WESTLAKE UNIVERSITY

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Evaluation of the stratospheric contribution to the inter-annual variabilities of tropospheric CH_4 growth rates

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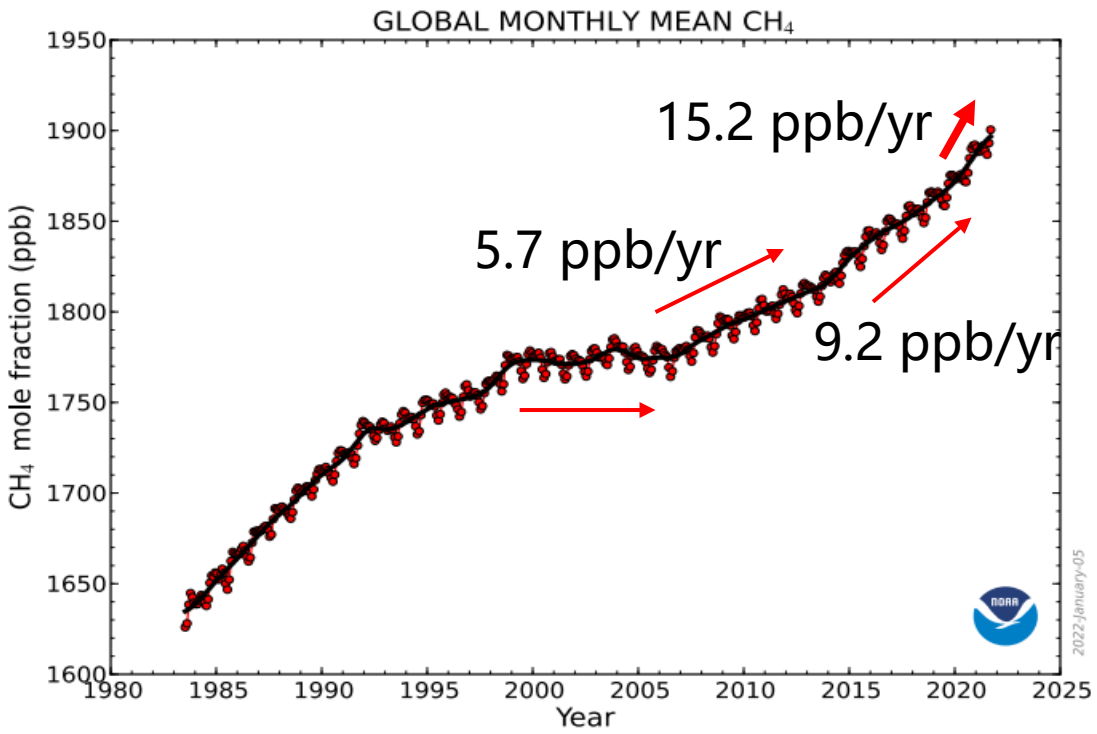
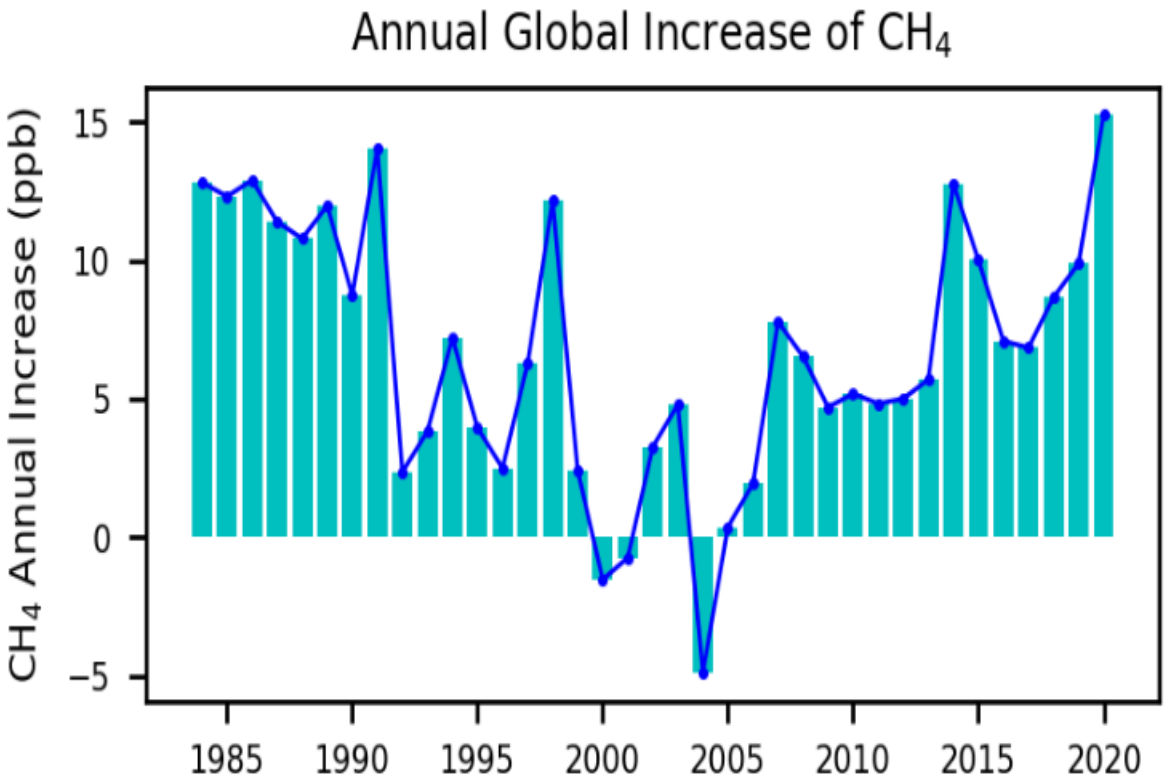
Global Methane Budget

Long term trends



Inter-annual variability



Based on observations at **surface site** by NOAA

Methane Sources and Sinks

CH_4 ⟶

sinks

Lifetime of 10 years

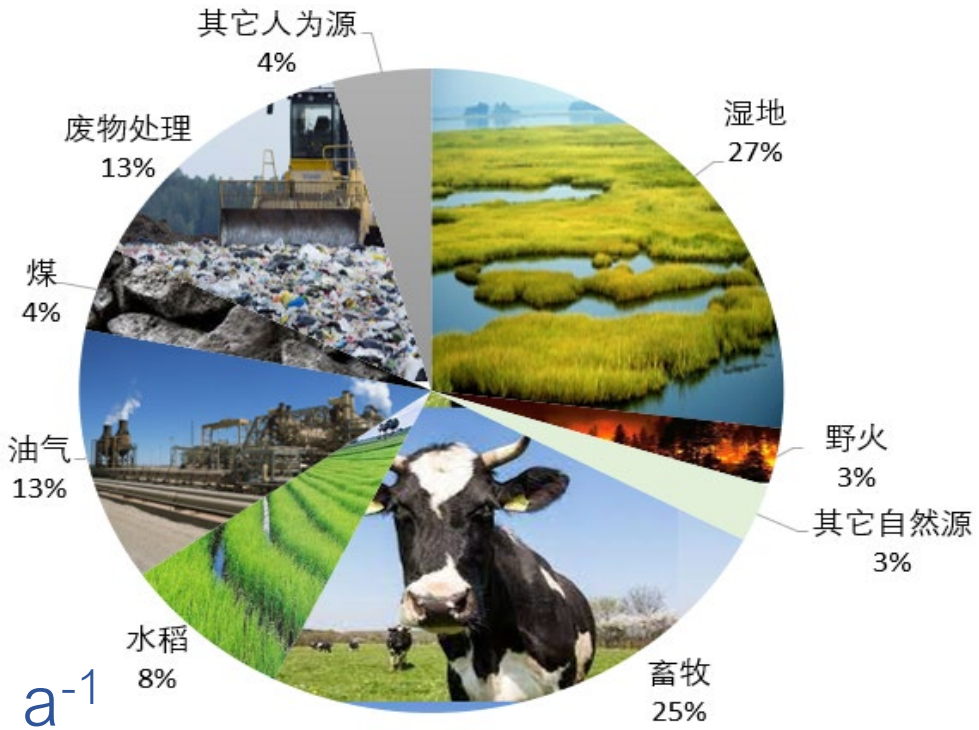
Tropospheric OH
89%

$CH_4 + OH \rightarrow CH_3 + H_2O$

Soil Absorption

Stratospheric Loss

Tropospheric Cl

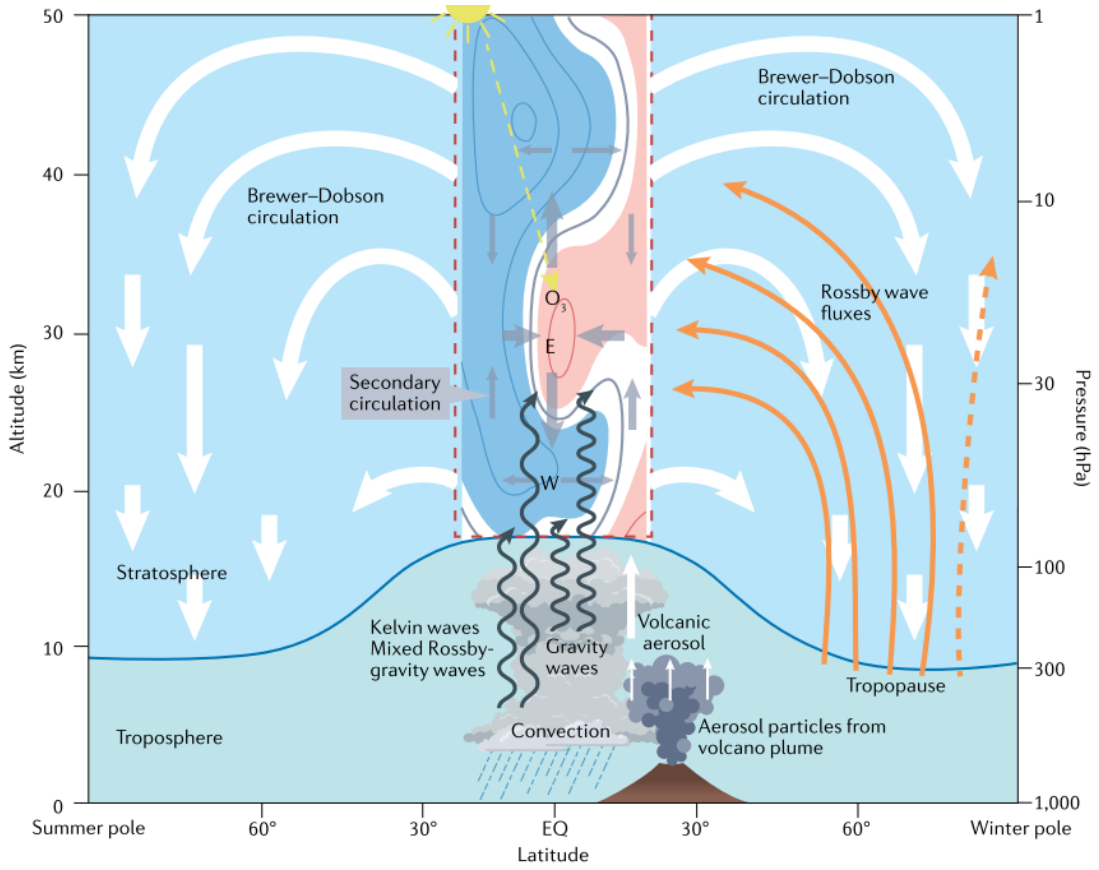


sources

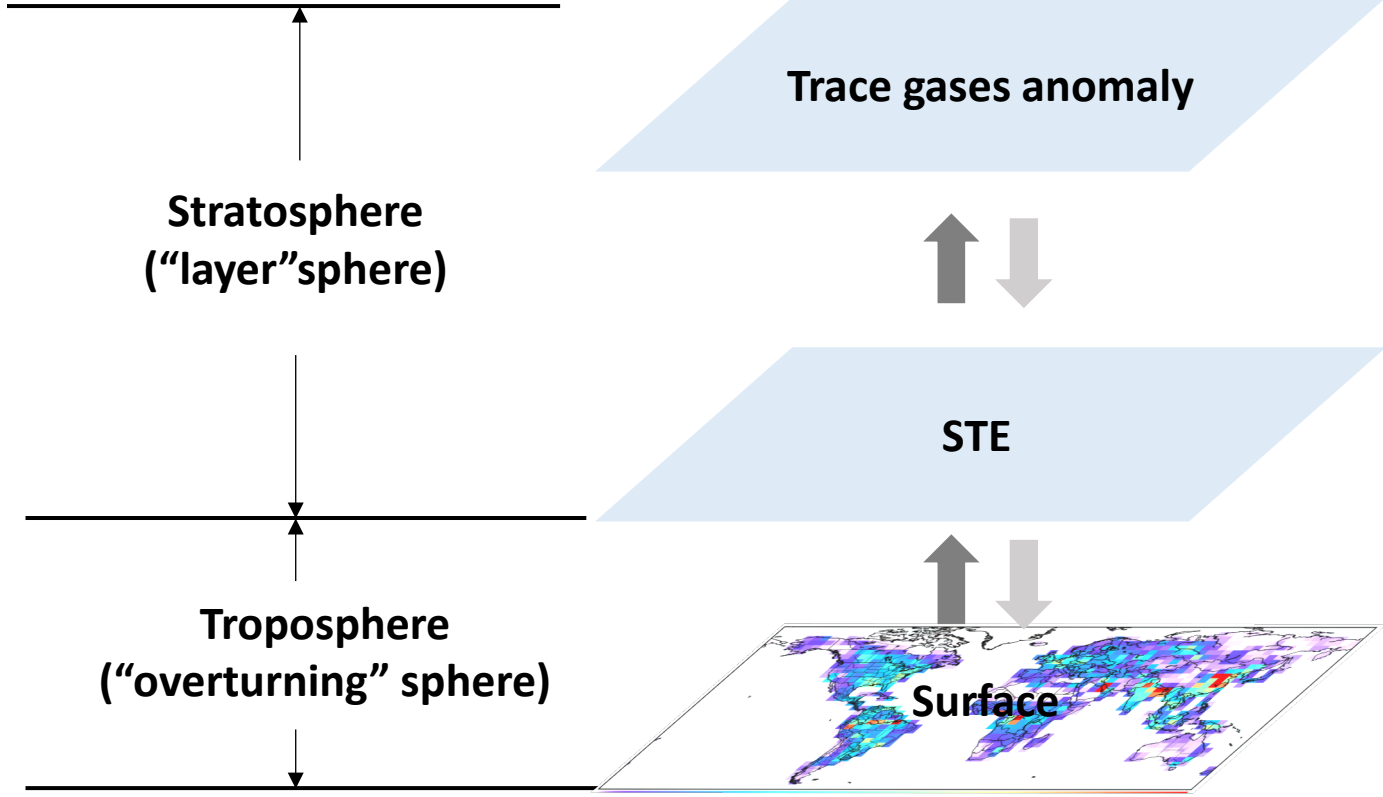
550 ± 60 Tg a^{-1}

Stratospheric Dynamical Processes

Brewer-Dobson Circulation



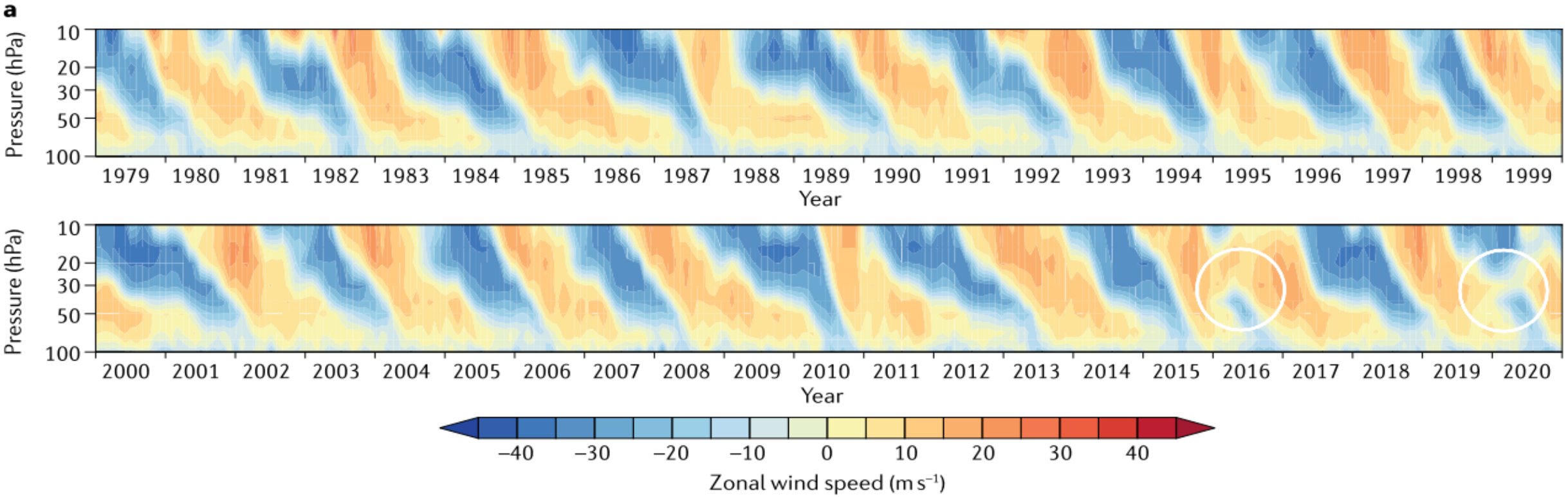
Anstey et al ., (2022)



Stratospheric Dynamical Processes

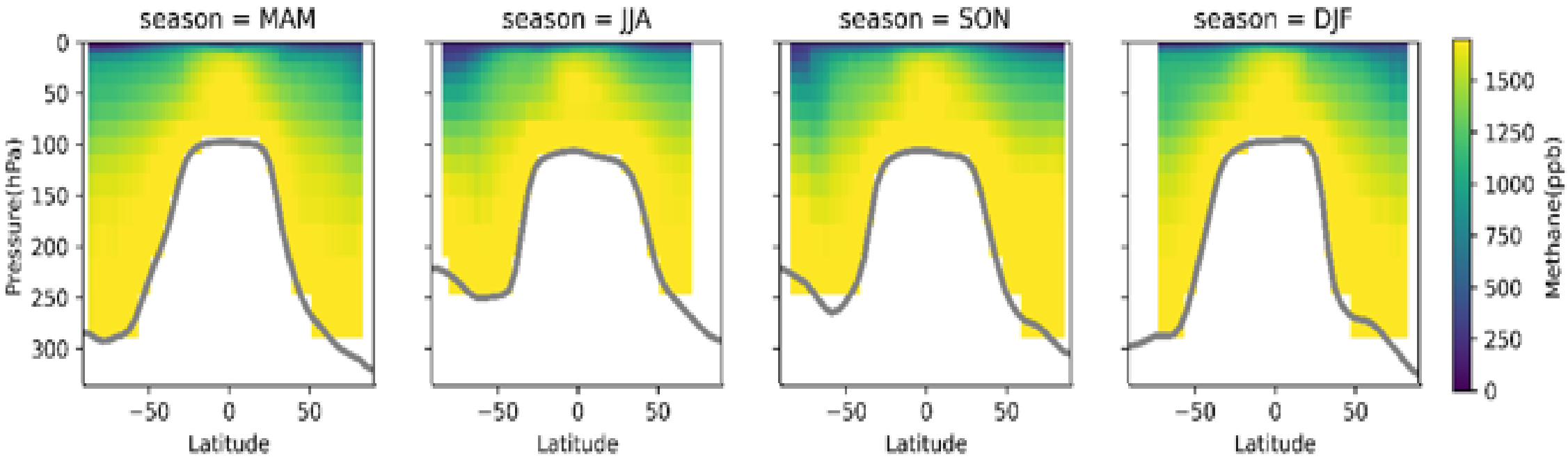
Quasi Biennial Oscillation(QBO)

alternating west and east wind(period≈28 months)

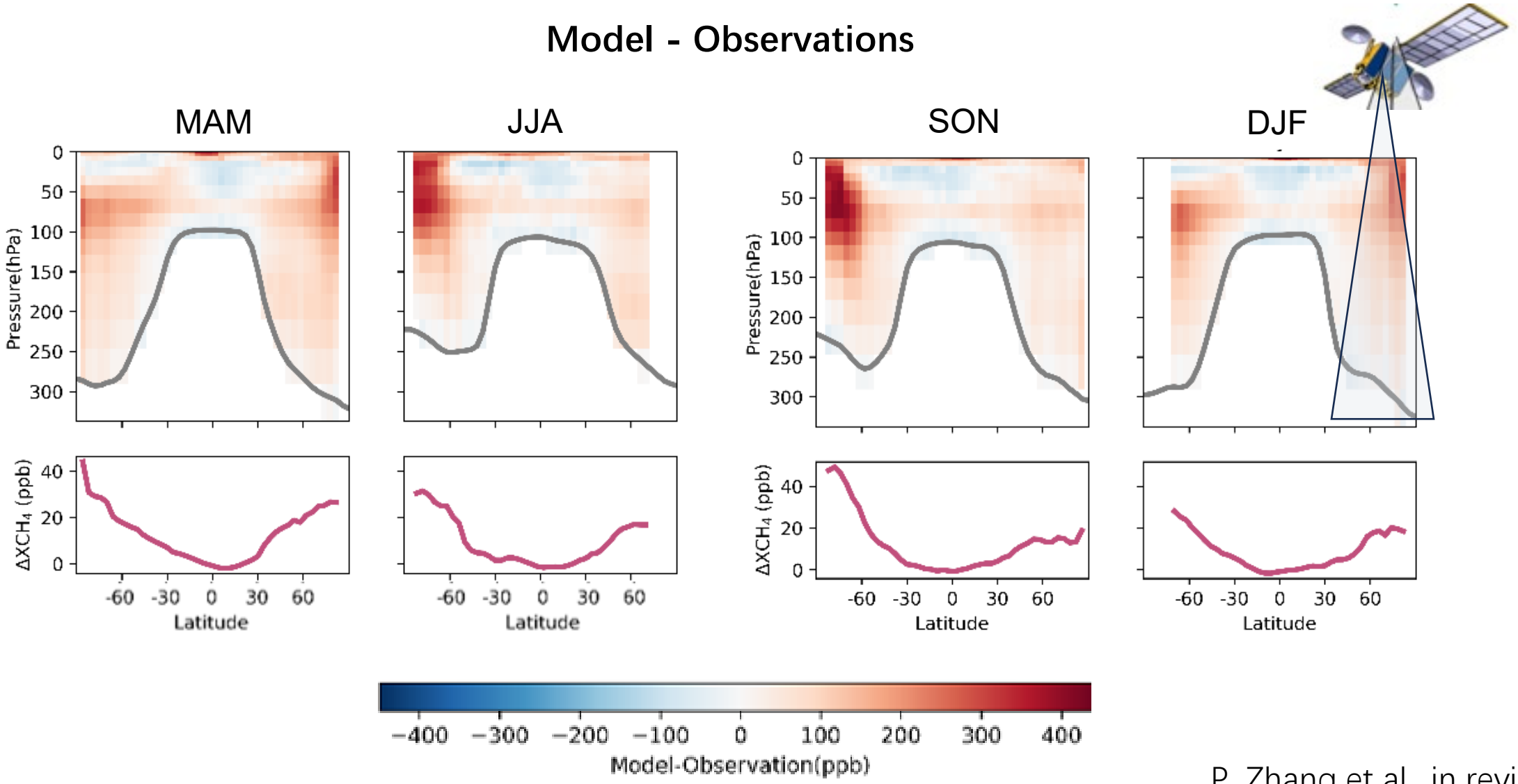


Strong Concentration Gradient in the Stratosphere

Satellite observed methane gradient in the stratosphere



Challenges for Models to Accurately Capture Strong Gradient



P. Zhang et al., in review

Challenges for Models to Accurately Capture Strong Gradient

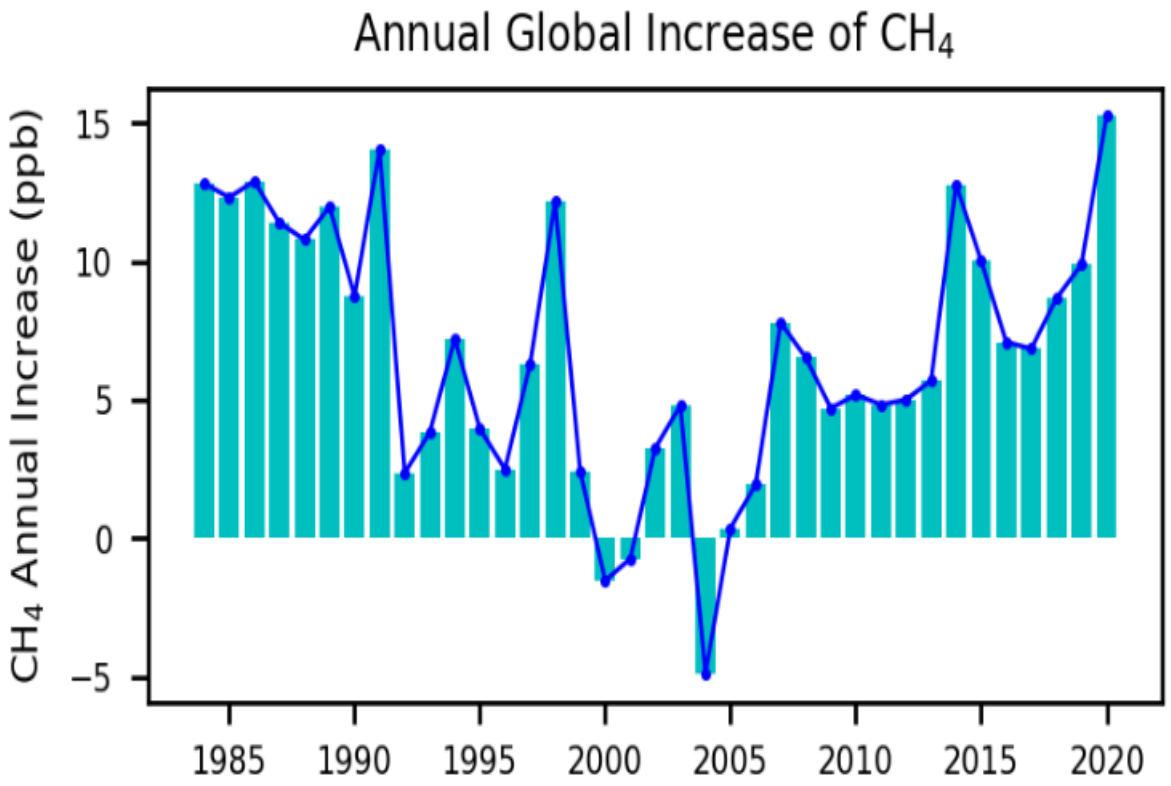
Methane emissions inferred from satellite inversion (Tg a^{-1})

Latitude Band	Original	Corrected				Corrected mean	Corrected SD	Corrected - Original
	SC0	SC1	SC2	SC3	SC4			
60N-90N	18.9	28.6	34.3	26.3	24	28.3	3.8	9.4
30N-60N	137.1	151.4	196.6	158.3	160.8	166.8	17.6	29.7
0-30N	225.1	211.3	191.6	210.6	204.2	204.4	7.9	-20.7
30S-0	123.7	114.6	110.5	127.2	127.6	120	7.6	-3.7
60S-30S	18.4	20.2	44.4	19.6	19.5	25.9	10.7	7.5
Global	523.1	526	577.4	542.1	536.1	545.4	19.4	22.3

P. Zhang et al., in review

What is the Impact of Stratosphere-Troposphere Exchange?

Annual growth rates of the surface CH_4



Aged CH_4-depleted influx

$$\frac{dB_T}{dt} = E_T - L_T + F_{S\rightarrow T}$$?

B_T: Tropospheric budget

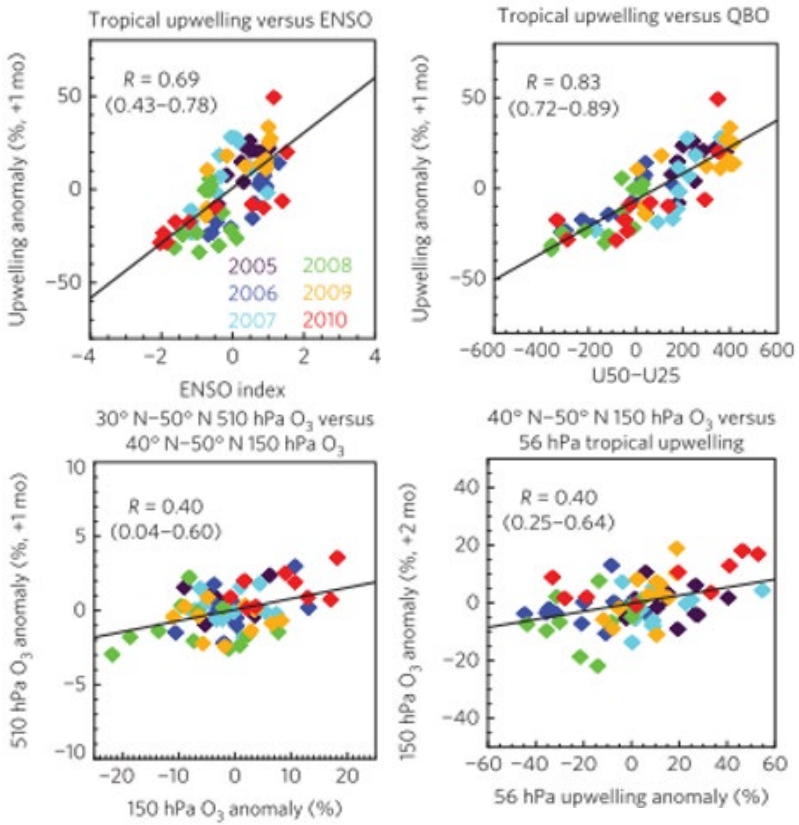
E_T: Surface emissions

L_T: Chemical loss with OH

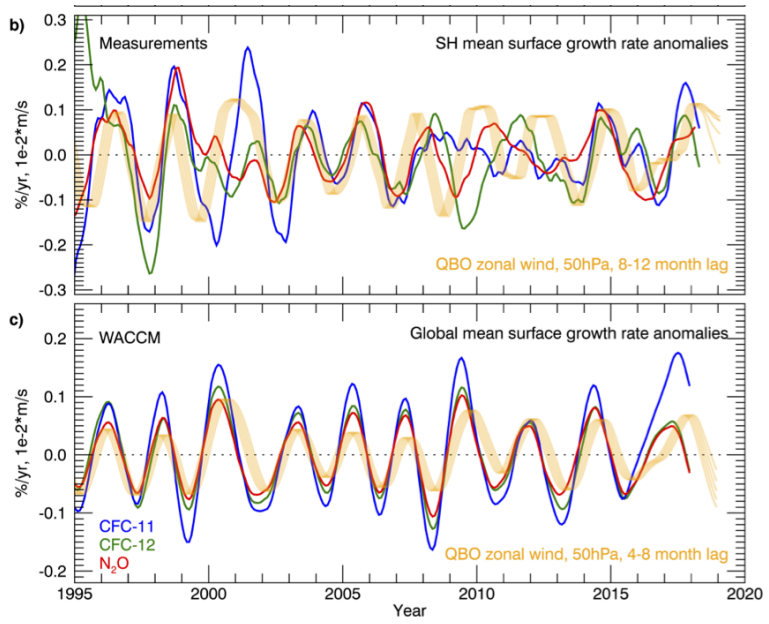
$F_{S\rightarrow T}$: Stratosphere-Troposphere-Exchange (STE) flux

Impact of STE on ozone, N_2O, and CO_2

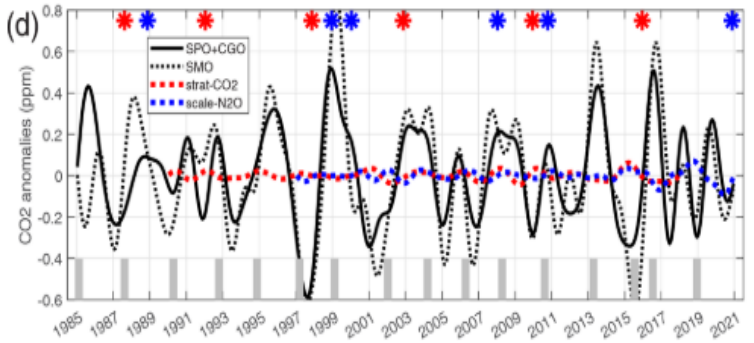
STE accounts for 16% variability of tropospheric **ozone** *(Neu et al., 2014)*



STE dominates the growth rate IAV of **N_2O**
Not accounting for it leads to 5-10% errors in annual emission inversion *(Ray et al., 2020)*



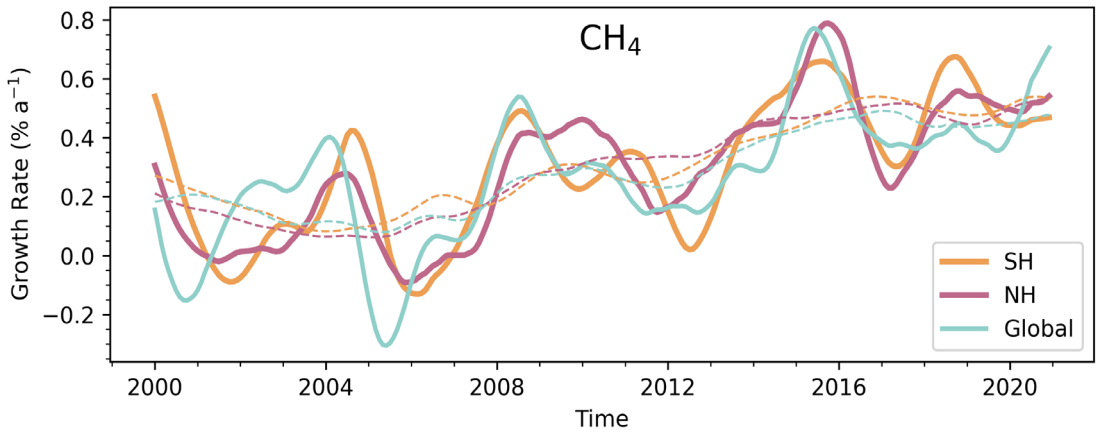
STE contributes negligible for surface **CO_2** variability *(Prather, 2022)*



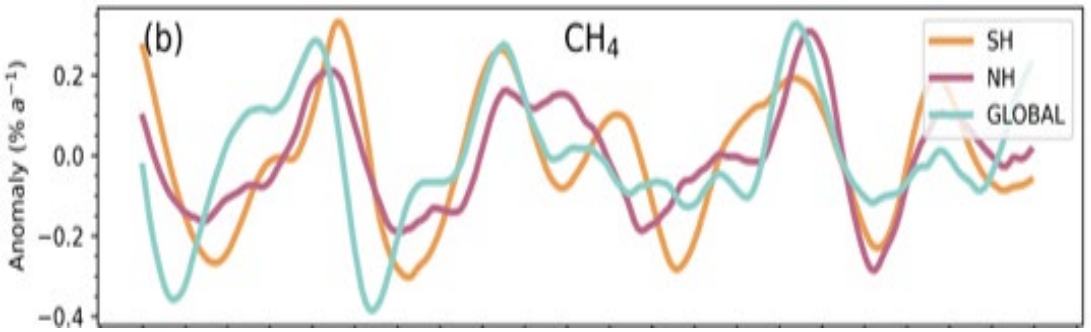
How about CH_4?

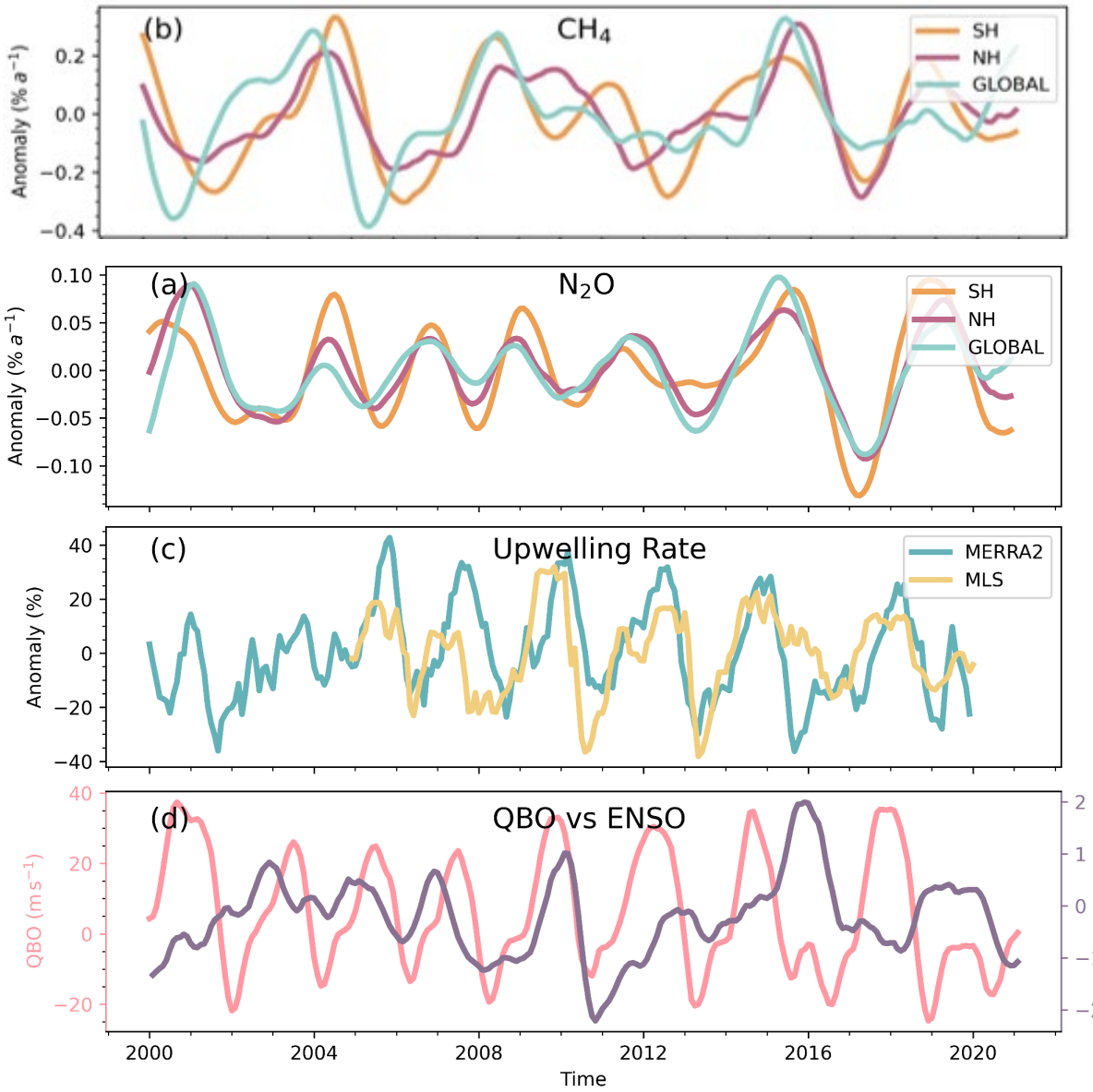
Growth rate anomalies of tropospheric CH_4

Growth rate



Growth rate anomalies





Quantification of $F_{S\rightarrow T}$

$$\frac{dB_T}{dt} = E_T - L_T + F_{S\rightarrow T}$$

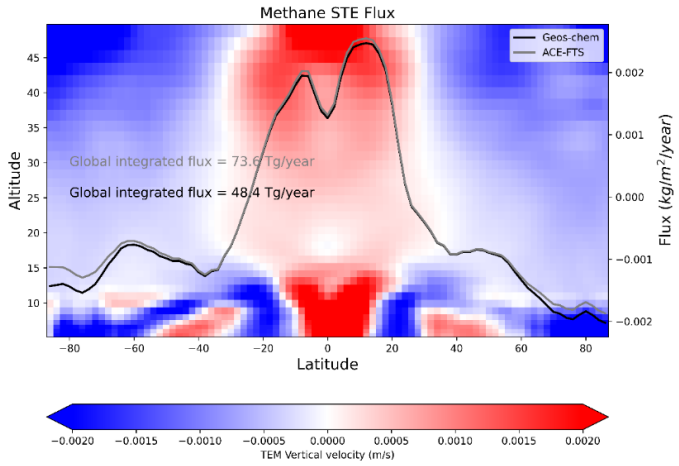
1) W*-derived

Transformed Eulerian mean vertical velocity

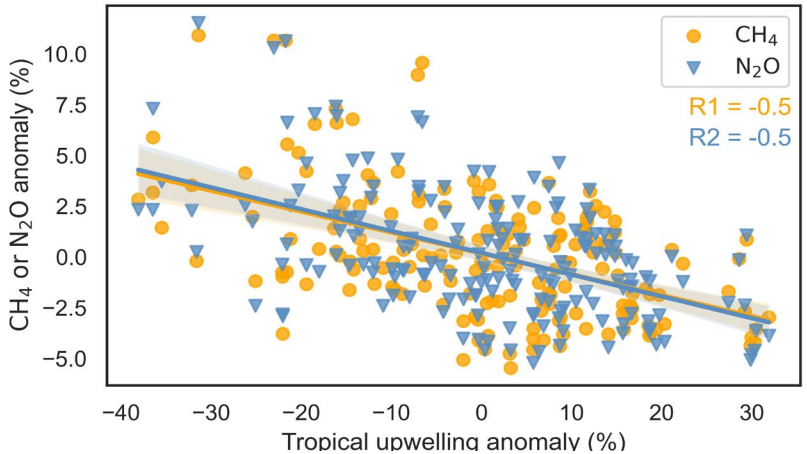
$$\bar{v}^* = \bar{v} - \partial_p\left(\frac{\overline{v'\theta'}}{\partial_p\bar{\theta}}\right)$$

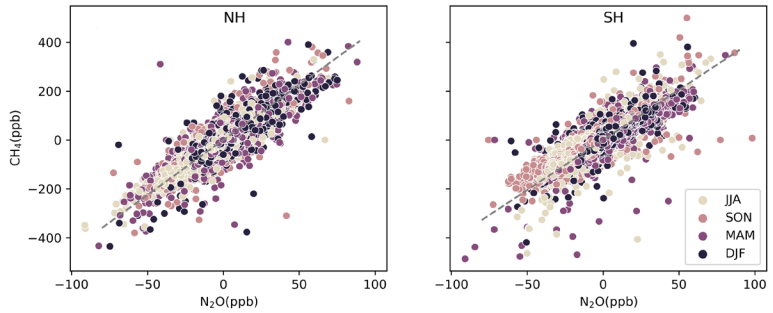
$$\bar{w}^* = \bar{w} + \frac{1}{a\cos\phi}\partial_\phi\left(\frac{\overline{v'\theta'}\cos\phi}{\partial_p\bar{\theta}}\right)$$

CH_4 STE fluxes: CH_4 concentration× w*

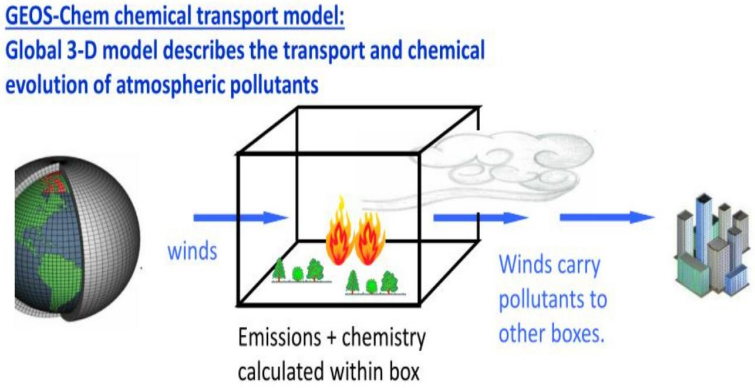


2) N_2O-scaled





3) Fixed-budget simulation



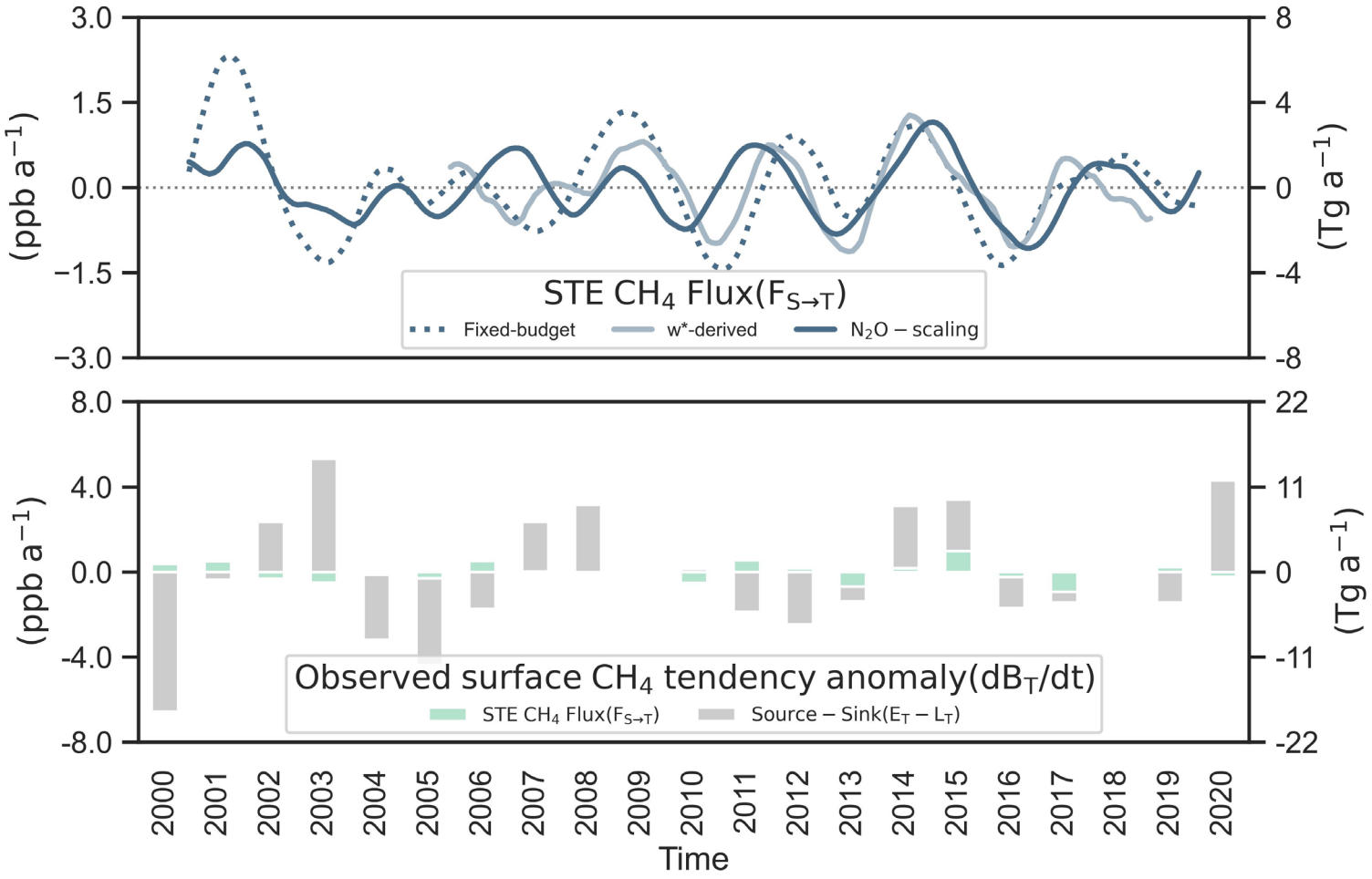
Unvarying emissions and sinks

Varying atmospheric transport

CH_4 STE fluxes: output from model

P. Zhang et al., GRL, 2023

Minor contribution globally

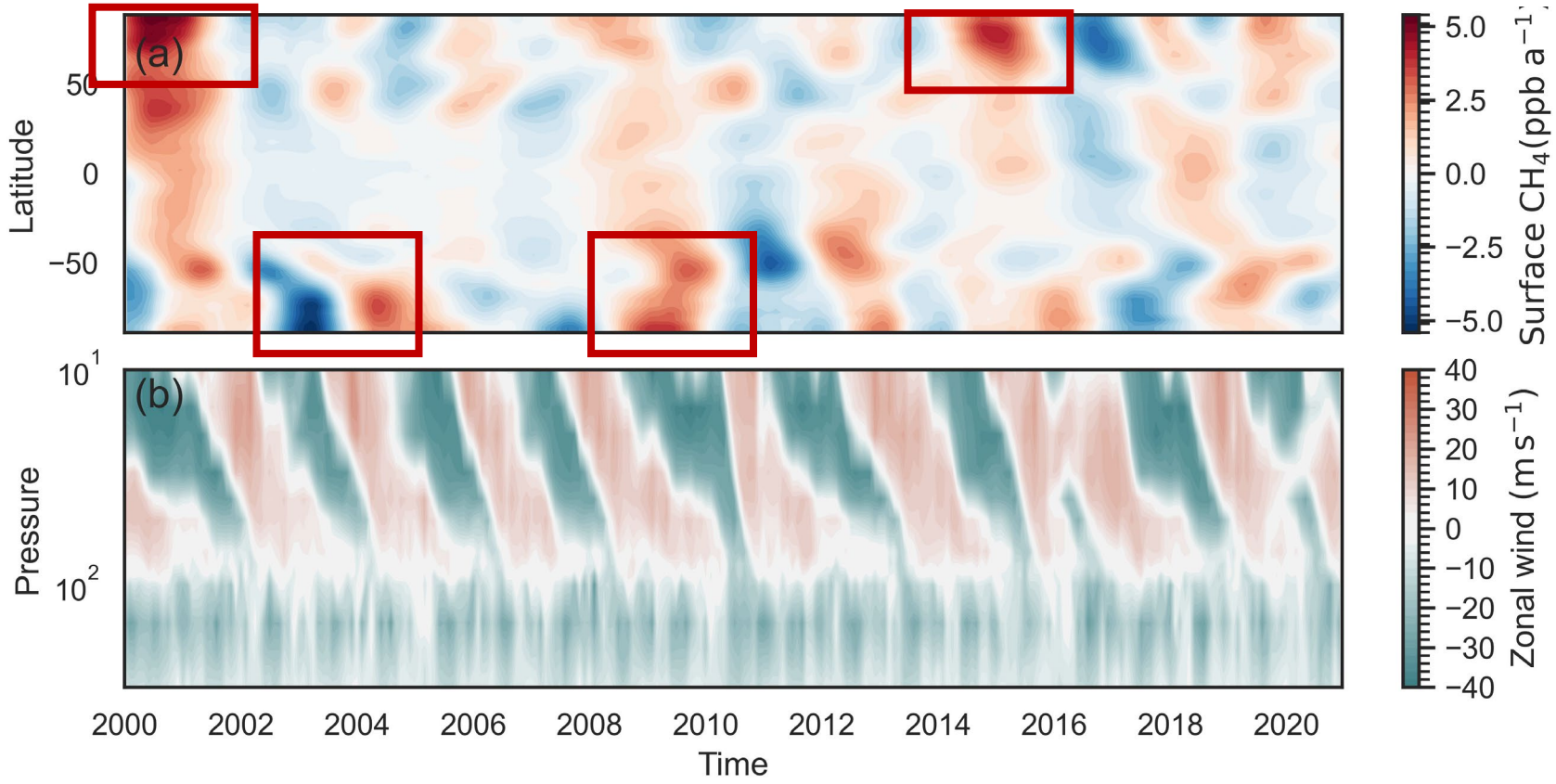


P. Zhang et al., GRL, 2023

STE-forced signal: about 2.0 Tg a^{-1} (~20 % of total IAV)

More Important at High Latitudes

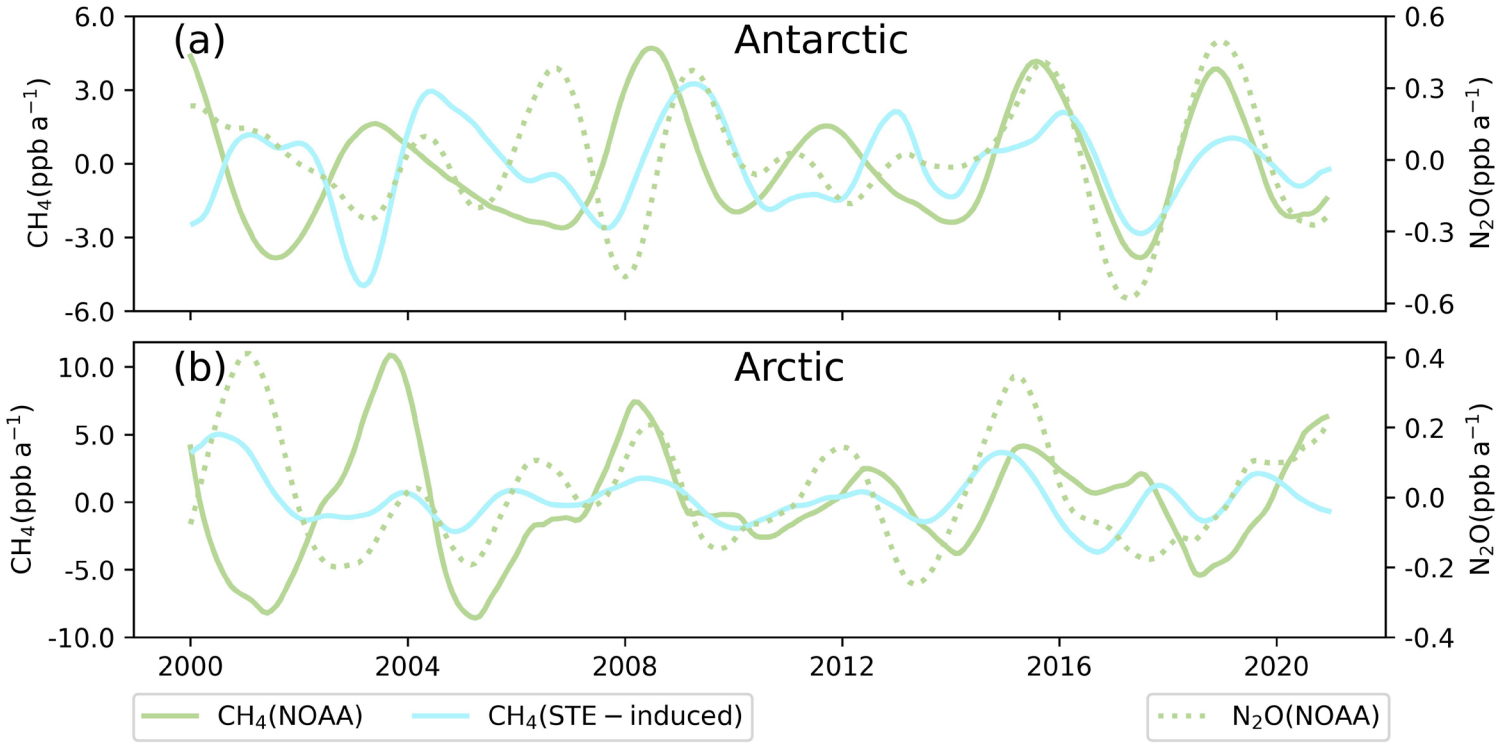
Fixed budget simulation



P. Zhang et al., GRL, 2023

A minor contributor globally but can be substantial at high latitudes

Important for Interpreting Surface Observations in Polar Regions



Observed anomalies at surface sites

STE-induced anomalies from simulation

Antarctic : ~80% **Arctic : ~40%**

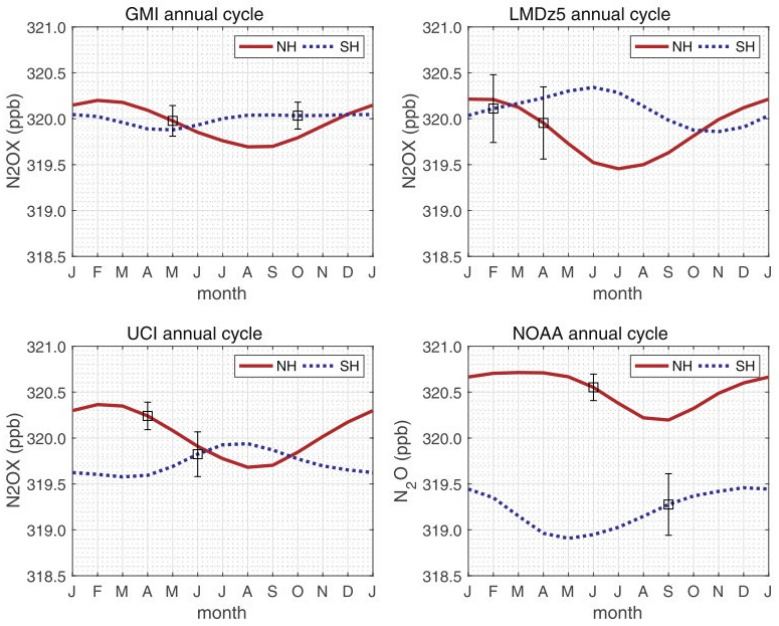
P. Zhang et al., GRL, 2023

Summary

1. The inter-annual variability of the CH_4 flux between the stratosphere and the troposphere is ~2.0 Tg a^{-1}, about 20% of global observed surface CH_4 growth rate variability.

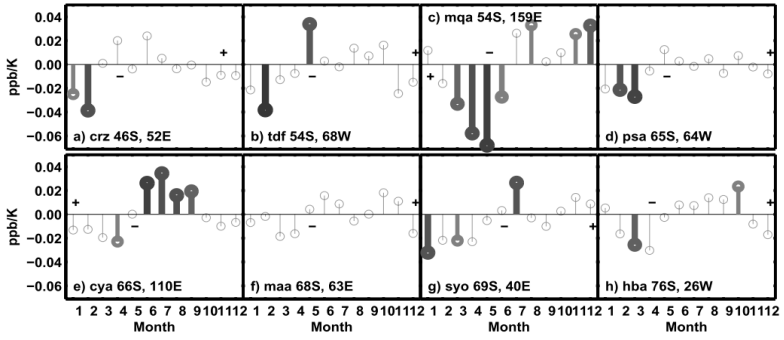
2. High-latitudes experience a larger STE-induced surface variability, which is ~80% in the Antarctic and ~40% in the Arctic.

现有研究的局限性：平流层对全球甲烷收支影响的研究局限



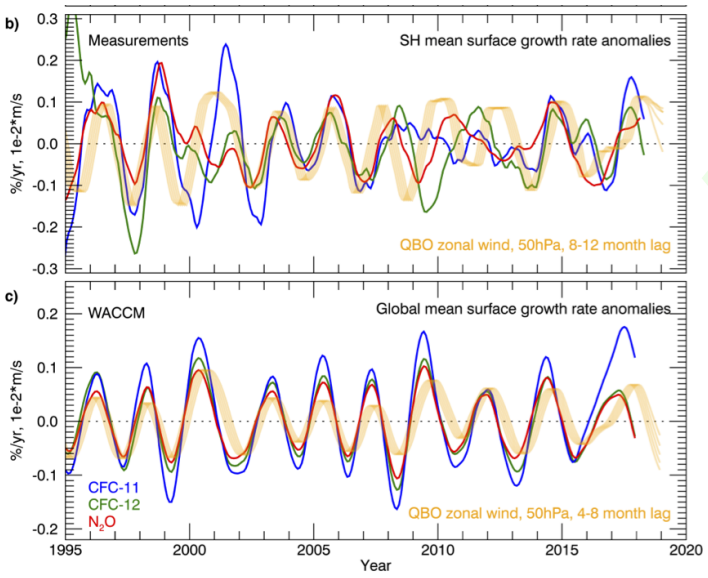
NH N_2O 季节性变化主要受平流层控制

(Ruiz et al., 2020)



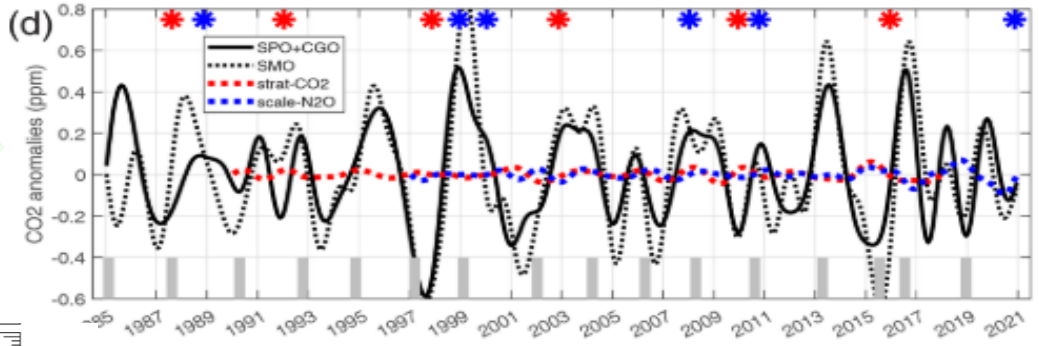
平流层对地表CO_2年际波动贡献较小（10%）

(Prather, 2022)



N_2O 季节性变化和冬季极区平流层下层温度反相关

(Nevison et al., 2011)



忽略平流层的QBO周期影响会对1-5年时间尺度内的N_2O排放估计造成误差（5-10%）

(Ray et al., 2020)

N_2O的NH-SH梯度年际波动中平流层占比60%-70%

(Lickley et al., 2021)