

# RECENT CHANGES OF CH<sub>4</sub> SINCE 2005

## from FTIR observations and GEOS-CHEM simulation

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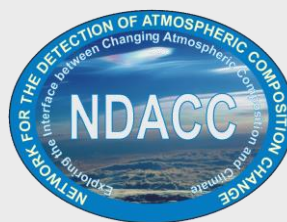
A. Turner



P. Bernath



E. Buzan



# Methane changes

- Second anthropogenic greenhouse gas -  $\text{GWP}_{100} = 28$  (IPCC-AR5)
- 1824 ppb : new high of +260% wrt pre-industrial levels (1750)
- ~1/5 of the increase in radiative forcing by human-linked greenhouse gases since 1750 is due to methane [Nisbet et al., 2014]
- Non monotonic behaviour
- Last 25 years...
  - Increase in the 90s
  - 2000-2005/2006 : stable
  - The need "For a proper closure of the methane budget and the development of realistic future climate scenarios, methane emissions during this stabilization period should be understood and precisely quantified" Pison et al., 2013
  - From 2005/2006 : new increase → Why ?

# Methane changes

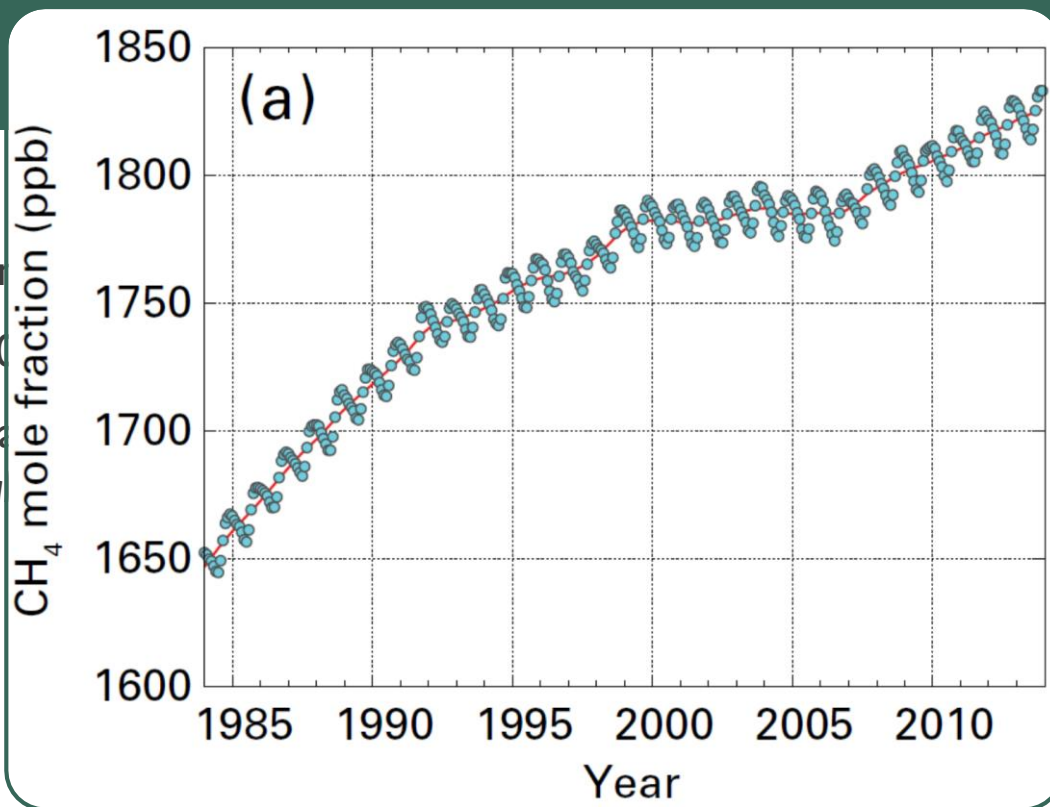
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- From 2005/2006 : new increase → Why ? → Source attribution ?



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# NDACC Sites

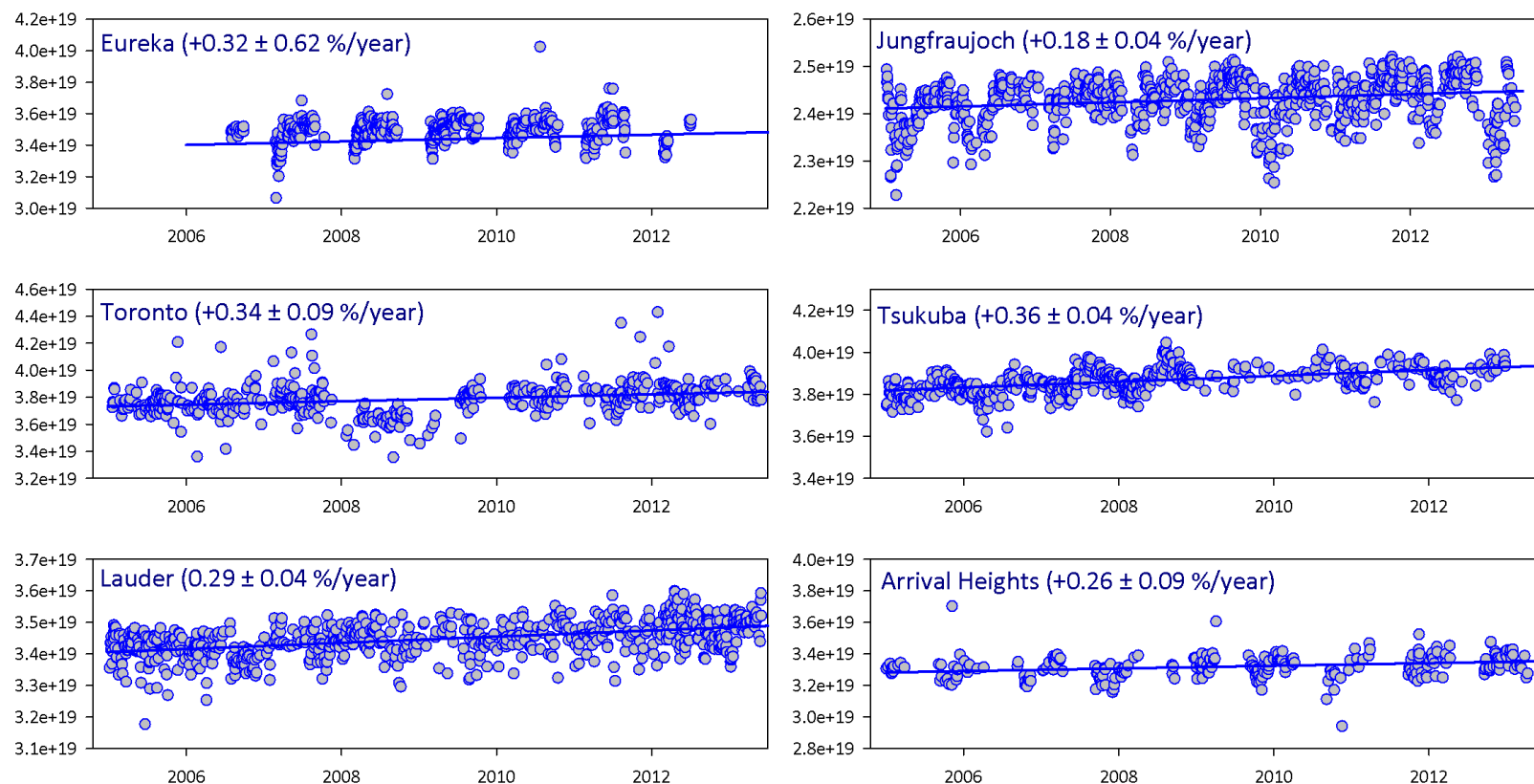


- <sup>1</sup> Eureka (80 °N, 86 °W)
- <sup>2</sup> Jungfraujoch (46 °N, 8 °E)
- <sup>3</sup> Toronto (44 °N, 79 °W)

- <sup>4</sup> Tsukuba (36 °N, 140 °E)
- <sup>5</sup> Lauder (45 °S, 169 °E)
- <sup>6</sup> Arrival Heights (77 °S, 166 °E)

# FTIR Observations - Total Columns

Daily Mean Methane Total Columns in molecules/cm<sup>2</sup>



CH<sub>4</sub> global increase from WMO/GAW global greenhouse gas monitoring network : 0.33%

**Source attribution ?**

# GEOS-CHEM tagged simulation

- ✓ GEOS-CHEM MODEL V9-02
- ✓ CHEMICAL TRANSPORT MODEL
- ✓ 2X2.5 & 47 vertical levels
- ✓ Time step : 3 hours
- ✓ GEOS5 (2005-2013/05)
- ✓ GFED3
- ✓ OH\_v5-07-08
- ✓ EDGAR v4.2 (2004-2008)
- ✓ K. Wecht et al., 2014
- ✓ Each tracer represents the contribution of each source to the simulated total column of methane

## Tracers

- |                            |
|----------------------------|
| 1- Total                   |
| 2- Gas and oil             |
| 3- Coal                    |
| 4- Livestock               |
| 5- Waste management        |
| 6- Biofuels                |
| 7- Rice cultures           |
| 8- Biomass burning         |
| 9- Wetlands                |
| 10- Other natural          |
| 11- Other anthropogenic    |
| <b>12- Soil absorption</b> |



# GEOS-CHEM Data Processing

- Nearest-neighbour interpolation to match ground-based instrument coordinates
- Conservative regridding scheme to the grid used in the FTIR retrieval
  - Specific to each station
- Smoothing of GEOS-CHEM data by the respective averaging kernels
- Changes calculation with a bootstrap resampling method
  - Linear fit + Fourier series (Gardiner et al., 2008)
  - Mean annual change (in %/year)
- Comparison only for days when observation is available



# FTIR Observations vs GEOS-CHEM

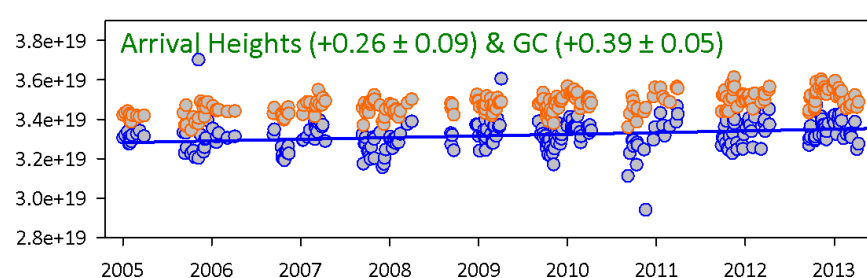
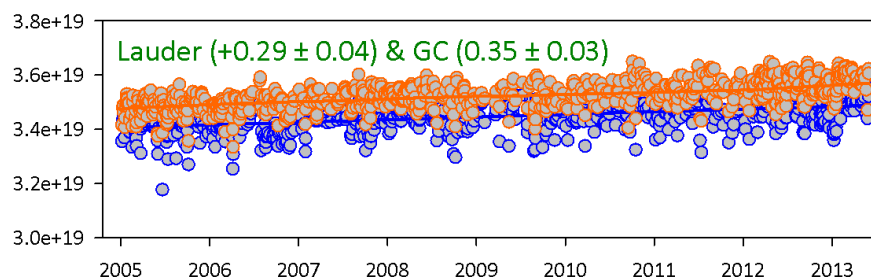
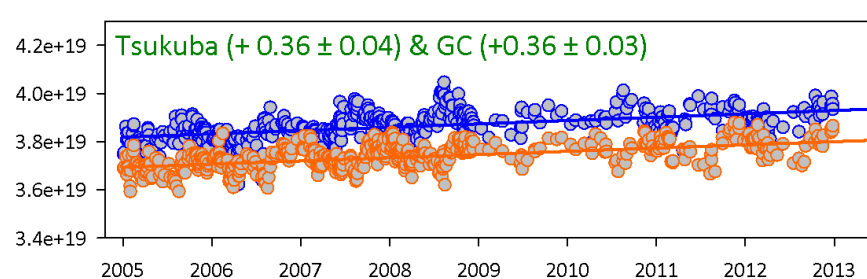
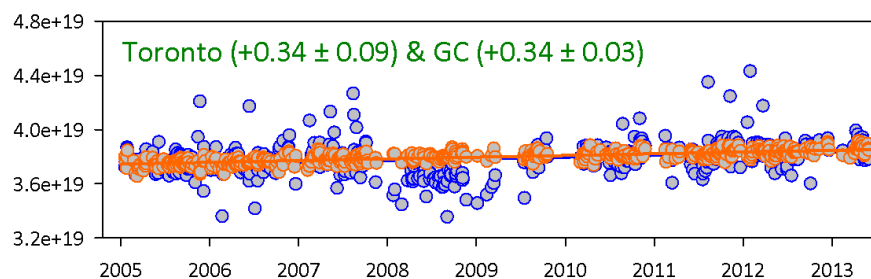
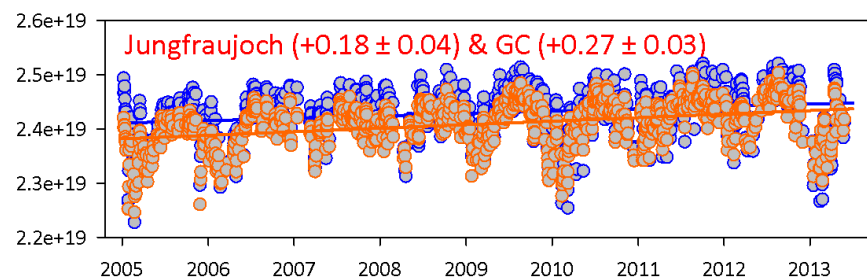
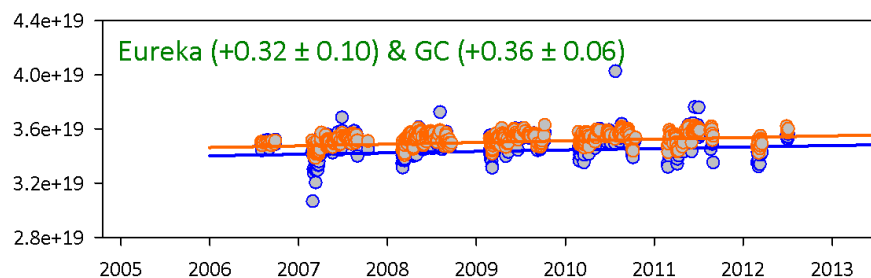
Total Column





# FTIR Observations vs. GEOS-CHEM Simulation Total Columns

Daily Mean Methane Total Columns in molecules/cm<sup>2</sup>  
Mean CH<sub>4</sub> changes in %/year



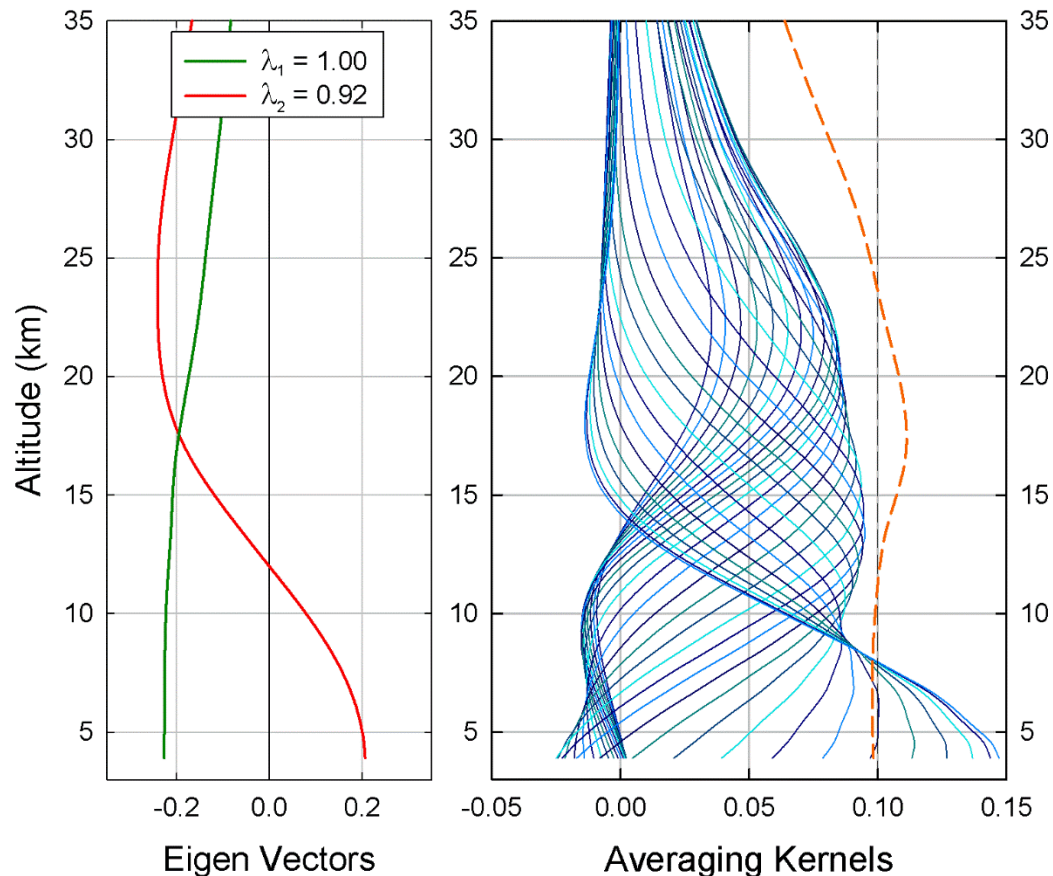
# GEOS-CHEM known issues

- EDGAR emission inventory
  - Spatial patterns
  - Increase in Chinese CH<sub>4</sub> emissions from coal after 2002 not supported by surface aircraft or satellite observations
  - Best inventory available
- Simplistic stratosphere (first order-loss)
- Best version available so far
- How good is the GEOS-CHEM simulation vertically ?

# FTIR Observations Information Content

DOFS = ~2.2 - Information content allows us to retrieve two partial columns

A tropospheric and a stratospheric one



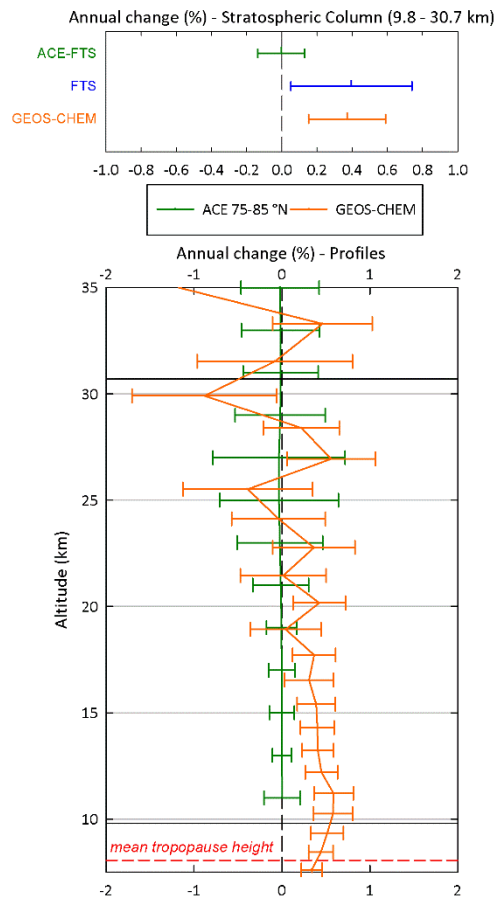


# FTIR Observations vs GEOS-CHEM

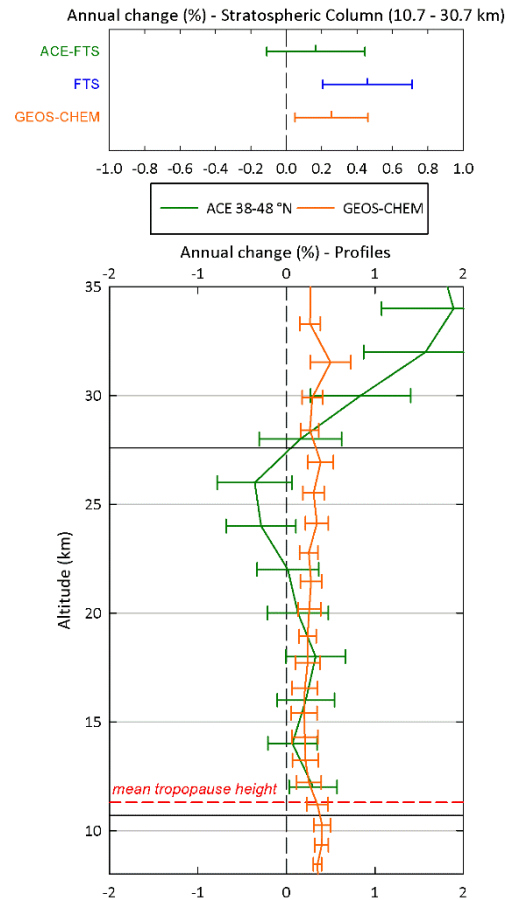
Stratospheric Column



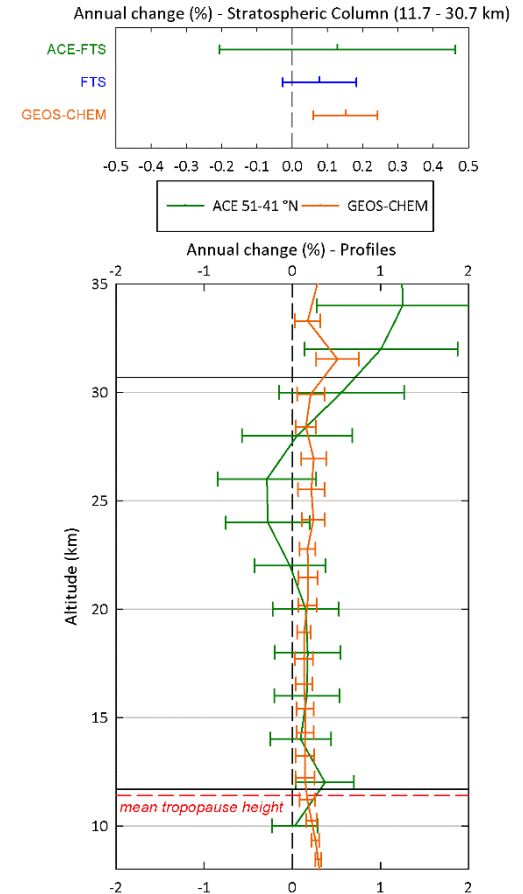
## Eureka



## Toronto



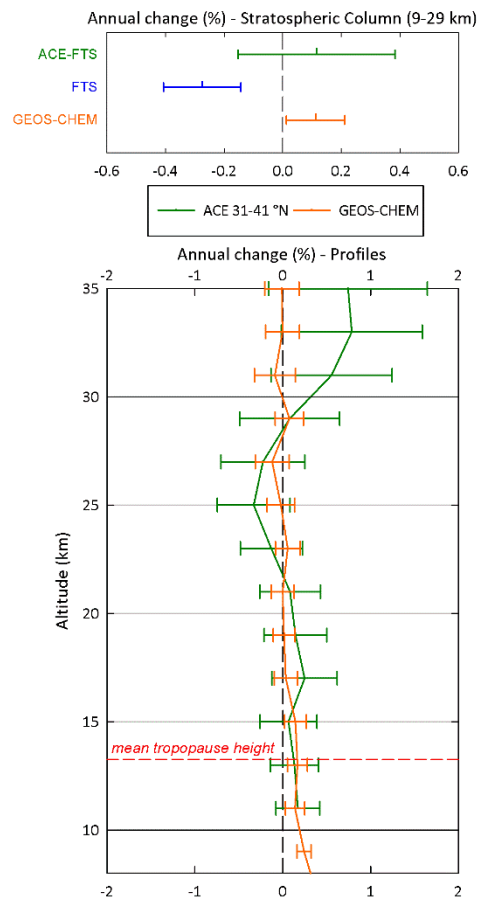
## Jungfraujoch



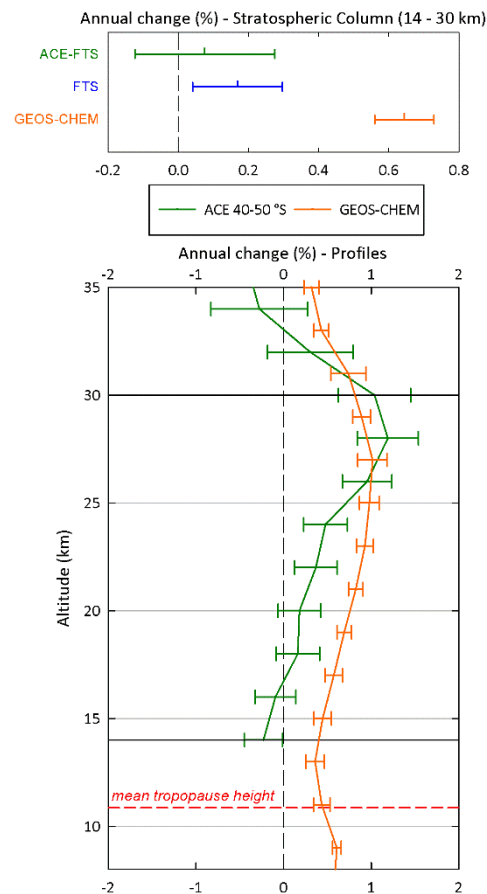
FTIR vs GEOS-CHEM  
Stratospheric Methane  
Mean Annual Changes in %

FTIR Observations, ACE-FTS occultations  
and the GEOS-CHEM simulation are  
statistically in agreement

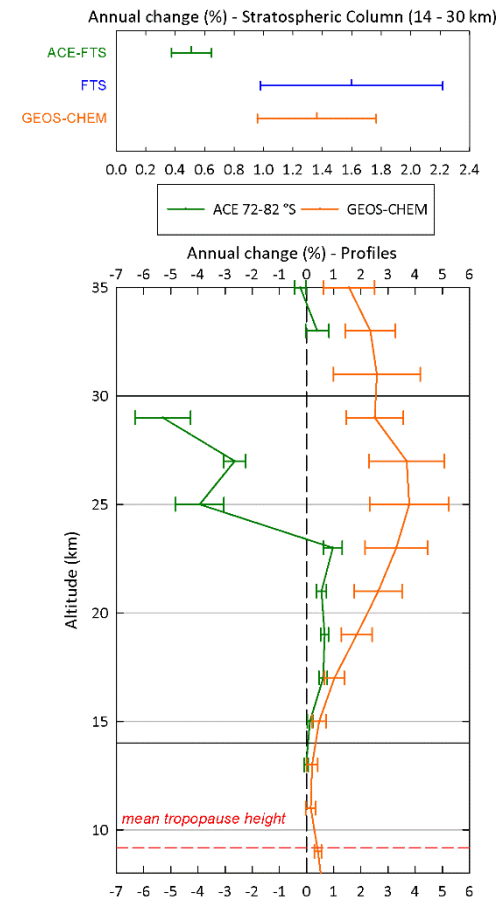
# Tsukuba



# Lauder



# Arrival Heights



FTIR vs GEOS-CHEM  
Stratospheric Methane  
Mean Annual Changes in %

TSU - GC and FTS are not in agreement  
LAU - GC overestimates measurements  
AHTS - ACE 10° band + polar vortex



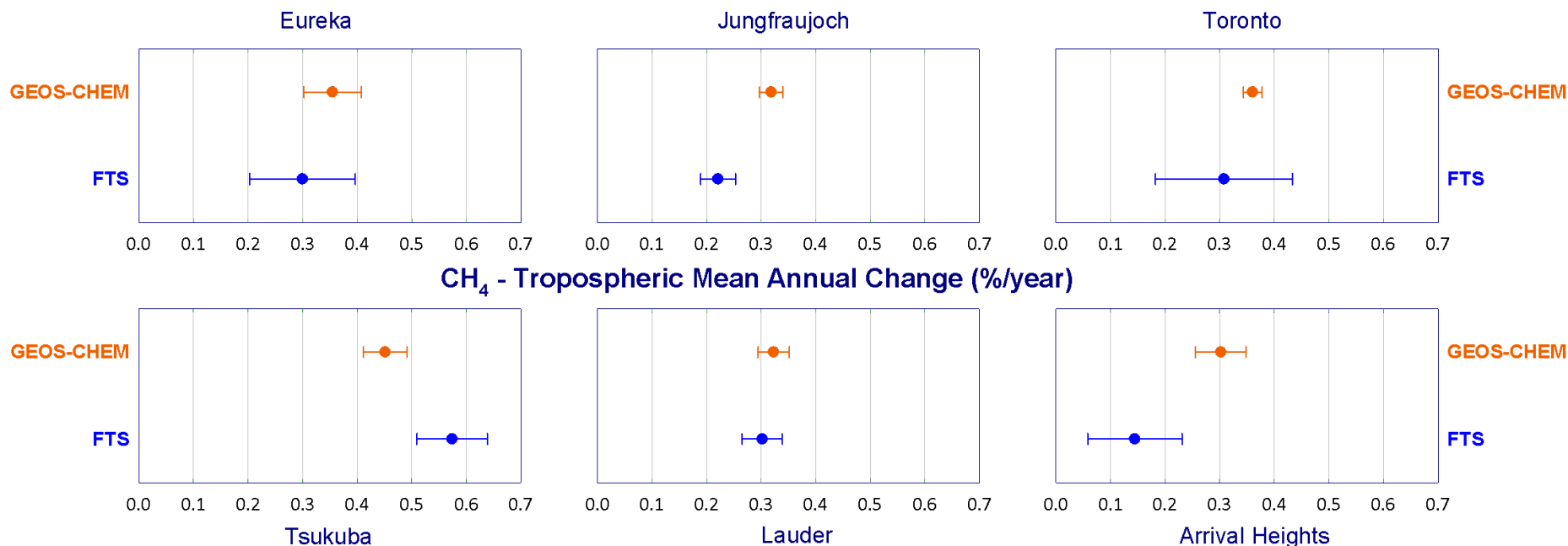
# FTIR Observations vs GEOS-CHEM

Tropospheric Column



# FTIR Observations vs GEOS-CHEM Simulation

## Tropospheric methane

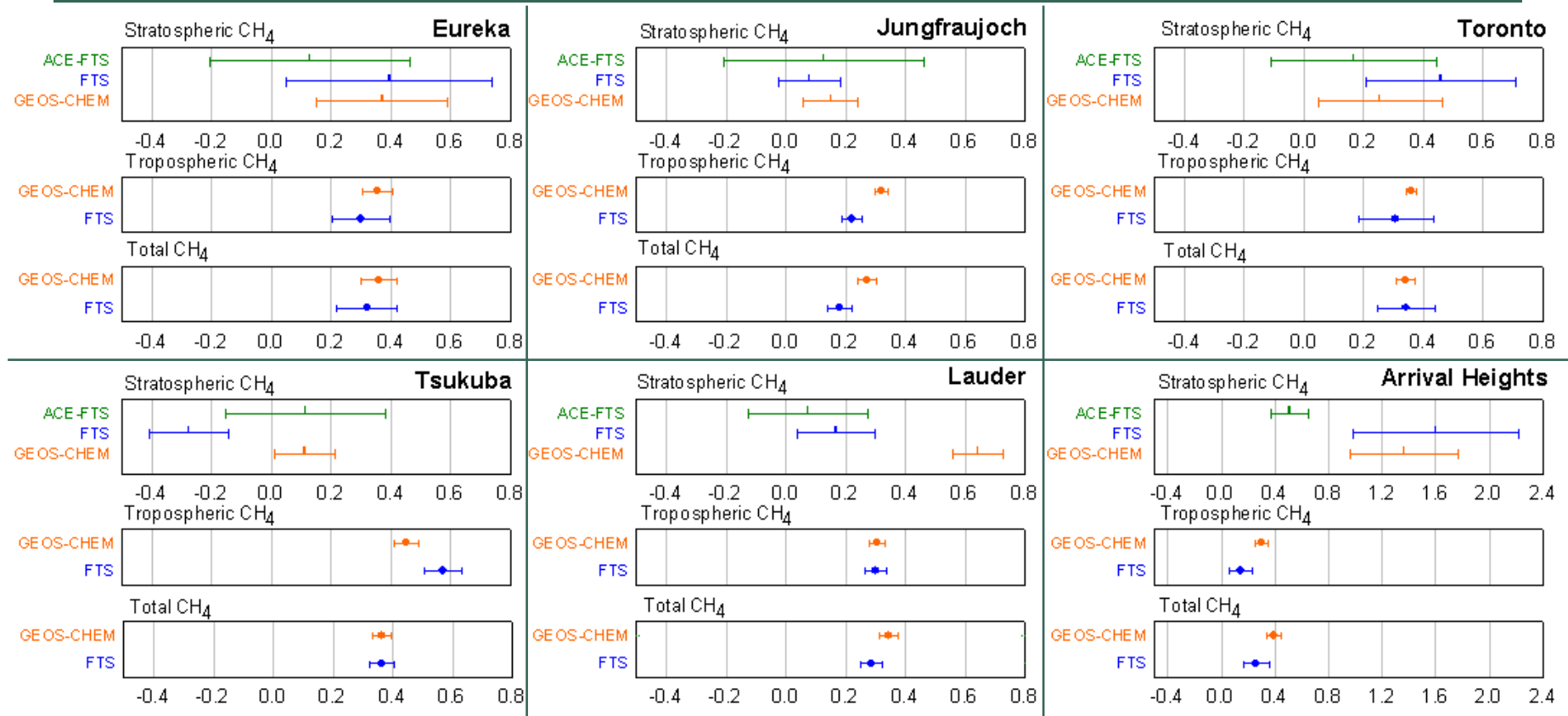


GEOS-CHEM tends to overestimate the tropospheric change but agrees within error bars for Eureka, Toronto and Lauder

Jungfraujoch : high altitude site (3.58 km) problem with vertical gradient of GC CH<sub>4</sub>  
 Arrival heights : Polar Vortex issue ?



# CH<sub>4</sub> changes - summary



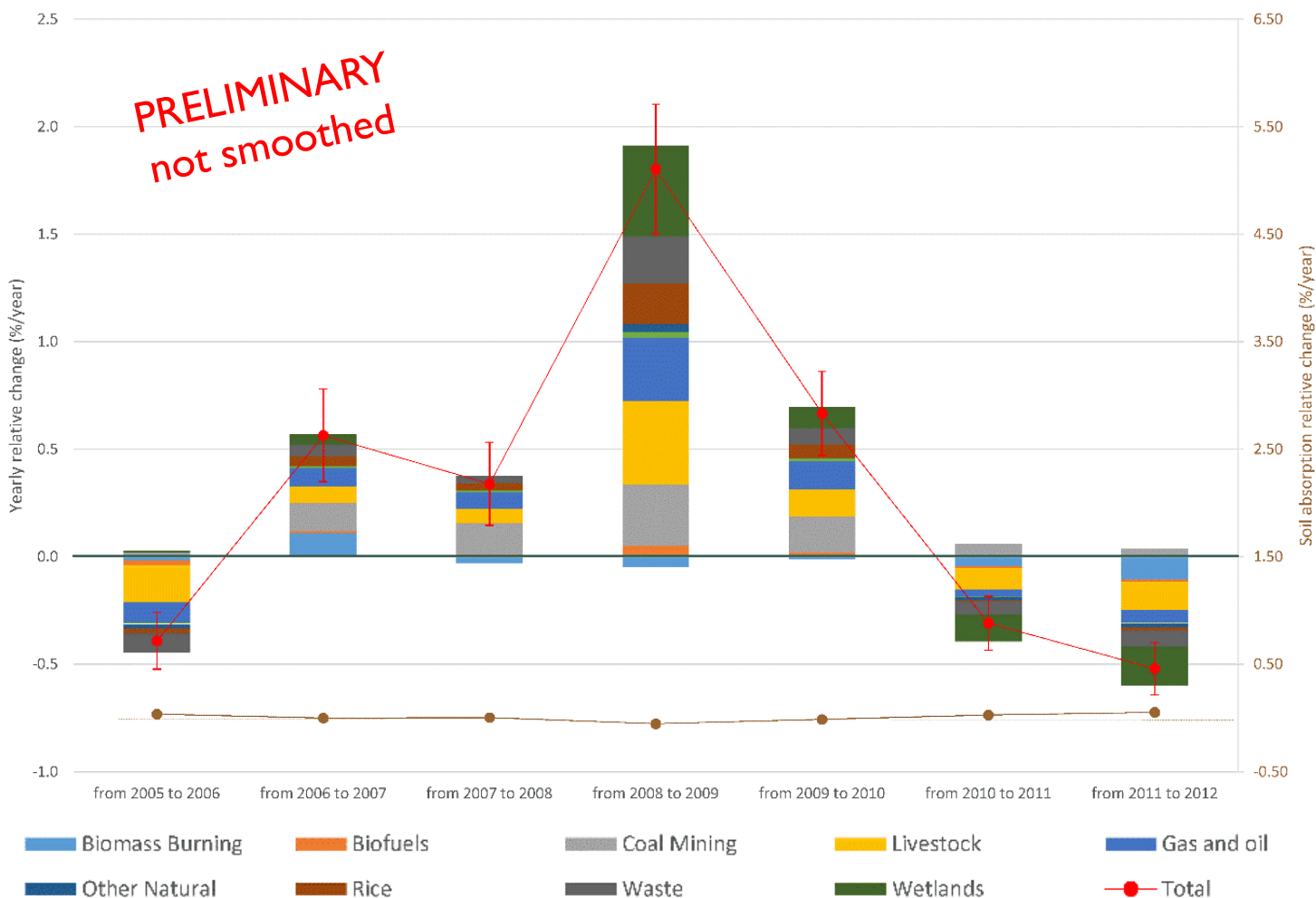
CH<sub>4</sub> total column changes are in the same order of magnitude than the tropospheric one as observed by FTS and simulated by GEOS-CHEM whereas stratospheric CH<sub>4</sub> show different type of regime from one station to another.



What does the tagged simulation tell us  
about the methane changes ?

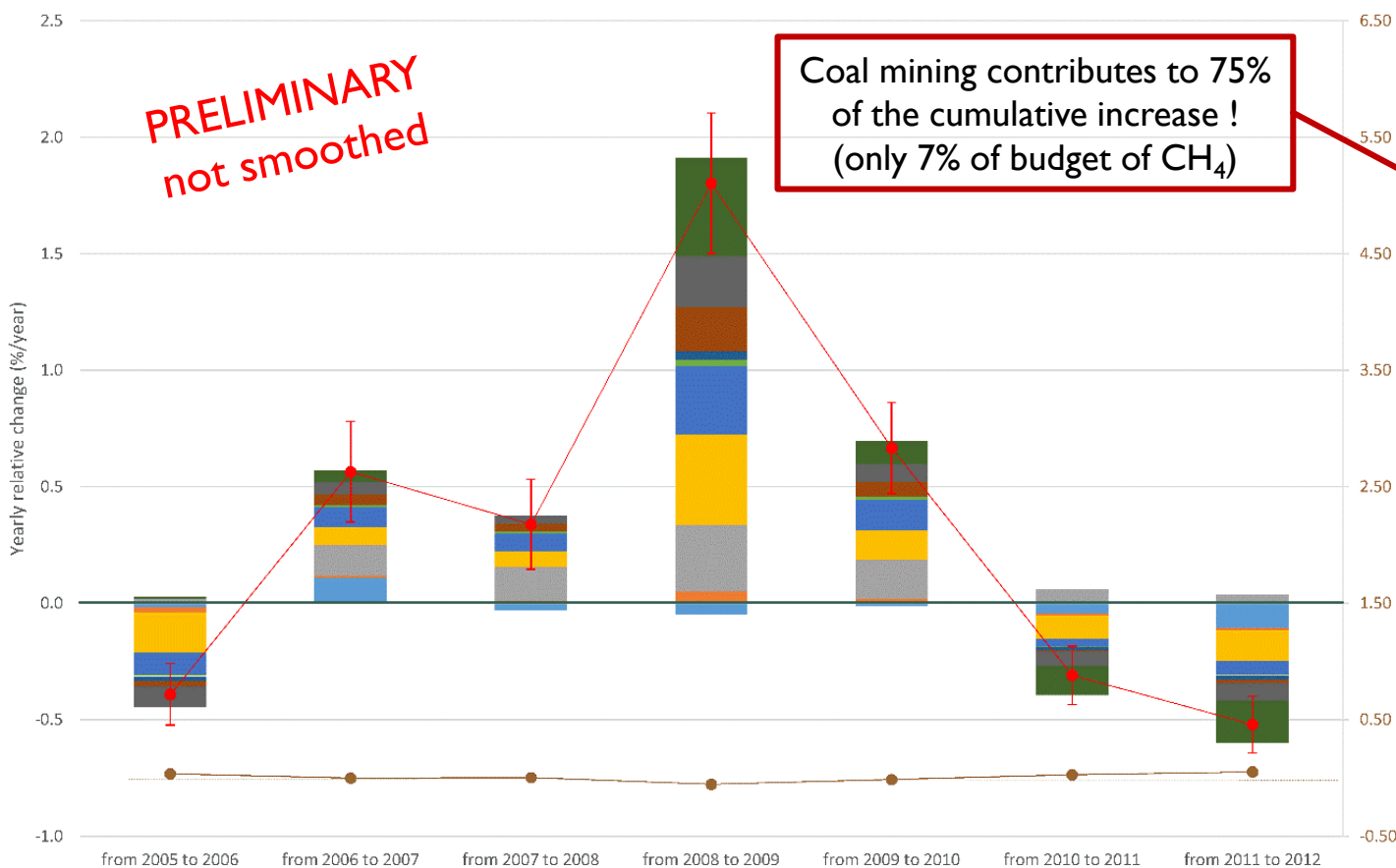


# GEOS-CHEM - Tracer Analysis Tropospheric CH<sub>4</sub> - Jungfraujoch



Yearly relative changes from one year to another to illustrate how each tracer contributes to the total CH<sub>4</sub> increase simulated by GEOS-CHEM

# GEOS-CHEM - Tracer Analysis Tropospheric CH<sub>4</sub> - Jungfraujoch

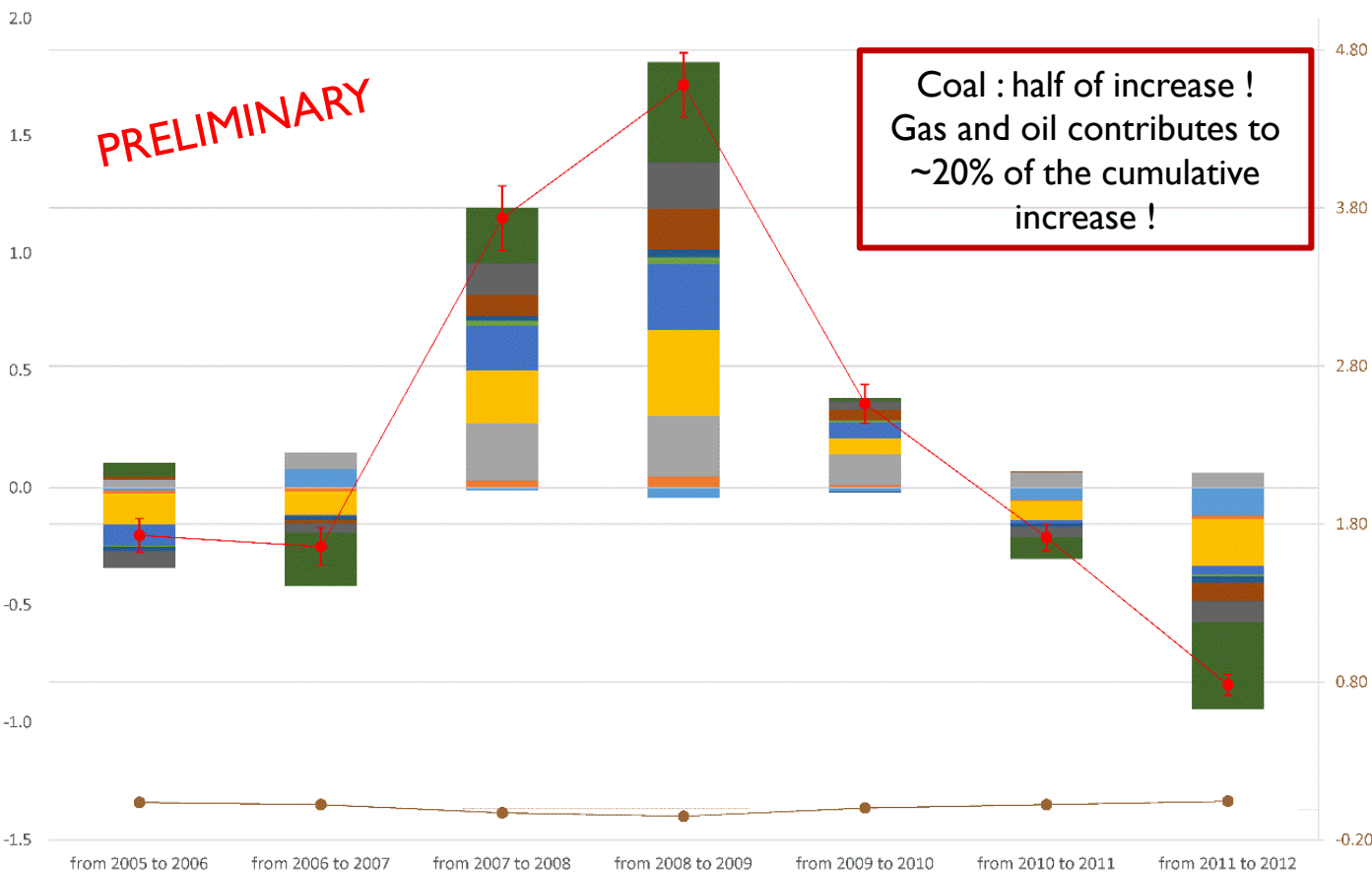


Cumulative increase of  
CH<sub>4</sub>  
in % since 2005

| Total                |                 | 1.14   |
|----------------------|-----------------|--------|
| 1                    | Coal Mining     | 0.85   |
| 2                    | Gas and oil     | 0.41   |
| 3                    | Rice            | 0.29   |
| 4                    | Wetlands        | 0.27   |
| 5                    | Livestock       | 0.24   |
| 6                    | Waste           | 0.16   |
| 7                    | Other Anthr.    | 0.049  |
| 8                    | Biofuels        | 0.047  |
| 9                    | Other Natural   | -0.017 |
| 10                   | Biomass Burning | -0.148 |
| sink Soil absorption |                 | 0.0541 |



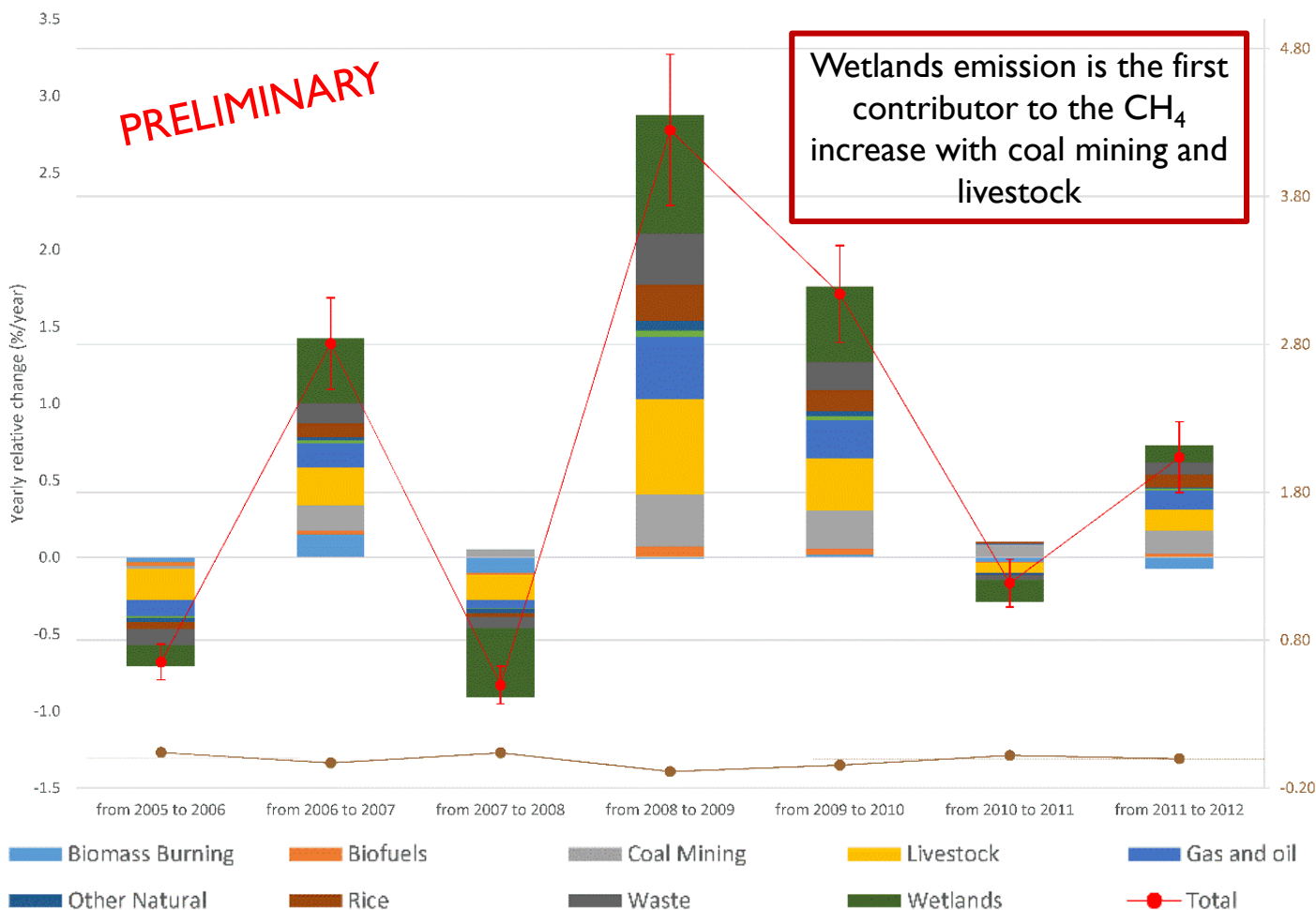
# GEOS-CHEM - Tracer Analysis Tropospheric CH<sub>4</sub> - Tsukuba



| Cumulative increase of CH <sub>4</sub> in % since 2005 |              |             |
|--|--------------|-------------|
| <b>Total</b>   |              | <b>1.72</b> |
| 1 Coal Mining  | 0.86         |             |
| 2 Gas and oil  | 0.39         |             |
| 3 Rice   | 0.24         |             |
| 4 Livestock  | 0.15         |             |
| 5 Waste  | 0.13         |             |
| 6 Other Anthr.   | 0.044        |             |
| 7 Wetlands   | 0.043        |             |
| 8 Biofuels   | 0.038        |             |
| 9 Other Natural  | -0.029       |             |
| 10 Biomass Burning                                     | -0.170       |             |
| <b>sink Soil absorption</b>                            | <b>0.059</b> |             |



# GEOS-CHEM - Tracer Analysis Tropospheric CH<sub>4</sub> - Lauder



Cumulative increase of  
CH<sub>4</sub>  
in % since 2005

|                             |               |
|-----------------------------|---------------|
| <b>Total</b>                | <b>4.85</b>   |
| 1 Wetlands                  | 1.07          |
| 2 Coal Mining               | 1.02          |
| 3 Livestock                 | 0.91          |
| 4 Gas and oil               | 0.77          |
| 5 Waste                     | 0.51          |
| 6 Rice                      | 0.49          |
| 7 Biofuels                  | 0.12          |
| 8 Other Anthr.              | 0.089         |
| 9 Other Natural             | 0.050         |
| 10 Biomass Burning          | -0.079        |
| <b>sink Soil absorption</b> | <b>-0.061</b> |

Ranking of CH<sub>4</sub> tracers contribution to the increase  
(from largest to smallest contribution)

**PRELIMINARY**

[illegible]

# Conclusions & next steps...

- Comparisons between FTIR observations and GEOS-CHEM simulation shows a good agreement in terms of changes in CH<sub>4</sub> total column
- Vertical differences of CH<sub>4</sub> changes between FTIR observations and GEOS-CHEM simulation have been characterised
  - Stratospheric comparisons supported by ACE-FTS occultations
  - Tropospheric changes  $\approx$  Total columns changes
- Preliminary tracer analysis shows a major contribution to the increase from coal mining and gas and oil exploitations
- Build CH<sub>4</sub> a priori profiles for each tracer in order to smooth the tagged simulation
- Site by site analysis of each tracer behaviour since 2005 and their contribution to the changes of methane



## Acknowledgments

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E. Mahieu



S. Conway

K. Strong



I. Murata



D. Smale



A. Turner



P. Bernath



E. Buzan

