNFAO

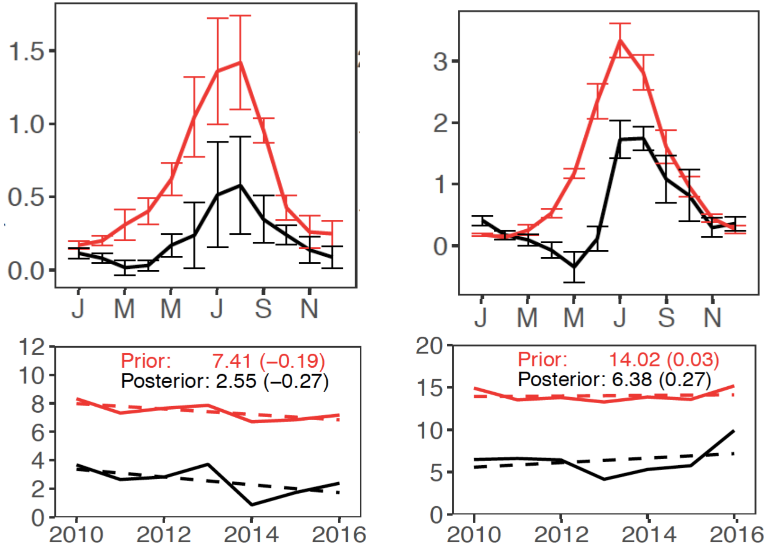
Country	Trend (million head per year)
Pakistan	1.4
Ethiopia	1.2
Tanzania	1.1
Brazil	0.9
Argentina	0.7

全球2010-2018 GOSAT反演：湿地源和OH汇

湿地排放

Prior

Posterior



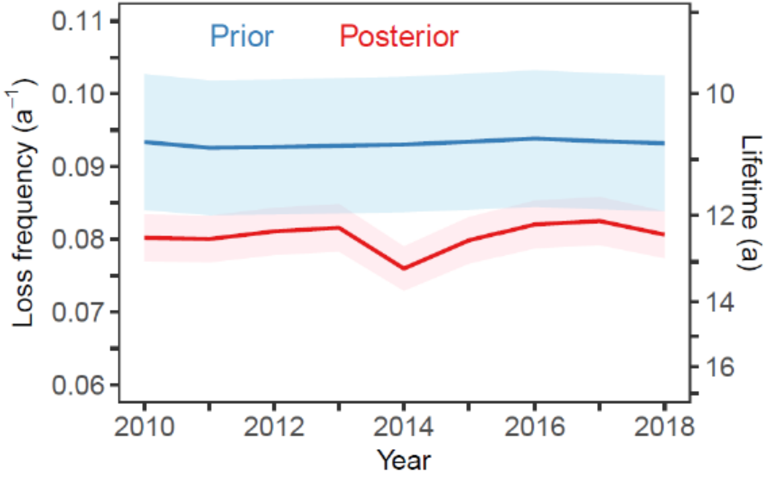
SEAC^{4}RS

Sheng et al., ACP, 2018

(ECCC)Surface

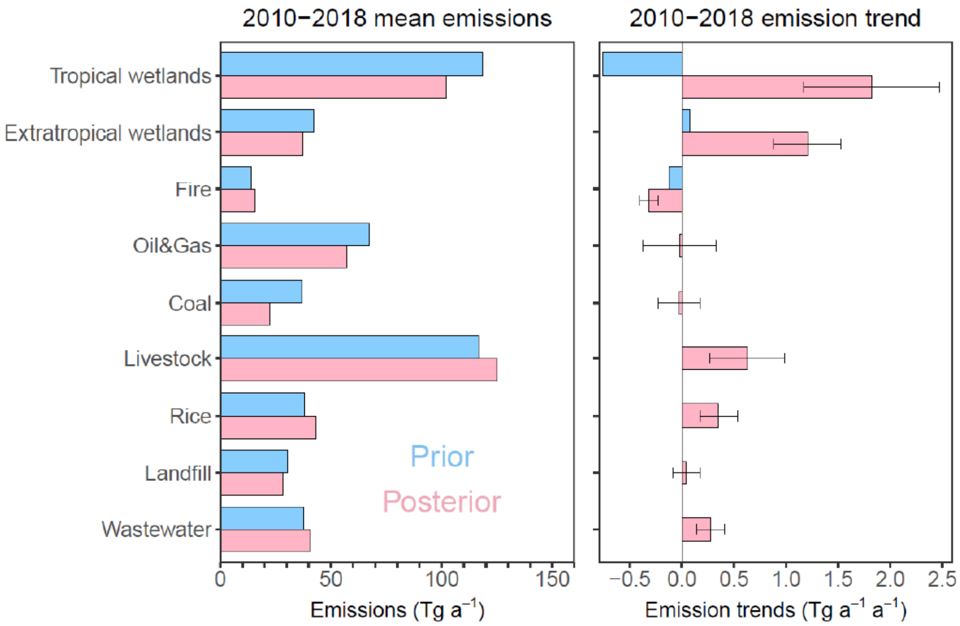
Baray et al., AGU, 2019

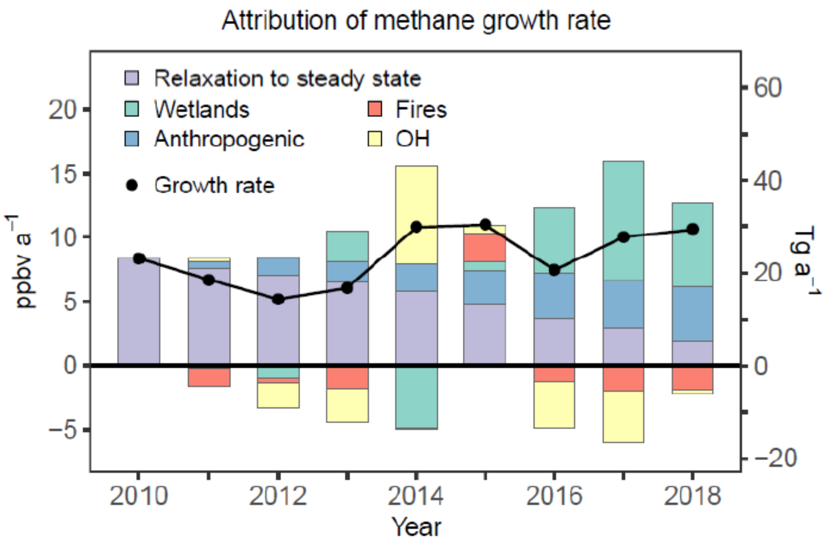
全球 OH 浓度



Zhang et al., ACPD, 2020

全球2010-2018甲烷收支变化的归因

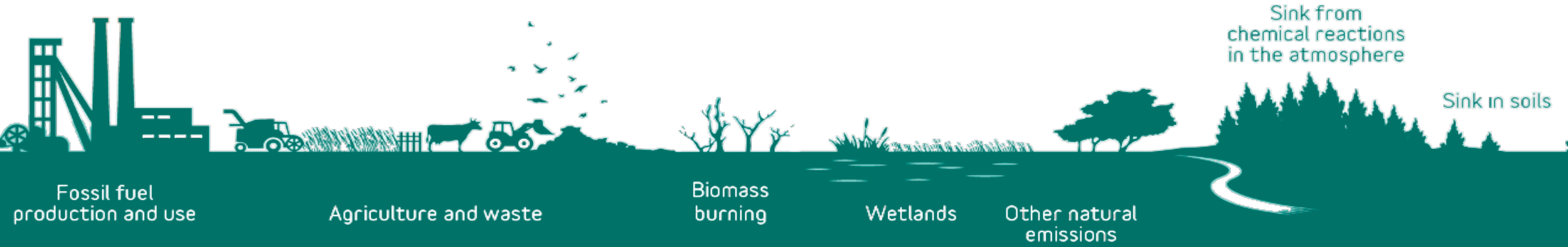




Zhang et al., ACPD, 2020

全球大气甲烷收支

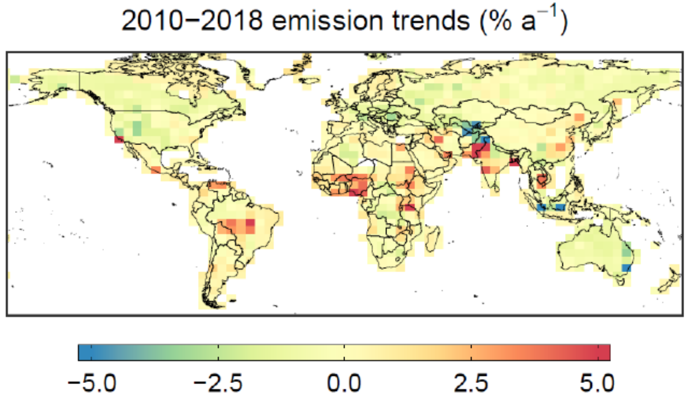
- 卫星观测以及反演分析可对全球大气甲烷的源（分布、趋势）和汇提供有用信息，特别是地表观测覆盖稀疏的南半球。
- 2010-2018年期间，湿地源和牲畜源排放的增加是大气甲烷浓度增长的最主要驱动因素。OH汇和野火排放的变异，也对2014-2015的极端增长事件有贡献。



大气甲烷：从全球收支到区域热点

Global

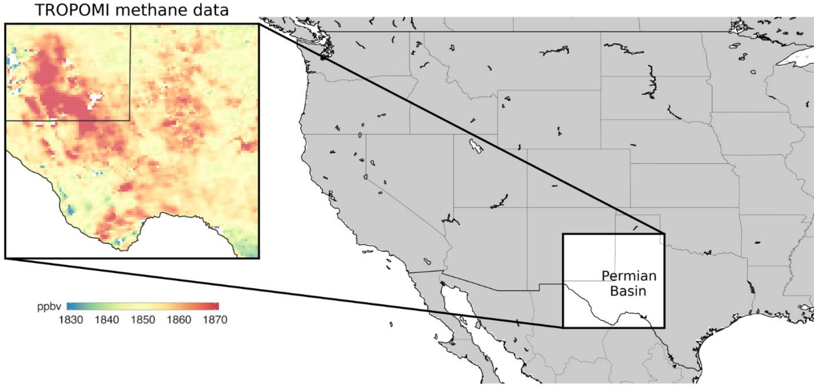
2010-2018全球大气甲烷收支



Zhang et al., 2020; Lu et al., 2020; Maasakkers et al., 2019; Zhang et al., 2018

Regional

美国最大油气盆地甲烷排放量估计



Zhang et al., Sci. Adv., 2020;
Zhang et al., GRL, 2019

美国二叠纪盆地甲烷排放

Zhang et al., Science Advances, 2020

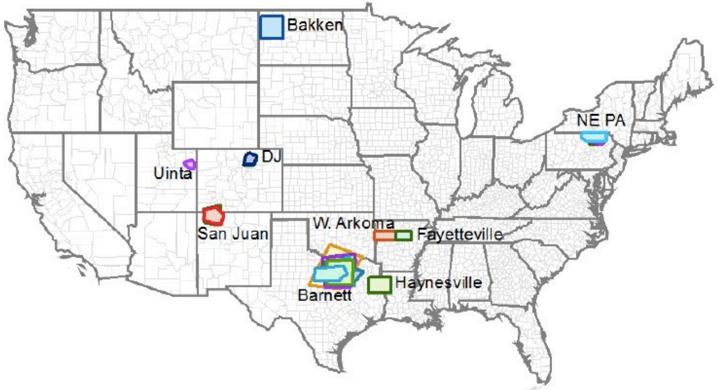
Permian 盆地：美国最大油气生产盆地，但其甲烷排放缺少“自上而下”的观测数据

REPORT

Assessment of methane emissions from the U.S. oil and gas supply chain

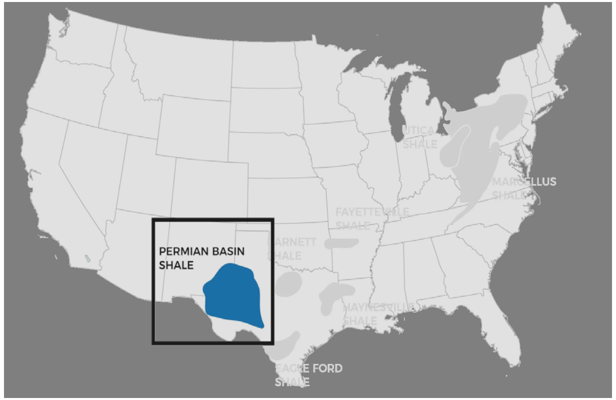
Ramón A. Alvarez[1,*], Daniel Zavala-Araiza[1], David R. Lyon[1], David T. Allen[2], Zachary R. Barkley[3], Adam R. Brandt[4], Kenneth J. Dav...
+ See all authors and affiliations

Science 13 Jul 2018:
Vol. 361, Issue 6398, pp. 186-188
DOI: 10.1126/science.aar7204

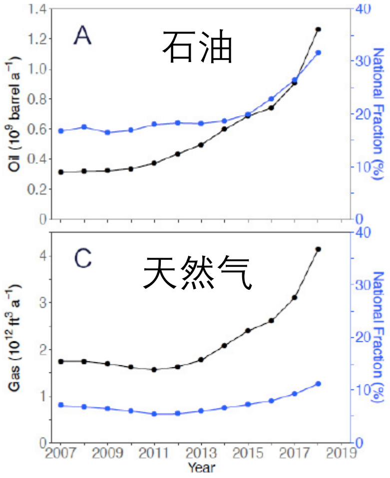


Alvarez et al., Science, 2018

Permian Basin



Oil & gas production

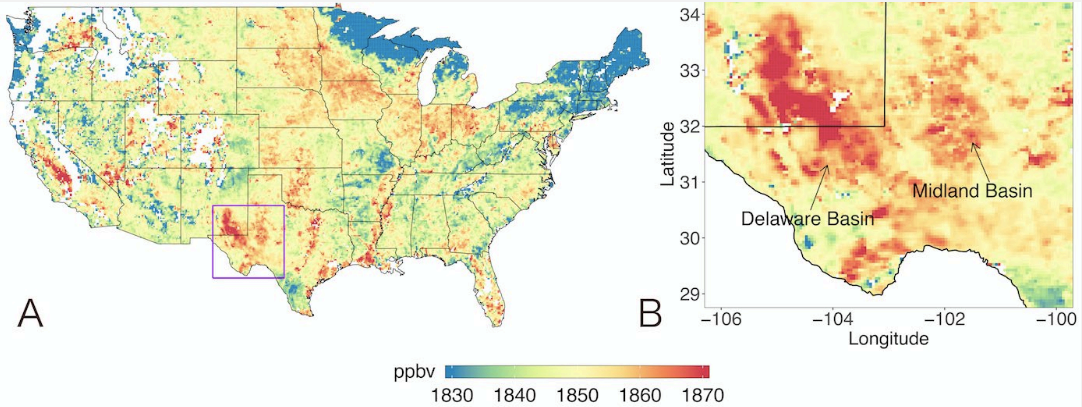


TROPOMI 卫星分析美国Permian盆地油气甲烷排放

甲烷浓度

TROPOMI

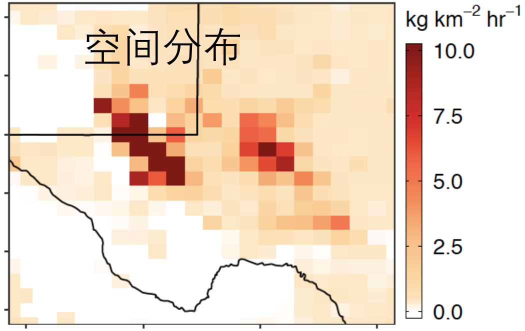
5/2018-3/2019



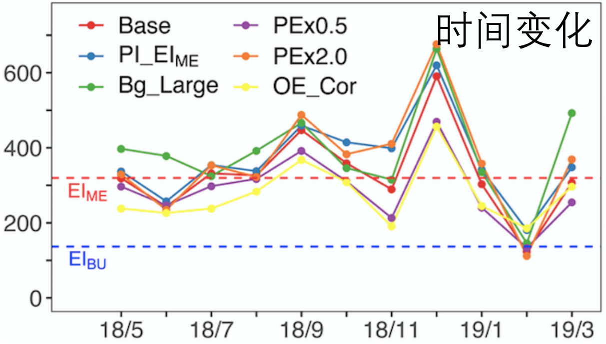
求解
逆问题

甲烷排放通量

空间分布



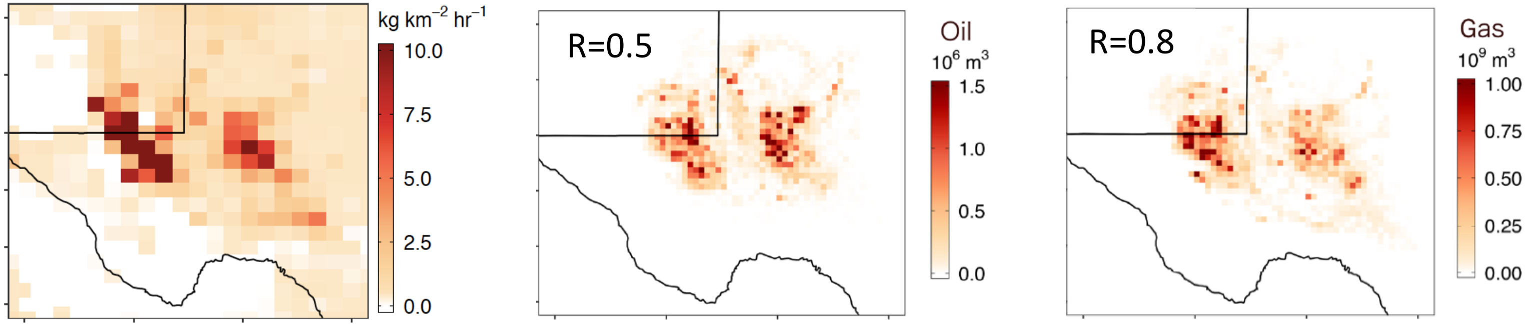
时间变化



Zhang et al., Science Advances, 2020

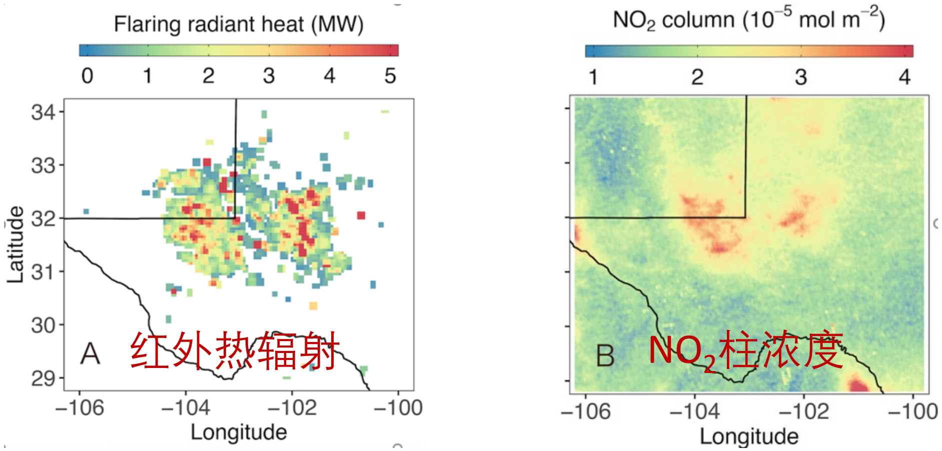
甲烷排放的空间分布

TROPOMI反演　　石油产量　　天然气产量



Gas flaring in oil & gas fields

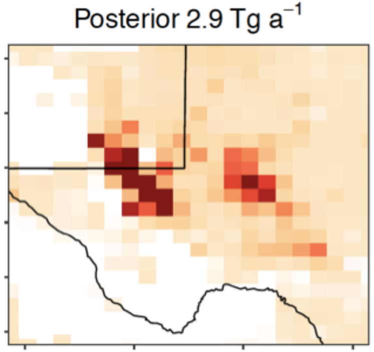
大量的火炬燃烧提示Permian盆地可能欠缺天然气处理能力



多种方法估计美国二叠纪盆地甲烷排放

基于TROPOMI数据

Atmospheric inverse modeling
0.25x0.3125 GEOS-Chem nested
Yuzhong Zhang (Westlake)

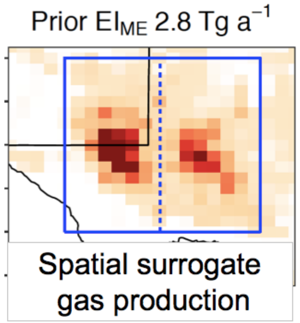


Mass balance method
Sudhanshu Pandey (SRON)
--> 3.2±2.0 Tg a^{-1}

基于少量地面观测外推

Site-level measurement extrapolation emission inventory
71 site-level measurements

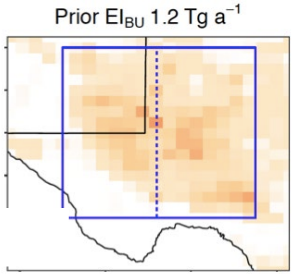
Mark Omara (EDF)



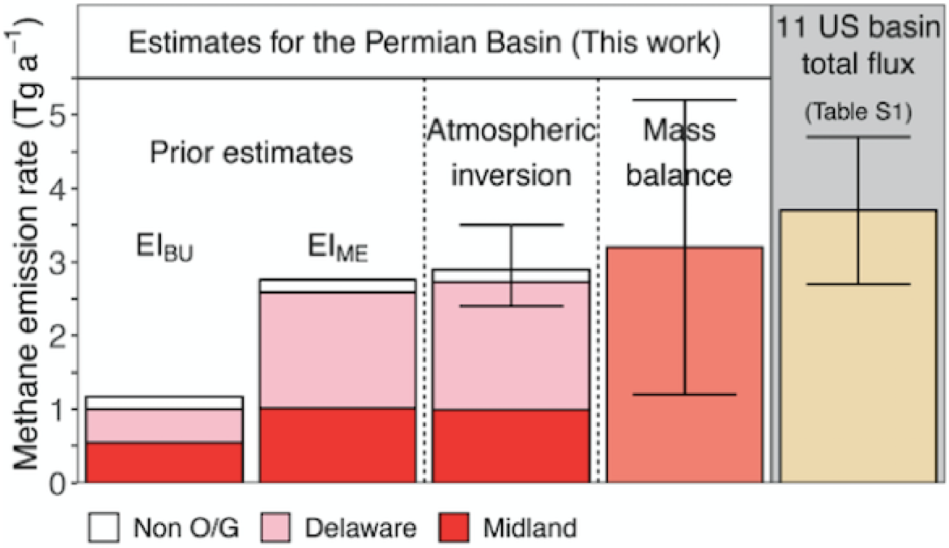
基于EPA排放清单

Bottom-up emission inventory
Extrapolation of EPA gridded inventory to 2018 DI info for O&G

Bram Maasakkers (SRON)



迄今报道的甲烷排放量最大的油气盆地

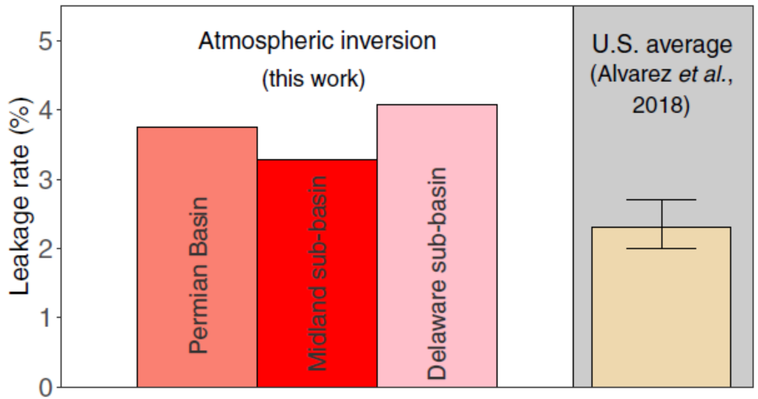


>2x higher than bottom-up estimate
4x higher than Eagle Ford -- the largest flux reported in literature

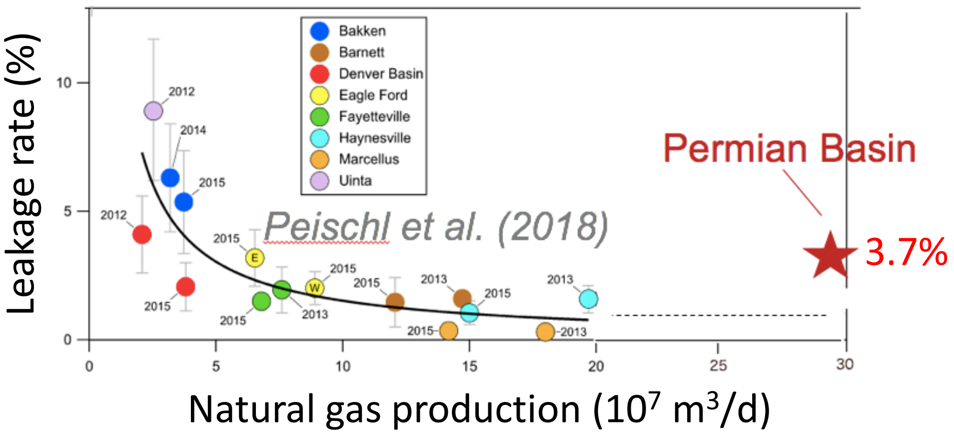
超过美国平均水平的泄漏率

泄漏率=甲烷排放量/（天然气生产量*天然气甲烷含量比例）

Leakage rate
with respect to gas production



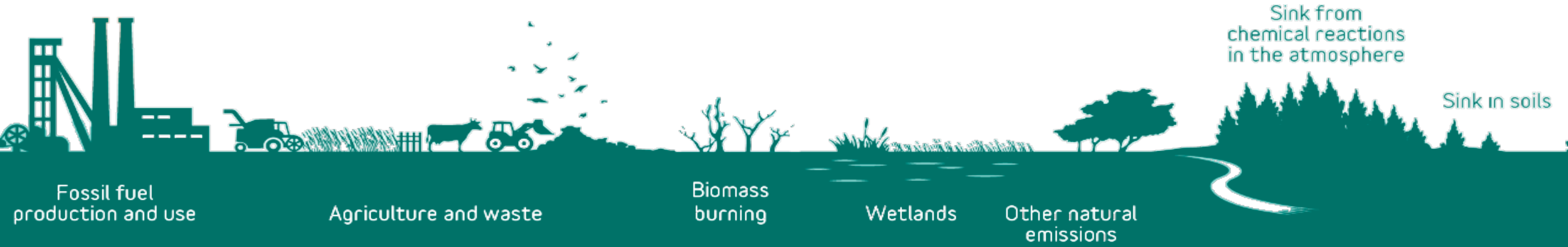
Leakage rate vs gas production



High gas production & high leakage rate indicates low efficiency in gas utilization

区域甲烷排放热点

- 利用TROPOMI甲烷观测，定量估计了Permian Basin（美国最大油气生产盆地）的甲烷排放通量 (~2.7 Tg a^{-1})；此排放通量大于任何文献报道的单一盆地的排放估计，是用EPA清单方法估计的2倍；
- 可能反映了油气生产过程中（因为经济原因）天然气处理设施的滞后；
- 其它气体的卫星观测（如NO_2、SO_2）能为火炬燃烧等导致温室气体排放的过程提供独立信息。



谢谢！请大家提问及指正！