西湖大學
WESTLAKE UNIVERSITY

基于卫星观测定量估计甲烷排放

Quantify methane emissions with satellite observations

张 羽 中

大气环境遥感与协同分析青年学者论坛 广东珠海 2020.11.29

致 谢

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

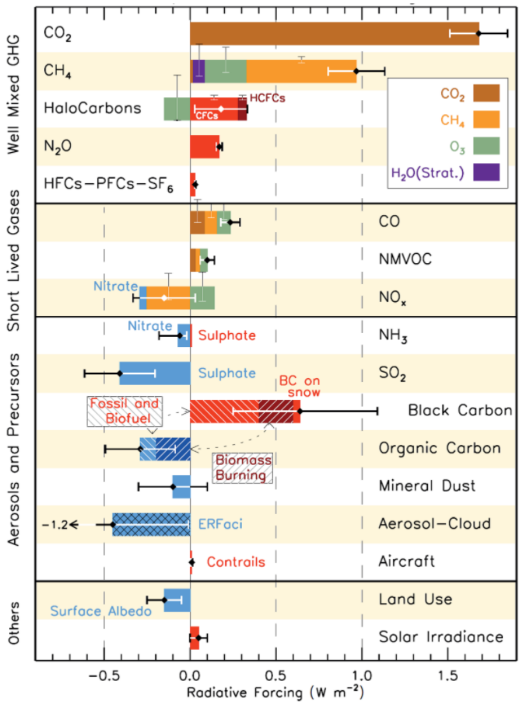
EDF
Ritesh Gautam, Mark Omara, Daniel Zavala-Araiza, David Lyon

JPL John Worden, Anthony Bloom, Shuang Ma

SRON Ilse Aben, Bram Maasakkers, Sudhanshu Pandey

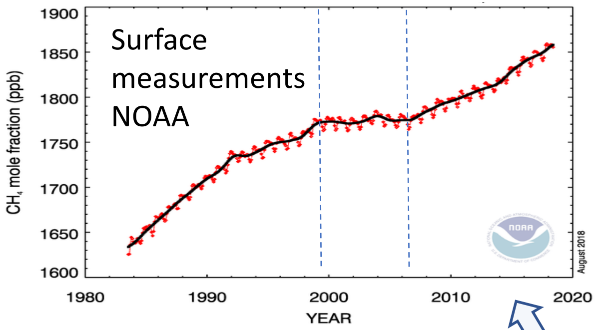
温室气体甲烷

Radiative forcing

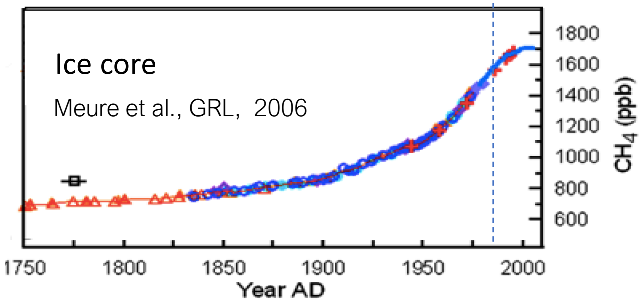


IPCC AR5

Methane concentration in last 35 years



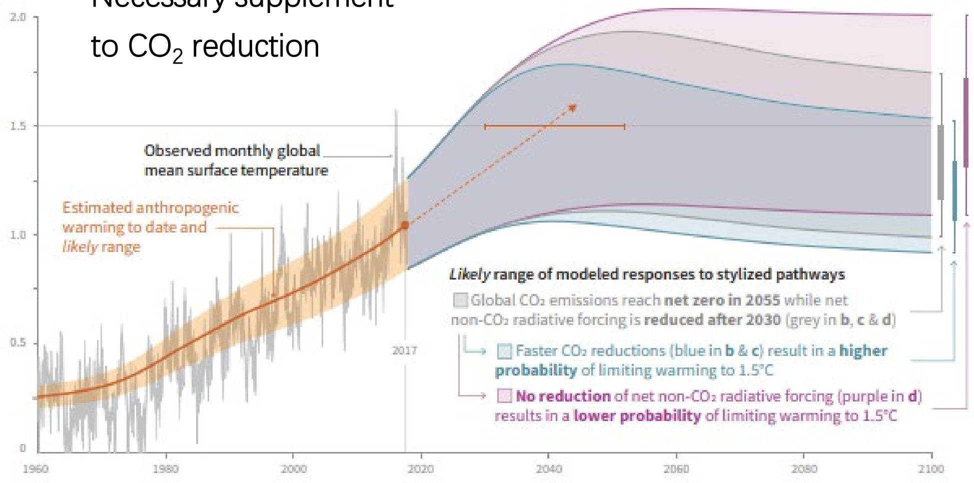
Methane concentration in last 300 years



甲烷减排的必要性和可行性

必要性

Necessary supplement
to CO_2 reduction

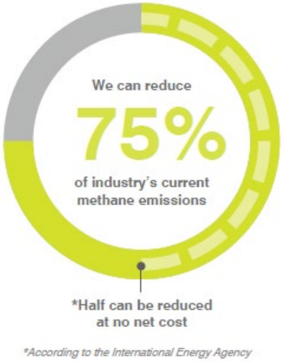


IPCC, 2018

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



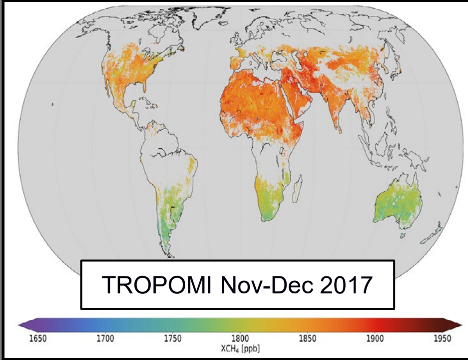
具有挑战的监测需求

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

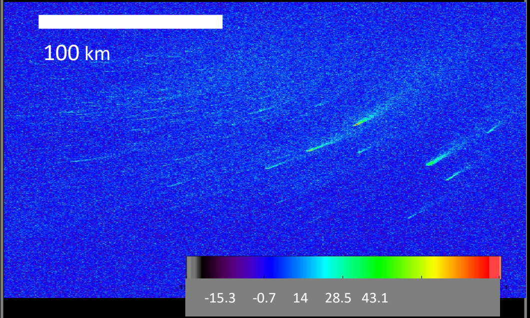
源监测
源数量多、种类多
绝对量较小、但波动很大

国家/全球尺度



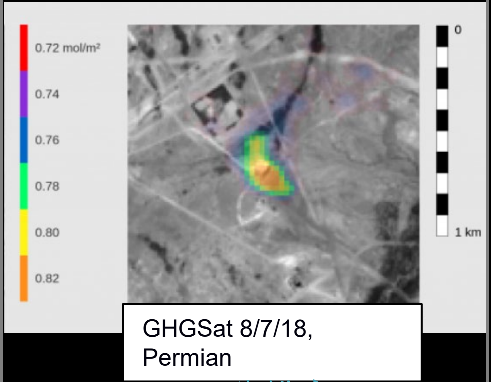
5-10 km 分辨率

区域/盆地尺度



~500-1000 m 分辨率

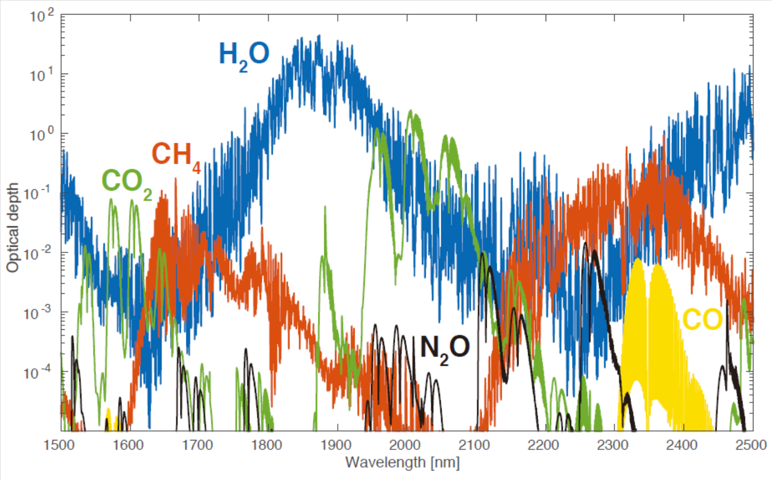
设施尺度



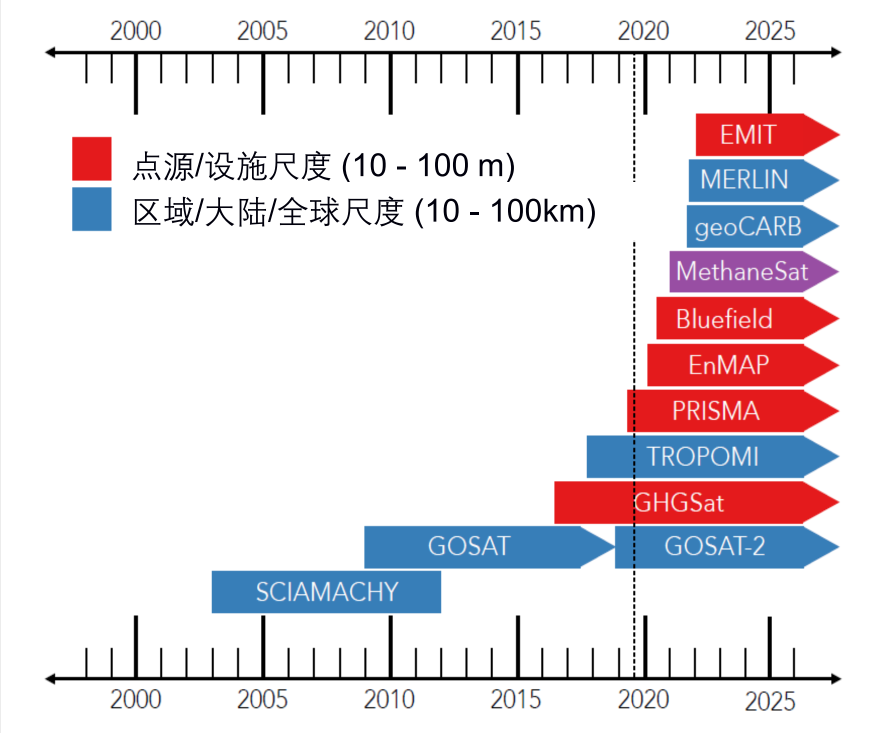
~10 m 分辨率

迅速发展的卫星观测能力

SWIR波段大气光学厚度

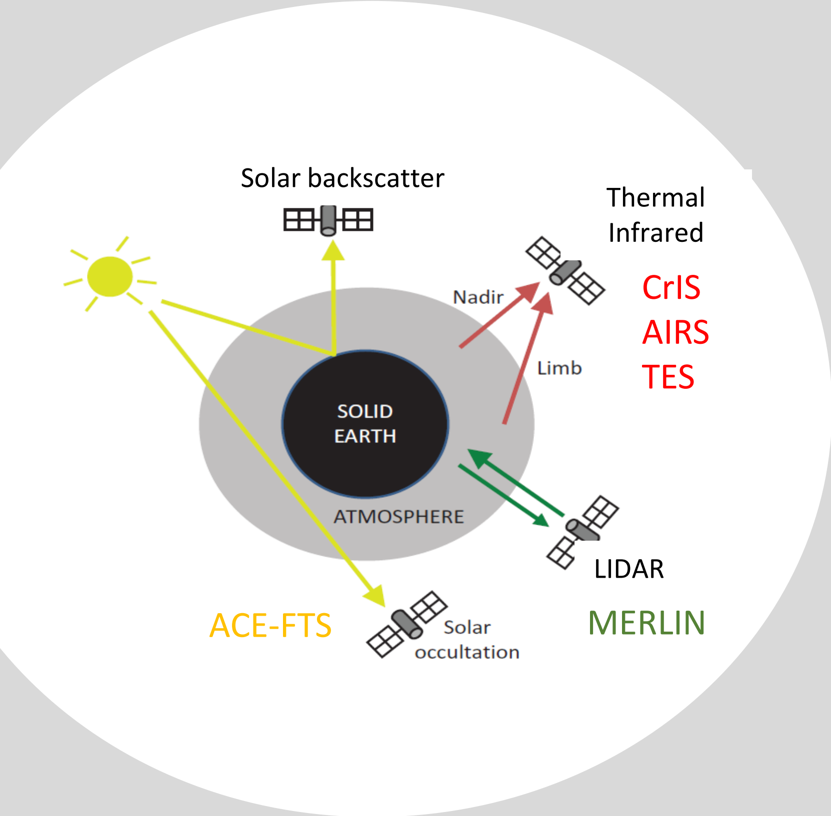


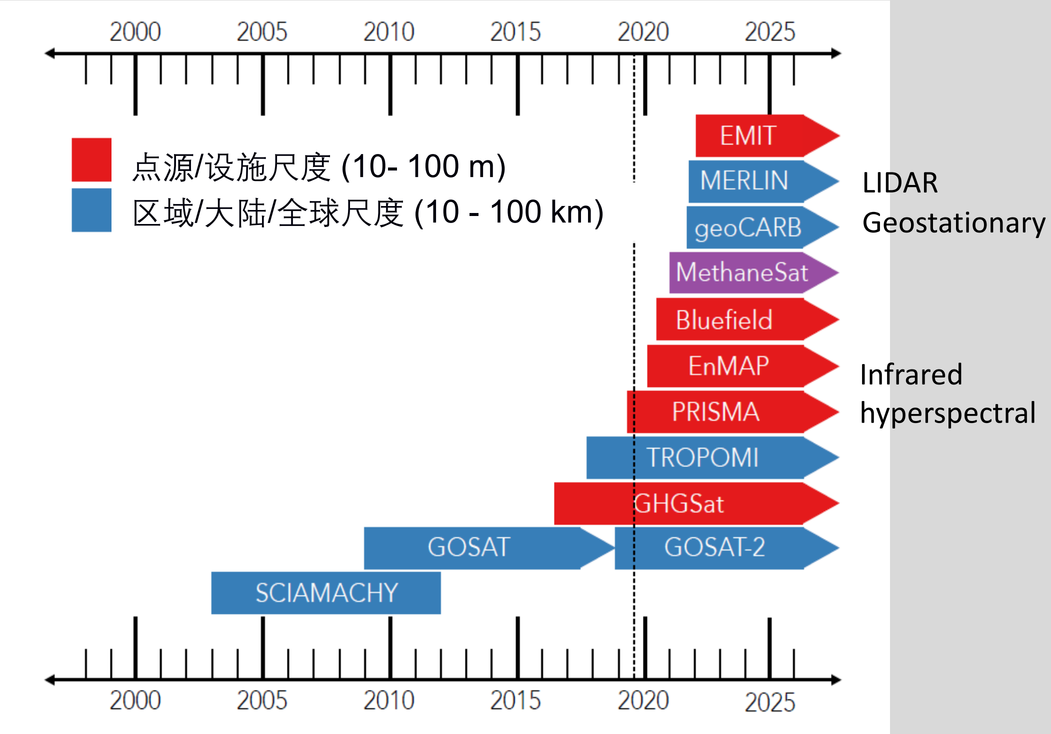
Jacob et al., 2016



Daniel Varon, Harvard

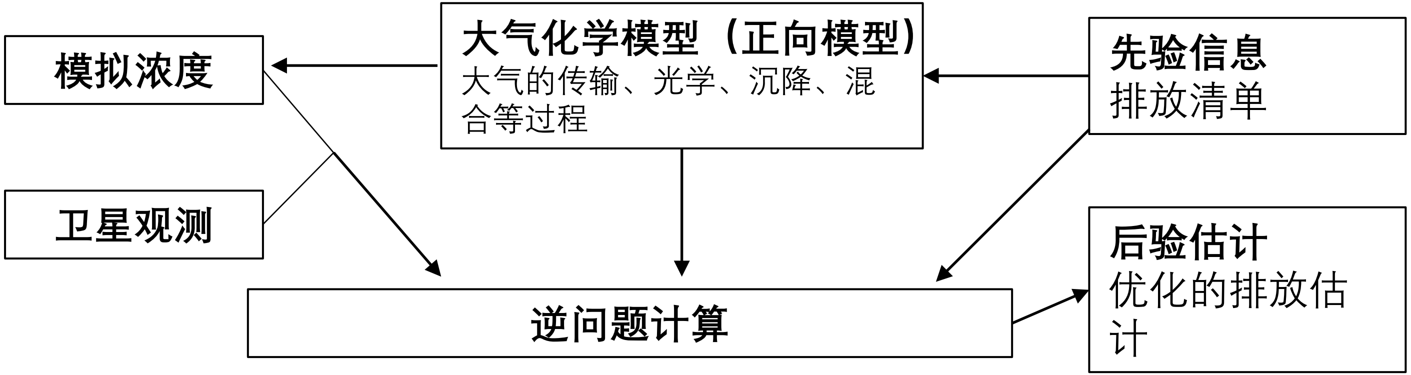
迅速发展的卫星观测能力





Daniel Varon, Harvard

基于卫星观测定量甲烷排放



$$J(\boldsymbol{x}) = (\boldsymbol{x} - \underline{\boldsymbol{x}_{\mathrm{a}}})^{\mathrm{T}}\mathbf{S}_{\mathrm{a}}^{-1}(\boldsymbol{x} - \boldsymbol{x}_{\mathrm{a}}) + \gamma(\underline{\boldsymbol{y}} - \mathbf{K}\boldsymbol{x})^{\mathrm{T}}\mathbf{S}_{\mathrm{O}}^{-1}(\boldsymbol{y} - \underline{\mathbf{K}}\boldsymbol{x})$$

先验信息　　先验信息的不确定度　　卫星观测　　观测和模型的不确定度　　正向模型：观测对排放的敏感度

美国二叠纪盆地甲烷排放

Zhang et al., Science Advances, 2020

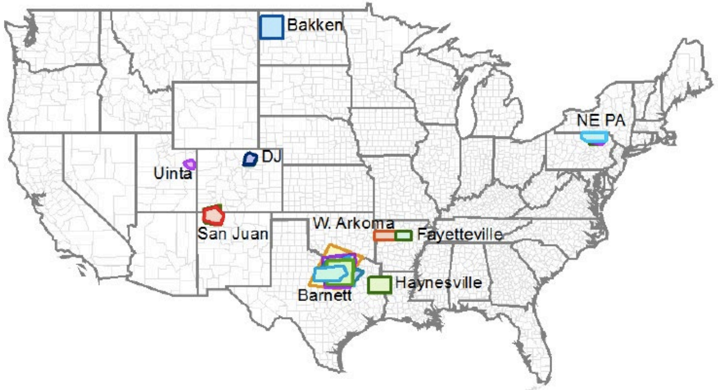
Permian 盆地：美国最大油气生产盆地，但其甲烷排放缺少“自上而下”的观测数据

REPORT

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

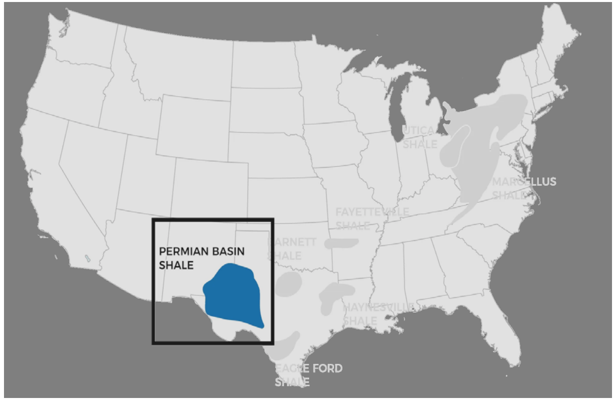
Ramón A. Alvarez[1,*], Daniel Zavala-Araiza[1], David R. Lyon[1], David T. Allen[2], Zachary R. Barkley[3], Adam R. Brandt[4], Kenneth J. Dav...
+ See all authors and affiliations

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

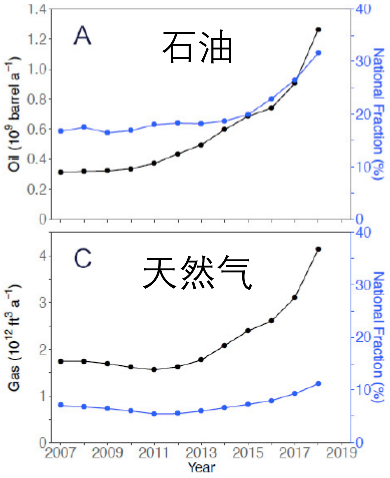


Alvarez et al., Science, 2018

Permian Basin

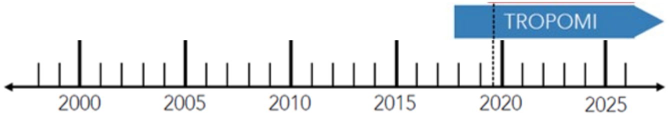


Oil & gas production



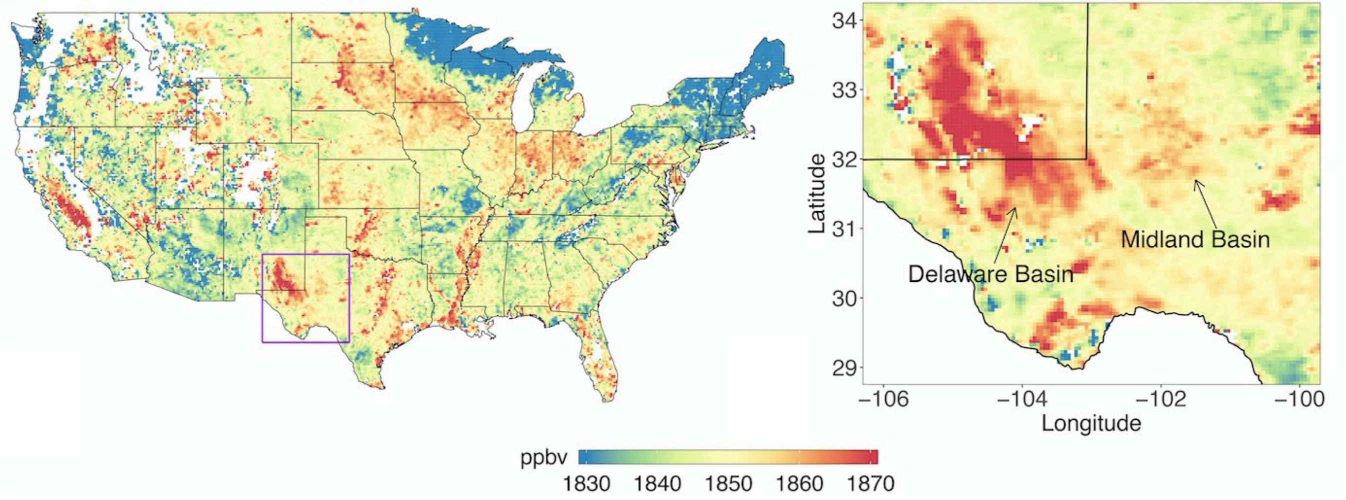
美国二叠纪盆地甲烷排放

Tropospheric Monitoring Instrument (TROPOMI)



Satellite: Sentinel-5 Precursor; Swath width: 2600 km;

Overpass: ~13:30 LT; Resolution: 7×7 km^2; Retrieval: "full physics" (*Hu et al., 2016*)



TROPOMI卫星反演美国二叠纪盆地甲烷排放

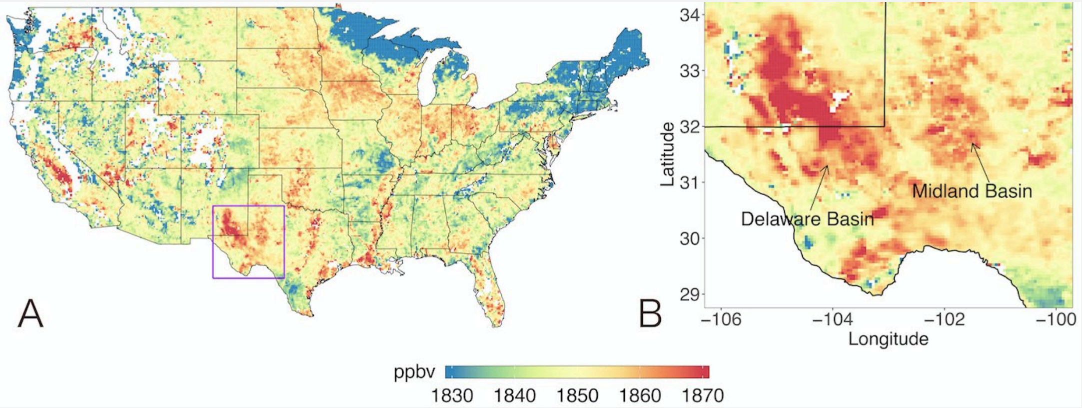
甲烷浓度

TROPOMI

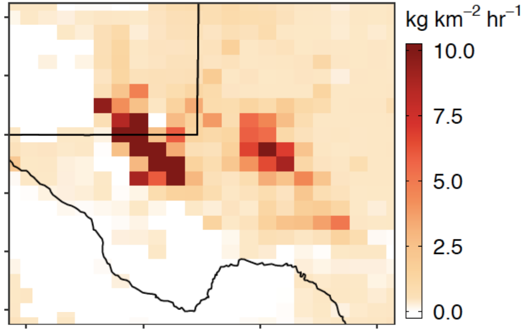
5/2018-3/2019

求解
逆问题

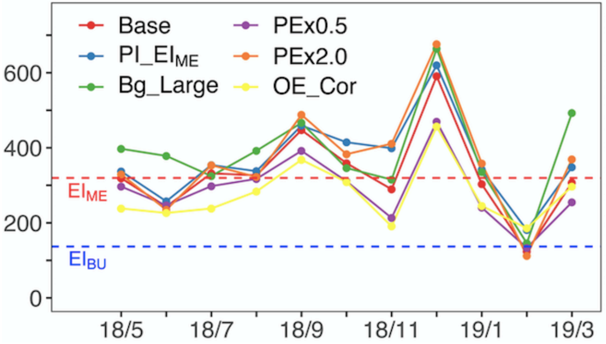
甲烷排放通量



空间分布

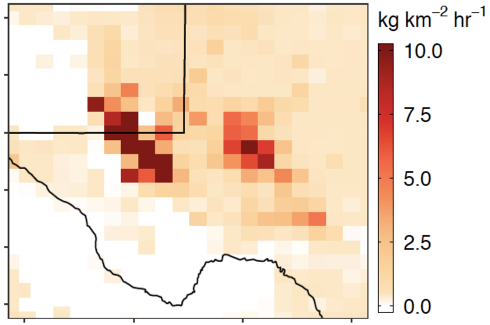


时间变化

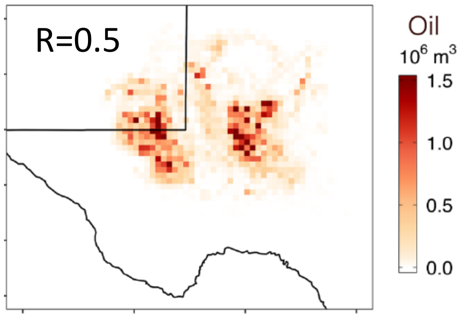


甲烷排放的空间分布

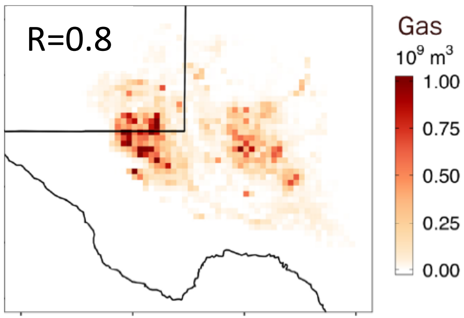
TROPOMI反演



石油产量

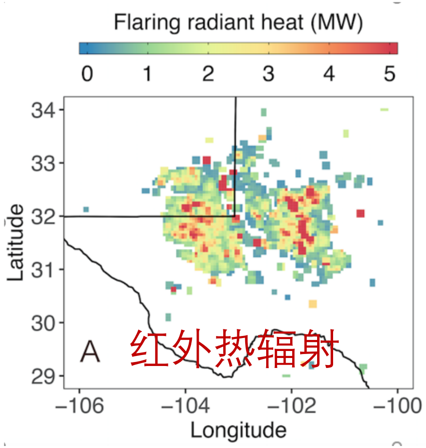


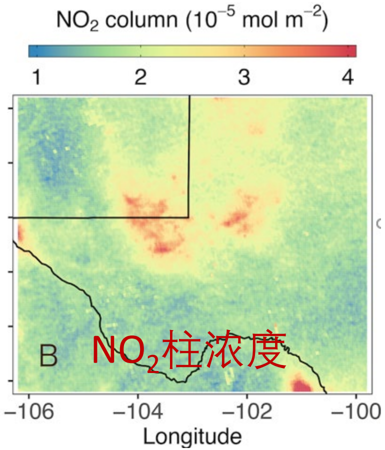
天然气产量



Gas flaring in oil & gas fields

Zhang et al., Satellite-Observed Changes in Mexico's Offshore Gas Flaring Activity Linked to Oil/Gas Regulations, *Geophysical Research Letters*, 2019

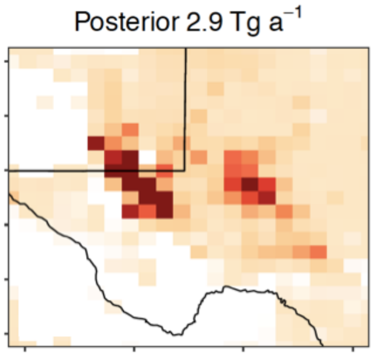




多种方法估计美国二叠纪盆地甲烷排放

基于TROPOMI数据

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

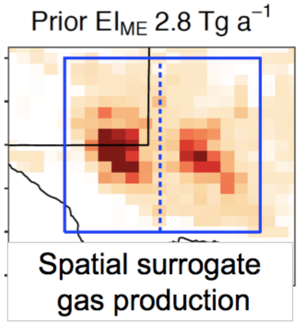


Mass balance method
Sudhanshu Pandey (SRON)
--> 3.2±2.0 Tg a^{-1}

基于少量地面观测外推

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

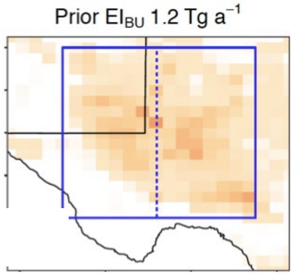
Mark Omara (EDF)



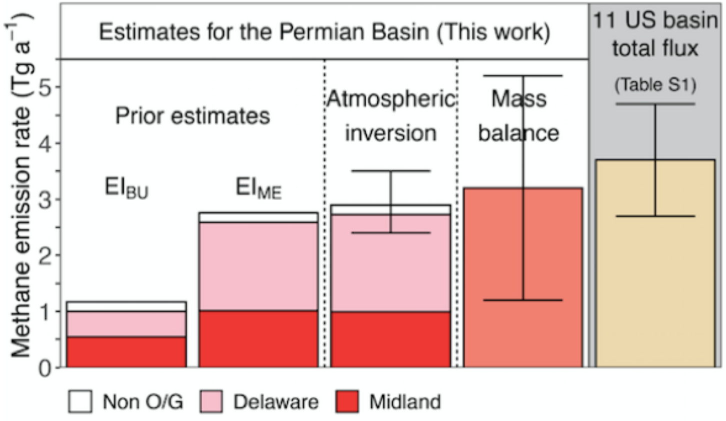
基于EPA排放清单

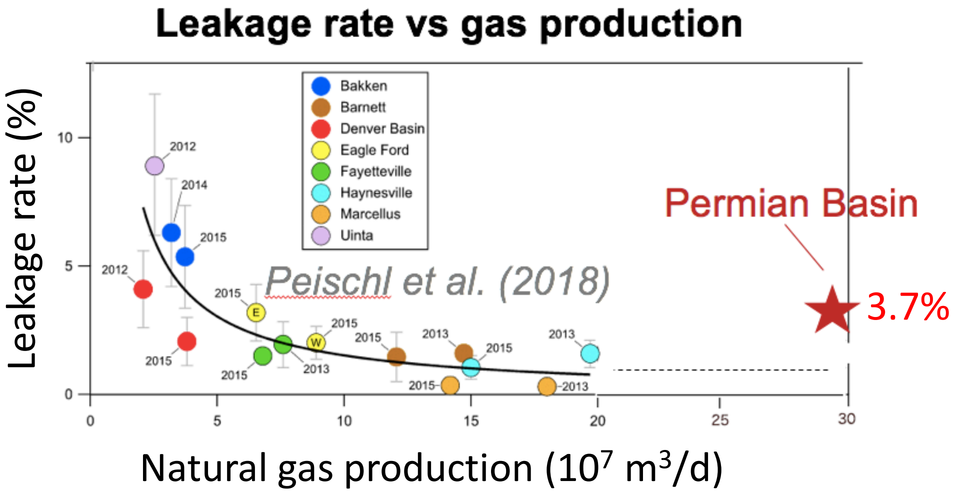
Bottom-up emission inventory
Extrapolation of EPA gridded inventory to 2018 DI info for O&G

Bram Maasakkers (SRON)



迄今报道的甲烷排放量最大的油气盆地



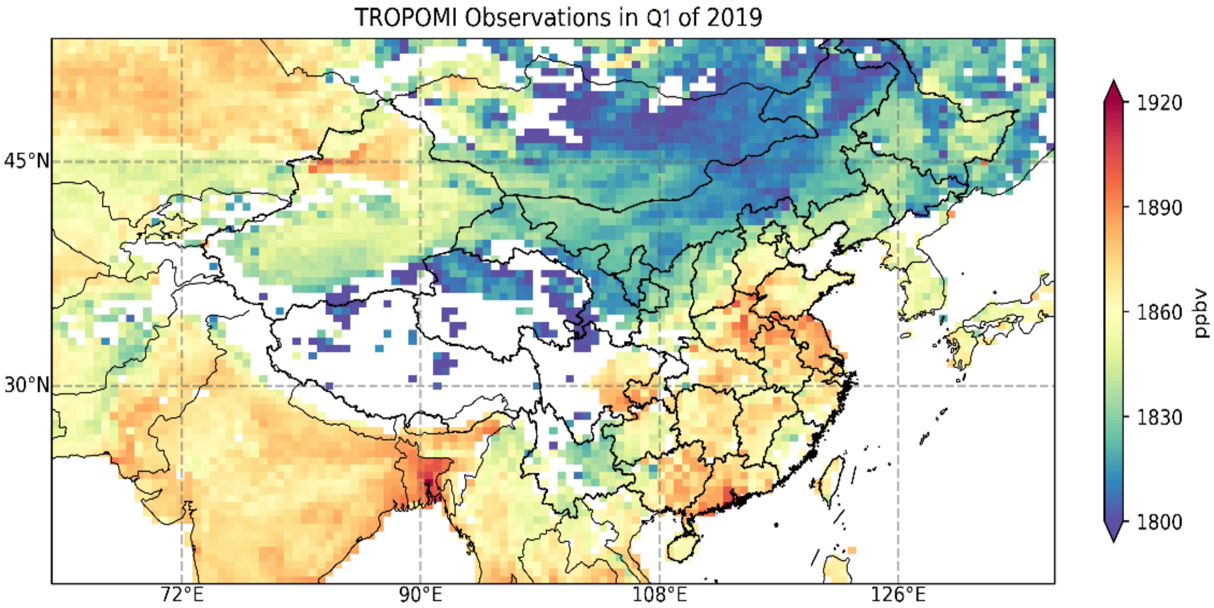


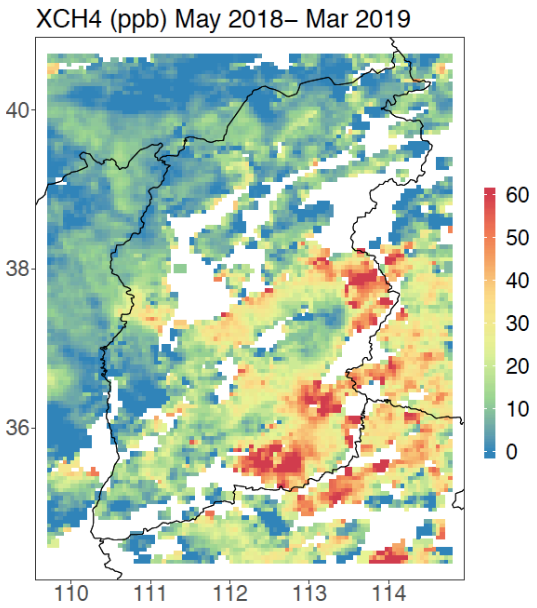
>2x higher than bottom-up estimate
4x higher than Eagle Ford -- the largest flux reported in literature

High gas production & high leakage rate

TROPOMI甲烷观测——中国

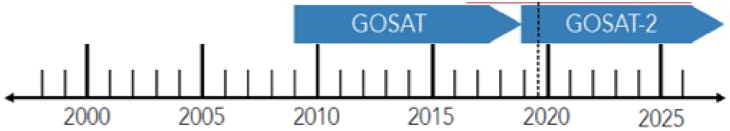
山西

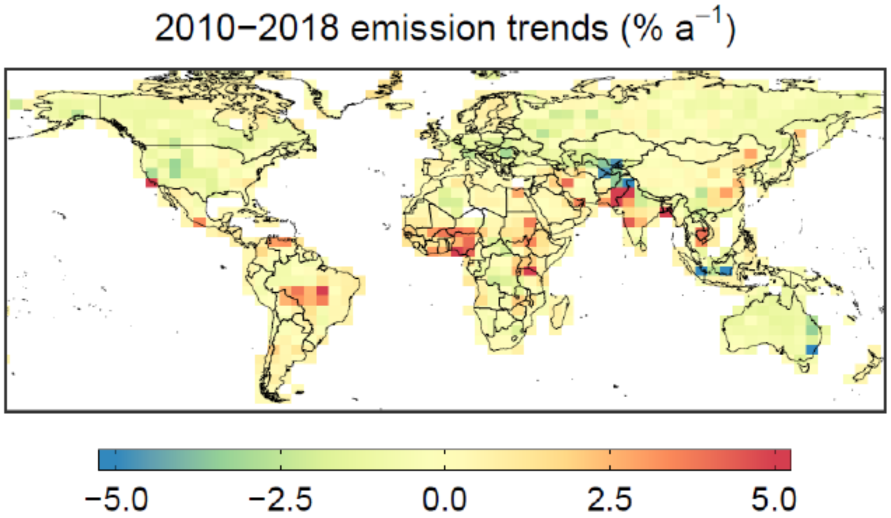




全球大气甲烷排放量和趋势分布

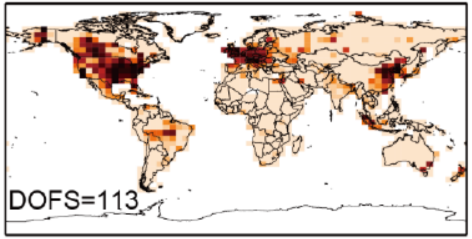
GOSAT 卫星 （2010-2018）



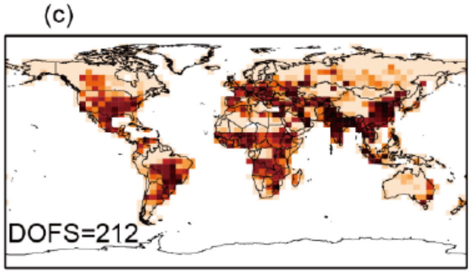


观测所蕴含的信息量

地面站点



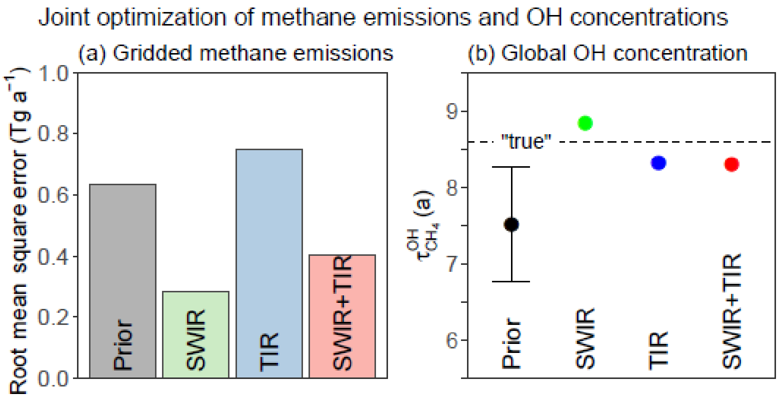
卫星观测

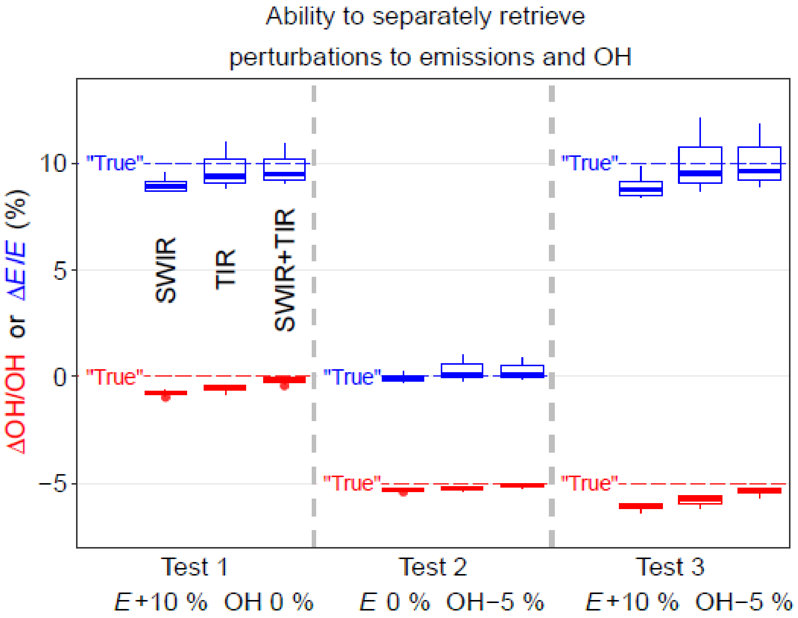


Zhang et al., ACPD, 2020; Lu et al., ACPD, 2020; Maasakkers et al., ACP, 2019

利用甲烷卫星观测监测全球OH浓度变化

通过反演解析排放的空间分布和OH（甲烷主要大气汇）的全球均值



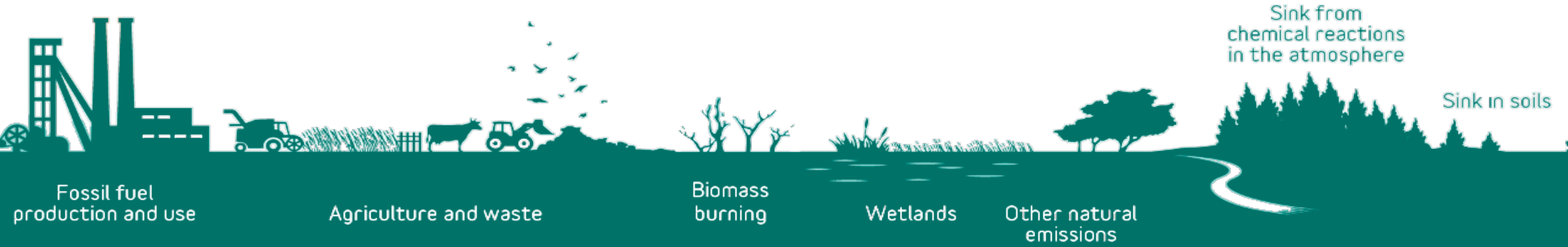


联合SWIR和TIR的甲烷观测可取的最优的效果

Zhang et al., ACP, 2018

总结

- 通过美国二叠纪盆地的个案研究，展示了利用卫星甲烷观测定量估计热点区域甲烷排放的能力。
- 估计Permian Basin每年排放~2.7 Tg a^{-1}甲烷，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；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。
- 卫星观测能与地面观测互补，分析全球甲烷源汇变化和分布。



大气甲烷的源


Wetlands

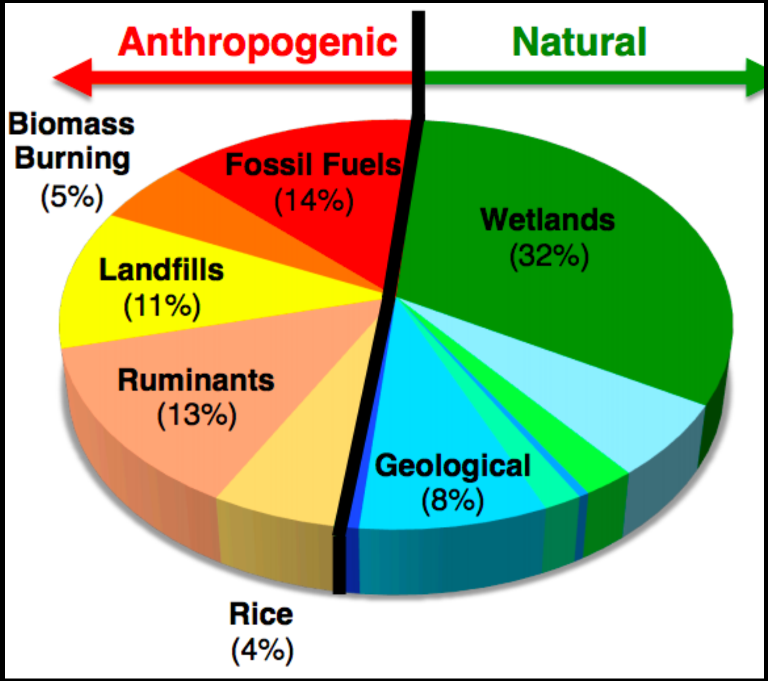

Oil/gas


Landfills,
wastewater

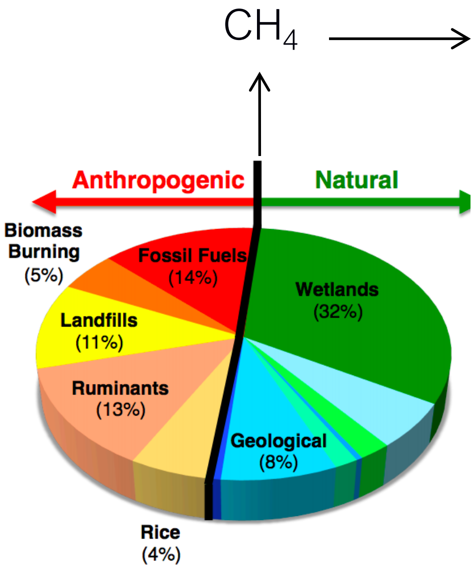

Livestock


Coal mines


Fires


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

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