Attributing changes in atmospheric methane 1850-2000 to changes in CH_4, NO_x, CO and NMVOC emissions

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+ other ACCMIPers:

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Some details in ACP paper: ACCMIP Special Issue
www.atmos-chem-phys.net/13/3063/2013/

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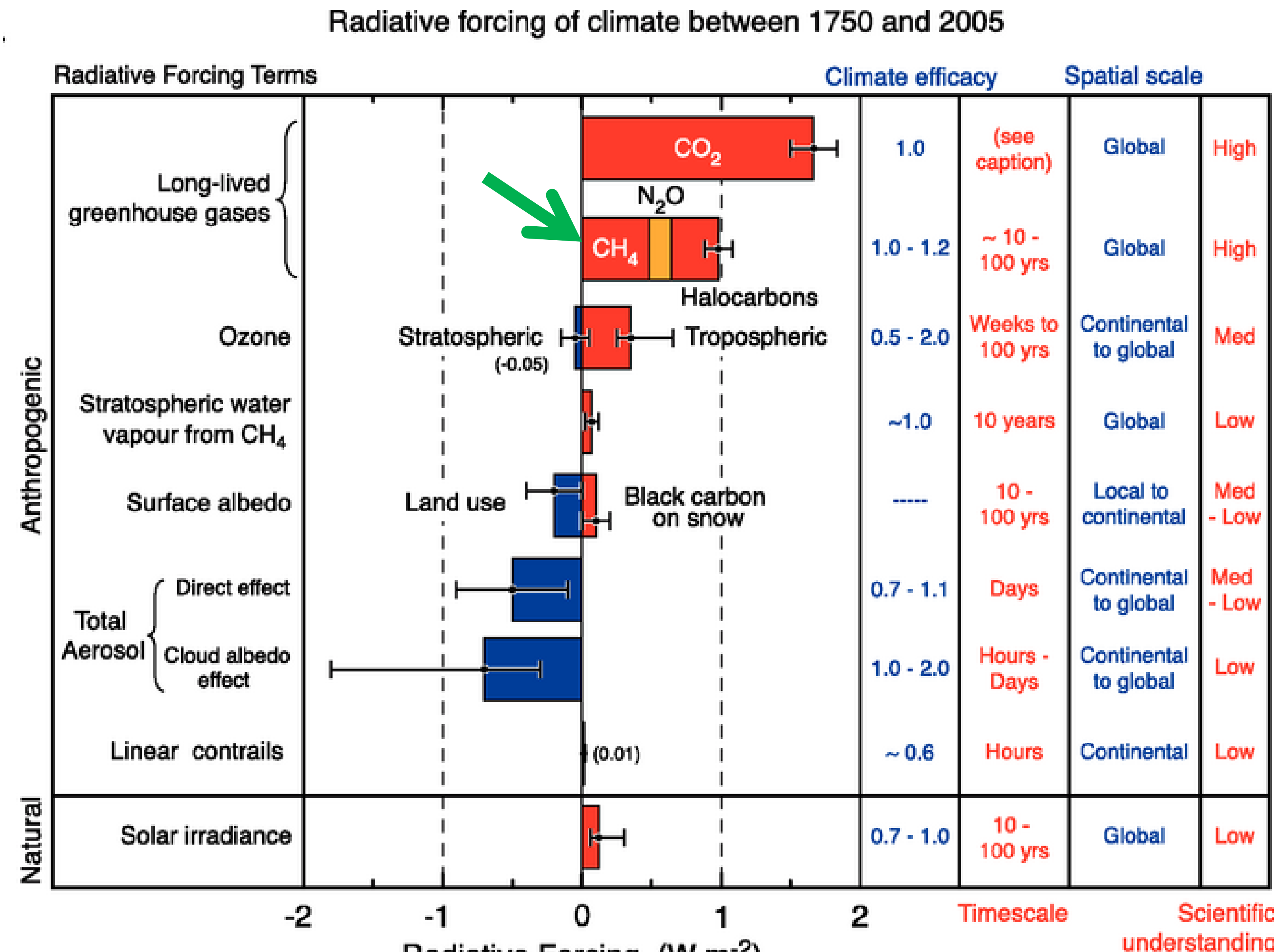
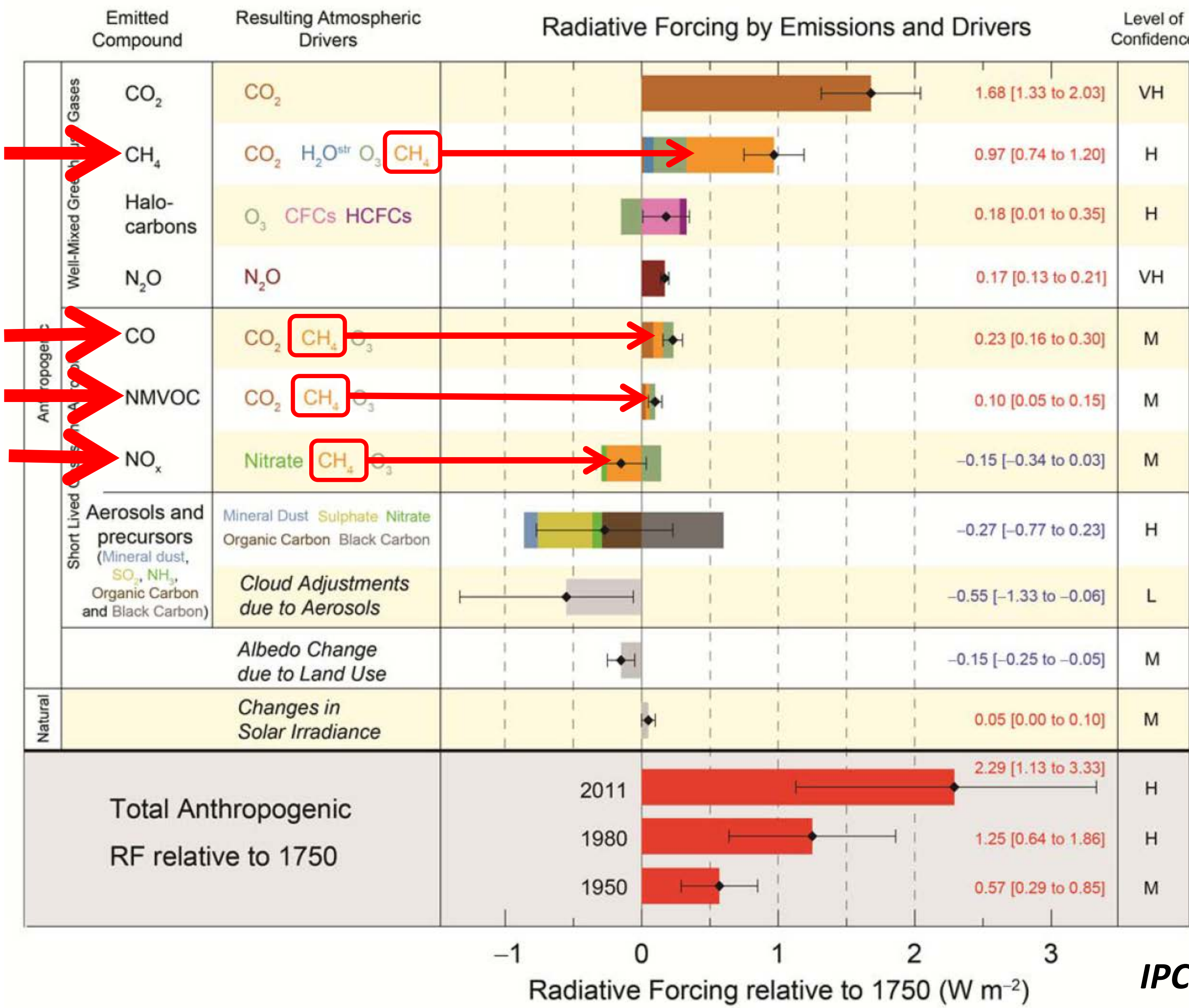
The abundance-based view of radiative forcing:



IPCC, 2007

The emissions-based view of radiative forcing:



IPCC (2013)

Shindell et al. (2005, 2009)

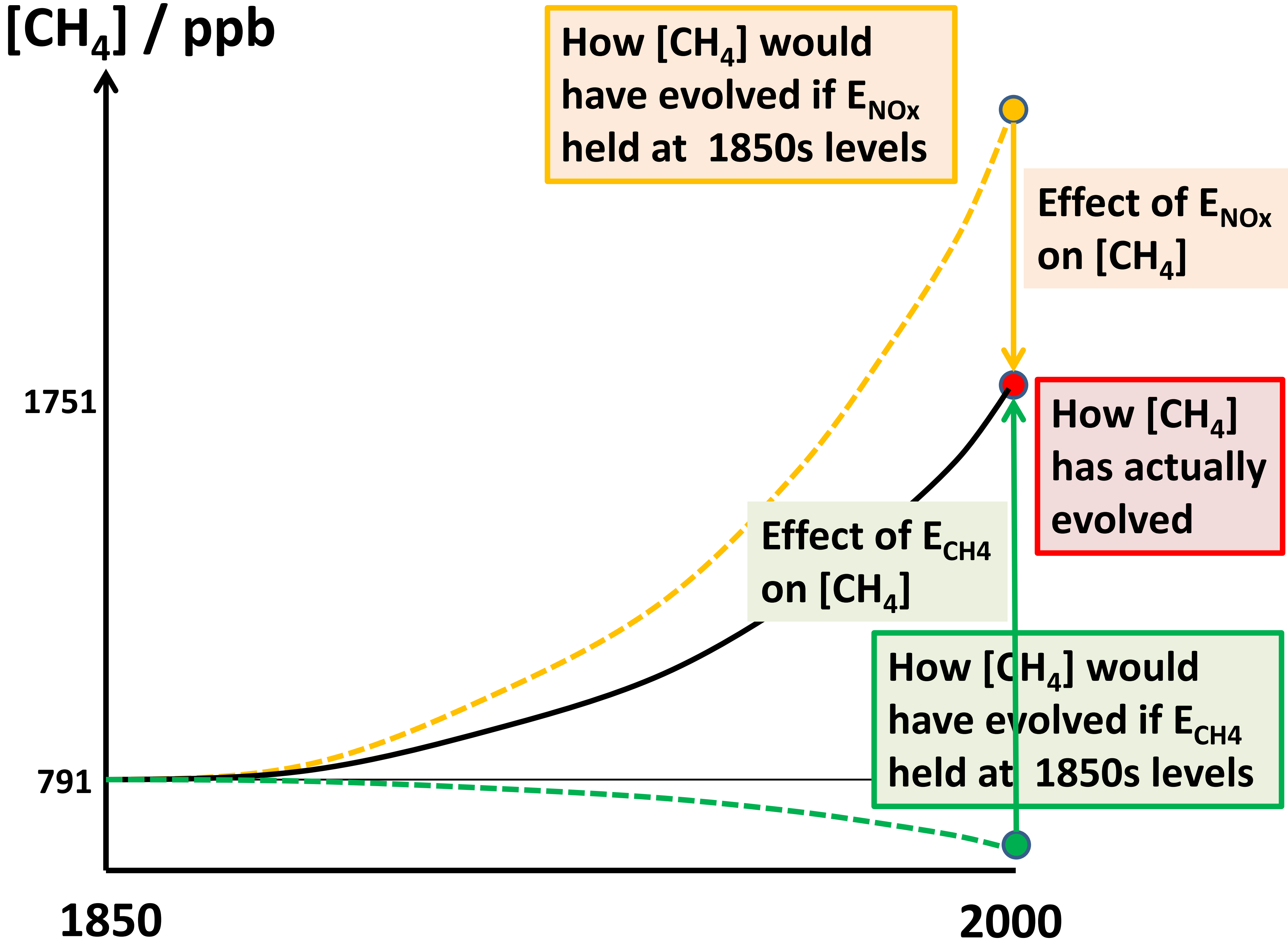
- GISS model
- Pre-industrial to present-day simulations
- Isolated response of CH_4 (and O_3) from individual emissions
- Found only a small (<10%) non-linearity (i.e. response to changing all together ≈ sum of individual responses
- Used methane emissions, not prescribed concentrations
- Only attribution studies prior to ACCMIP

ACCMIP Model	1850s	2000s	Attrib	ΔClim	Future
A. CESM-CAM-superfast	10	10	-	10	YnYY
B. CICERO-OsloCTM2	1	1	1	-	YYnY
C. CMAM	10	10	-	-	nYnY
D. EMAC	10	10	-	-	nYnY
E. GEOSCCM	10	14	-	-	nnnn
F. GFDL-AM3	10	10	-	10	YYYY
G. GISS-E2-R	50	50	-	40	YYYY
H. GISS-E2-R-TOMAS	10	10	-	10	nnnn
I. HadGEM2	10	10	-	10	YYnY
J. HadGEM2-ExtTC	10	10	10	-	nnnn
K. LMDzORINCA	10	5	-	-	YYYY
L. MIROC-CHEM	11	11	-	5	YnYY
M. MOCAGE	4	4	-	4	YnYY
N. NCAR-CAM3.5	8	8	8	8	YYYY
O. STOC-HadAM3	10	10	10	10	YnnY
P. UM-CAM	10	10	10	10	YYnY
Q. TM5	1	1	1	-	nnnn

Attribution experiment	Climate	$[CH_4]$	Anthropogenic Emissions		
			NOx	CO	NMVOC
#0 Em1850CH$_4$1850	2000s	1850s	1850s	1850s	1850s
#1 Em2000CH$_4$2000	2000s	2000s	2000s	2000s	2000s
#2 Em2000CH$_4$1850	2000s	1850s	2000s	2000s	2000s
#3 Em2000NOx1850	2000s	2000s	1850s	2000s	2000s
#4 Em2000CO1850	2000s	2000s	2000s	1850s	2000s
#5 Em2000NMVOC1850	2000s	2000s	2000s	2000s	1850s

Methane concentrations are prescribed and held fixed – to allow short (few years) runs.

But we want to know how methane concentrations would vary if its *emissions* were held at 1850s/2000s levels …


[CH4] / ppb
How [CH4] would have evolved if ENOx held at 1850s levels
Effect of ENOx on [CH4]
1751
How [CH4] has actually evolved
Effect of ECH4 on [CH4]
How [CH4] would have evolved if ECH4 held at 1850s levels
791
1850
2000

Adjusting to equilibrium $[CH_4]$

Diagnose CH_4 lifetime in attribution (τ_{att}) and base (τ_{base}) runs, then:

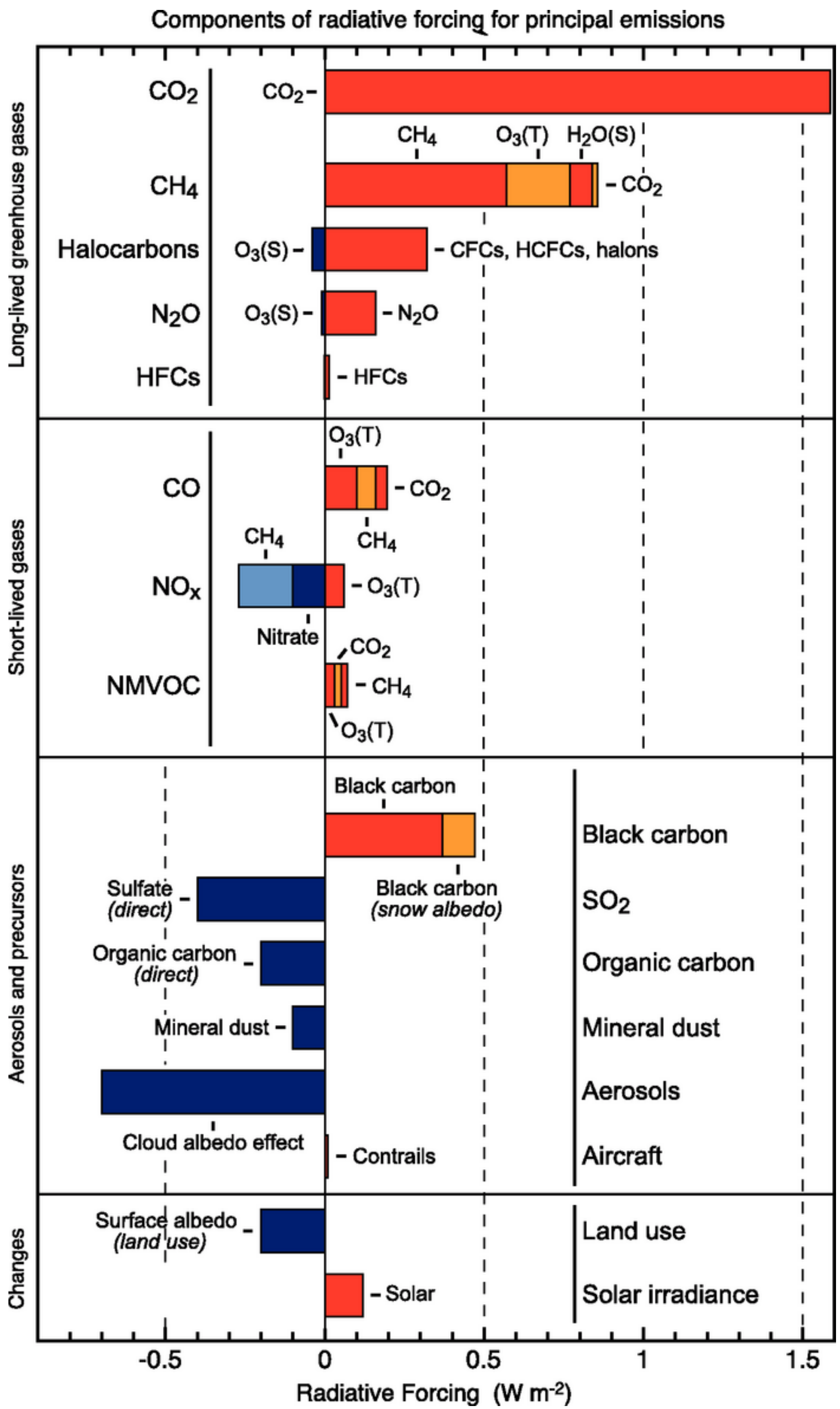
$$[CH_4]_{eq} = [CH_4]_{base} (\tau_{att} / \tau_{base})^f$$

Fuglestvedt et al 1999
West et al 2007
Fiore et al 2009
Prather 1996

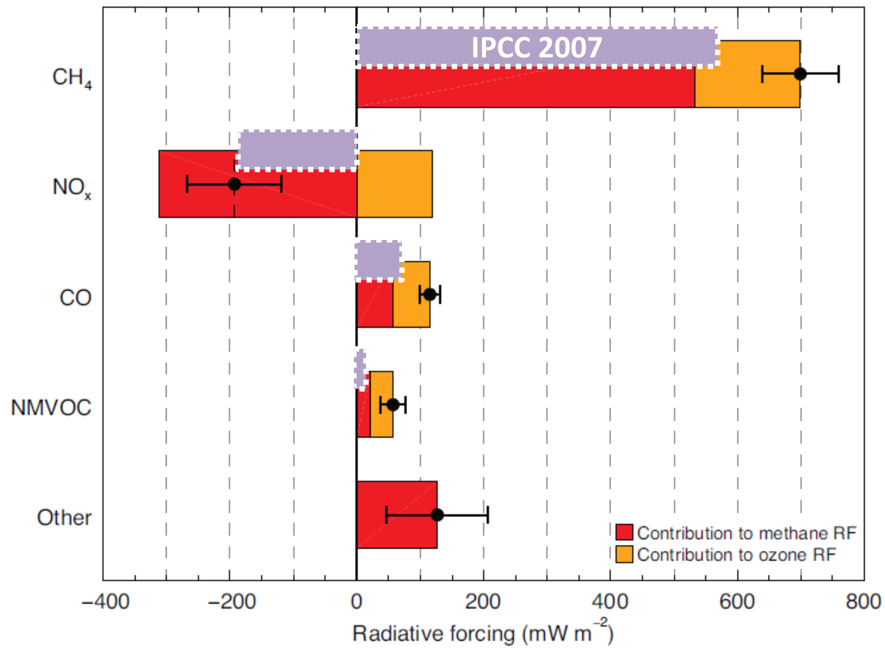
f is the CH_4-OH feedback factor:

$$f = 1/(1-s)$$
$$s = \delta \ln \tau / \delta \ln [CH_4]$$

(get from ΔCH_4 expt)



ACCMIP results (avg 6 models):

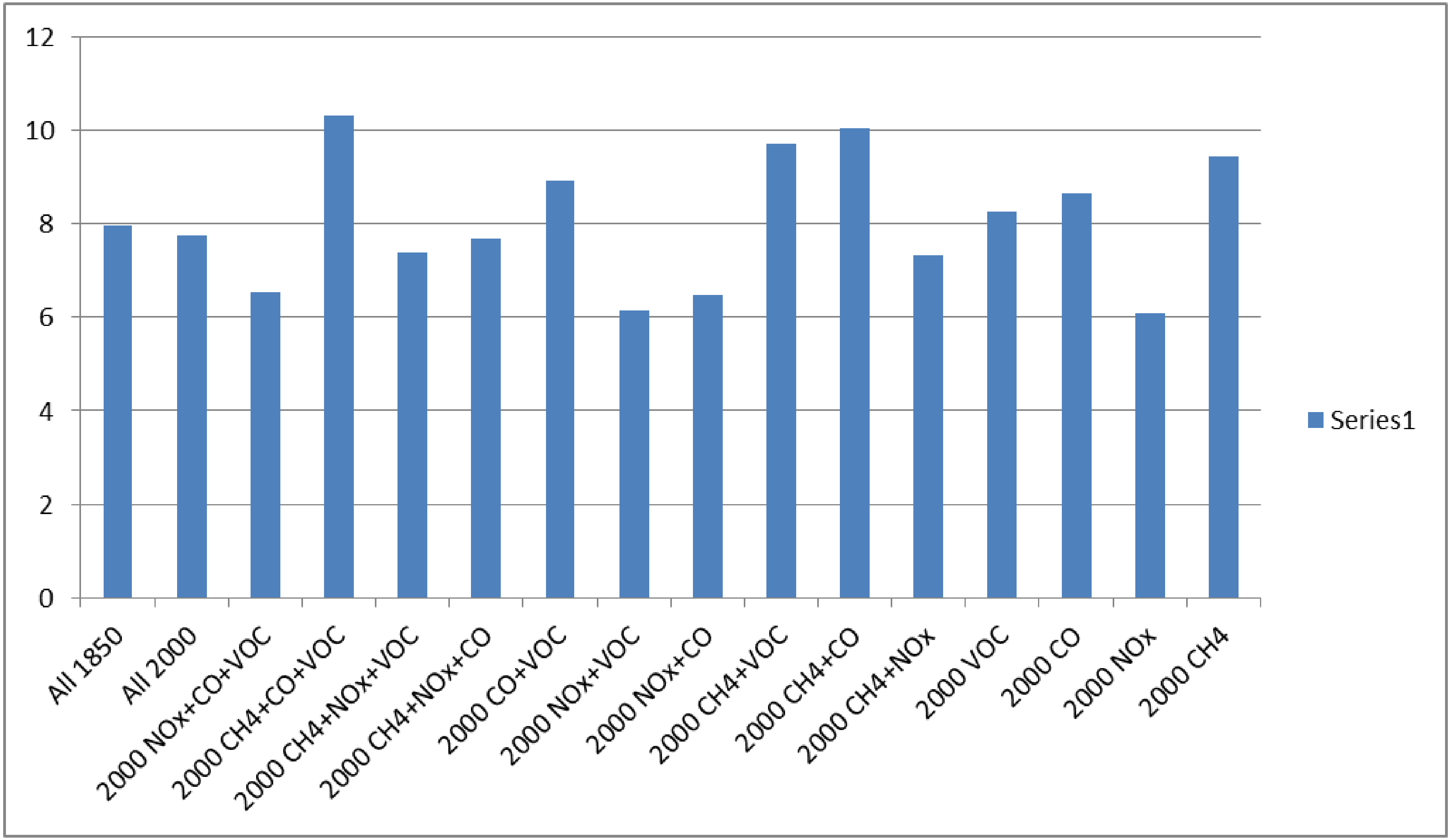


Compare to IPCC (2007):
CH_4 terms smaller
NOx terms larger
CO/NMVOC similar
Important non-linearity for CH_4

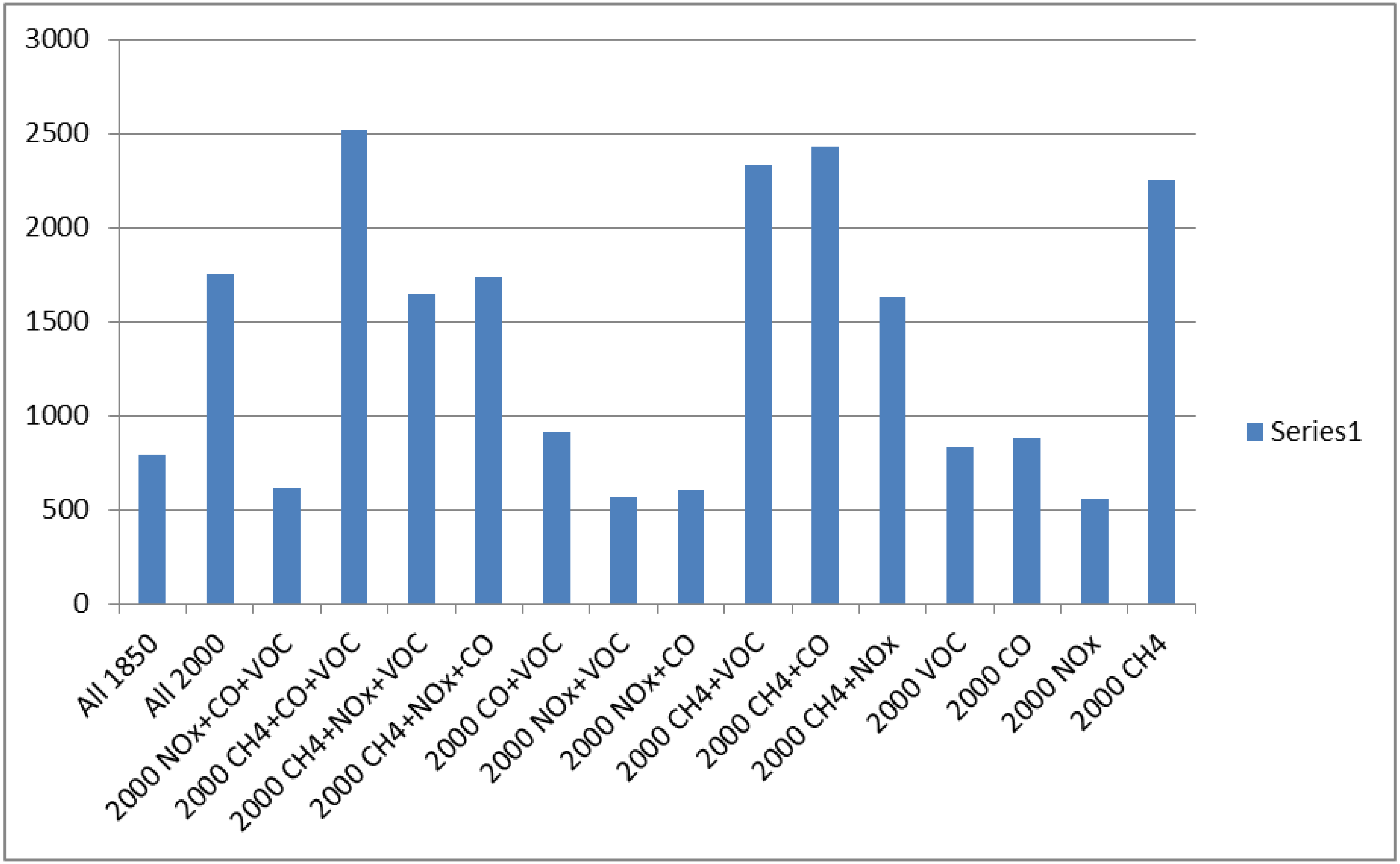
Since ACCMIP runs…

- Further attribution runs with STOC-HadAM3:
  - All combinations of CH_4, NOx, CO, VOC (1850-2000)

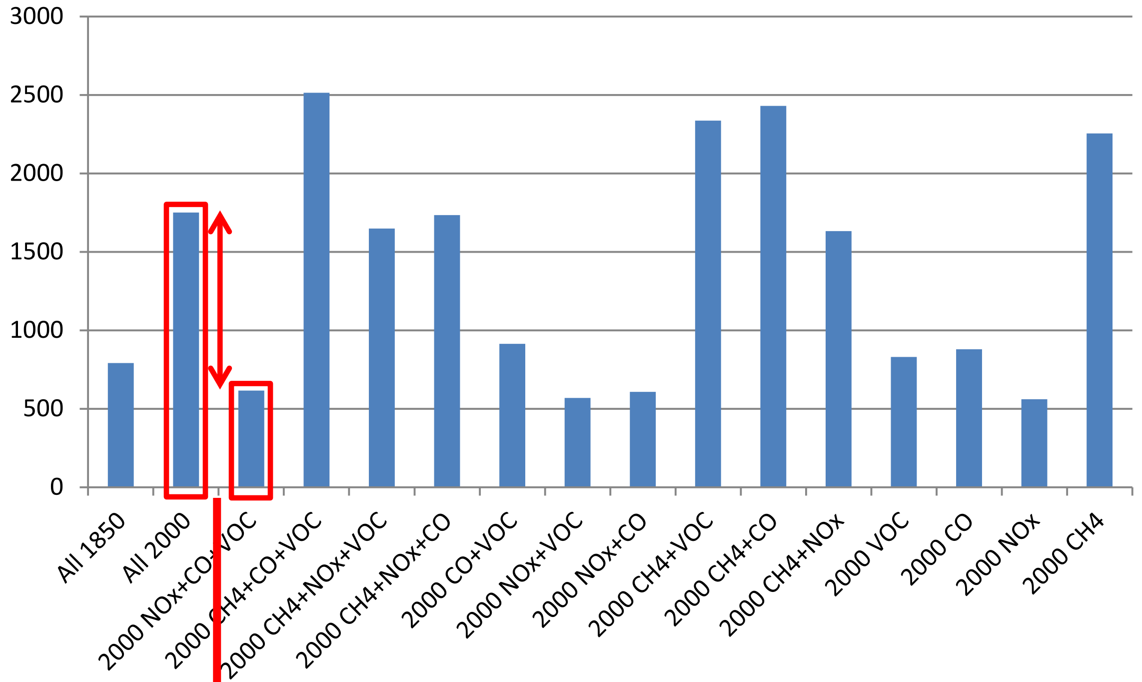
Methane lifetimes (yr) in attribution expts



Equilibrium [CH_4] values



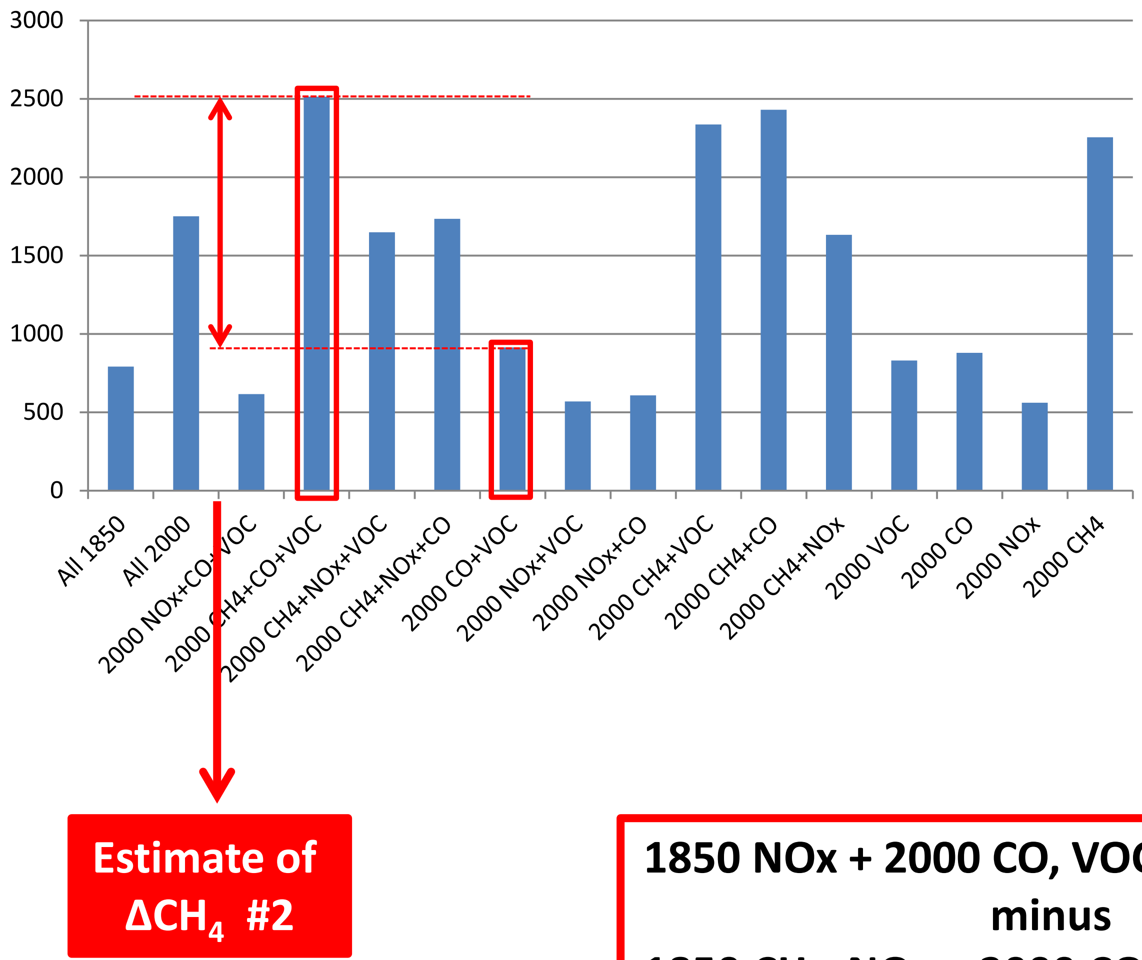
Impact of CH_4 emissions on $\Delta[CH_4]$



Estimate of ΔCH_4 #1 (this was the ACCMIP method)

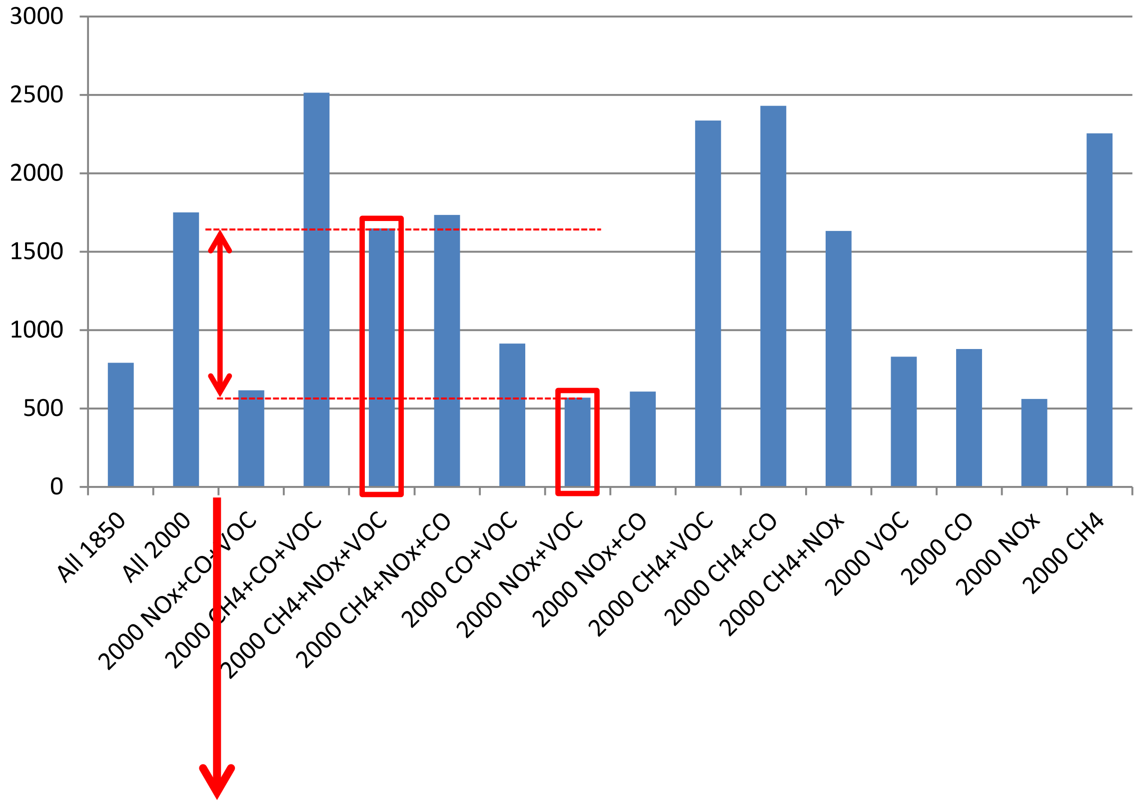
All 2000 emissions
minus
1850 CH_4, 2000 NOx, CO, VOC emissions
→ $\Delta[CH_4]$ = 1136 ppb

Impact of CH_4 emissions on $\Delta[CH_4]$



1850 NOx + 2000 CO, VOC, CH_4 emissions
minus
1850 CH_4, NOx + 2000 CO, VOC emissions
→ $\Delta[CH_4]$ = 1600 ppb

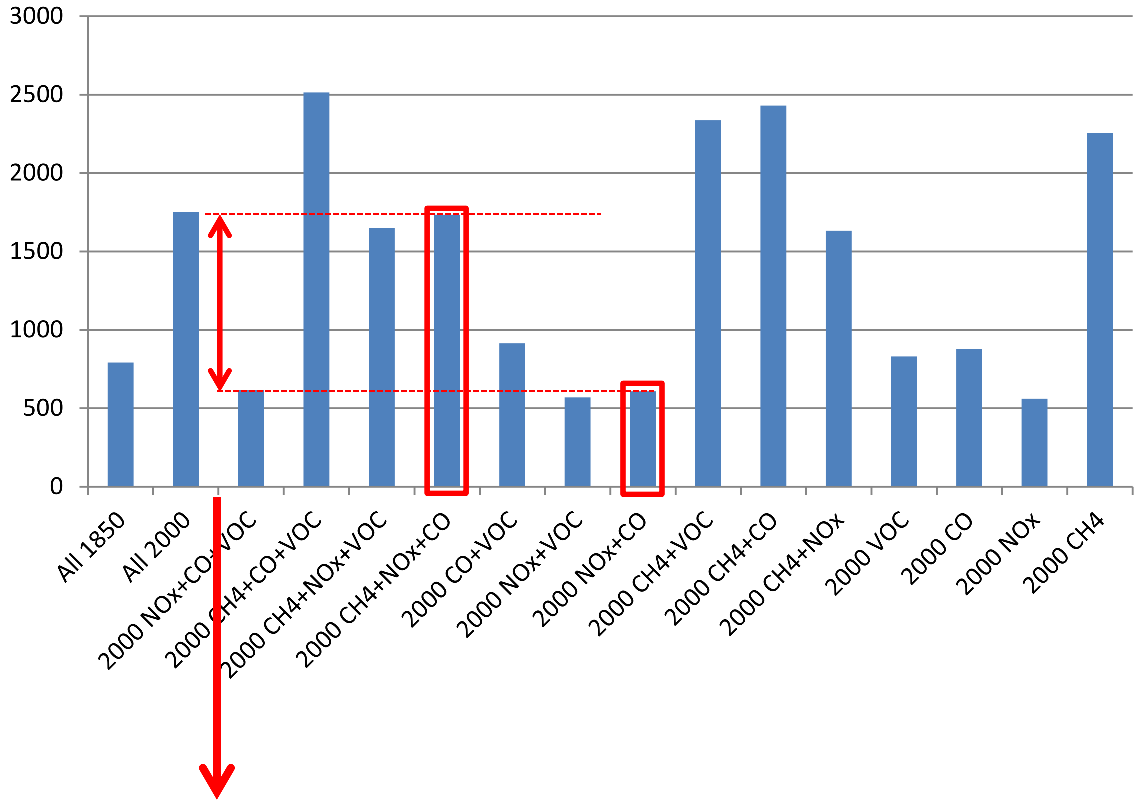
Impact of CH_4 emissions on $\Delta[CH_4]$



Estimate of ΔCH_4 #3

1850 CO + 2000 NOx, VOC, CH_4 emissions
minus
1850 CH_4, CO + 2000 NOx, VOC emissions
→ $\Delta[CH_4]$ = 1081 ppb

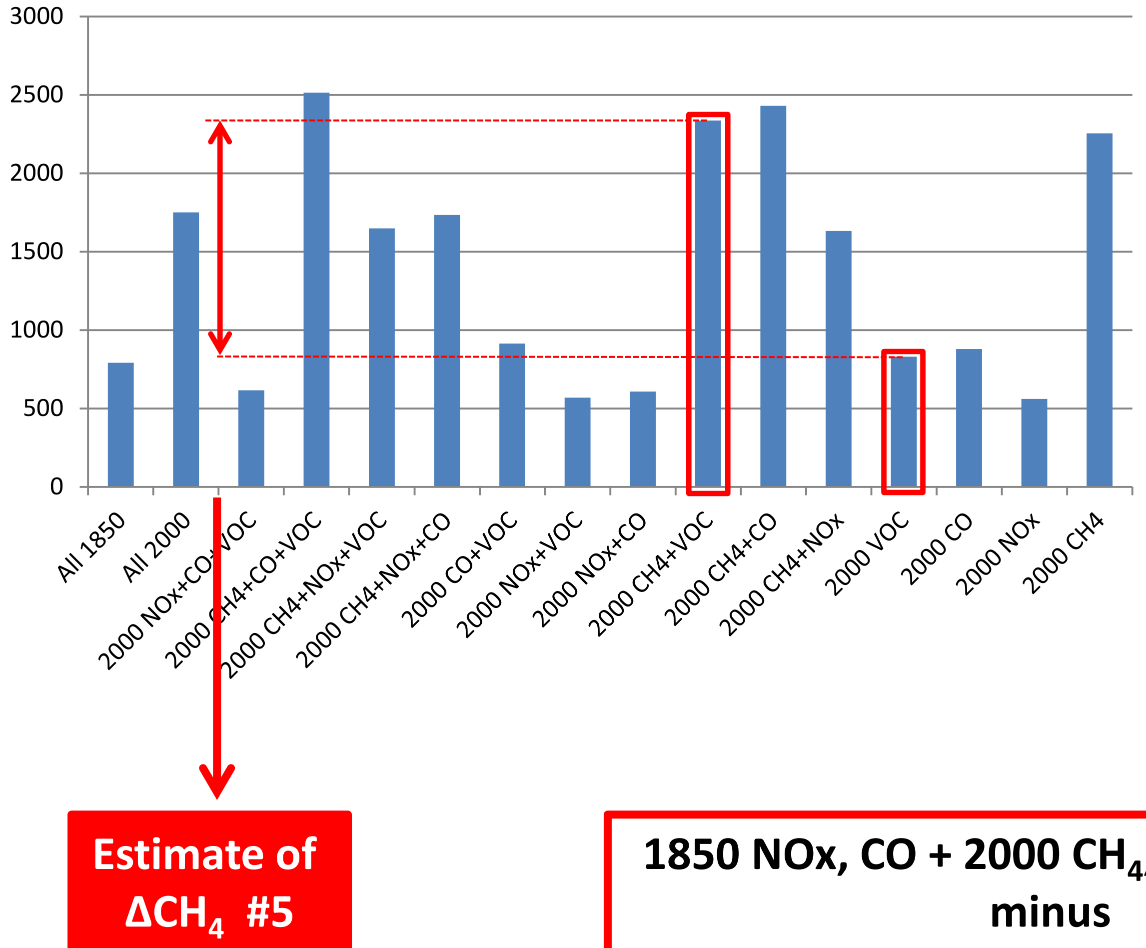
Impact of CH_4 emissions on $\Delta[CH_4]$



Estimate of ΔCH_4 #4

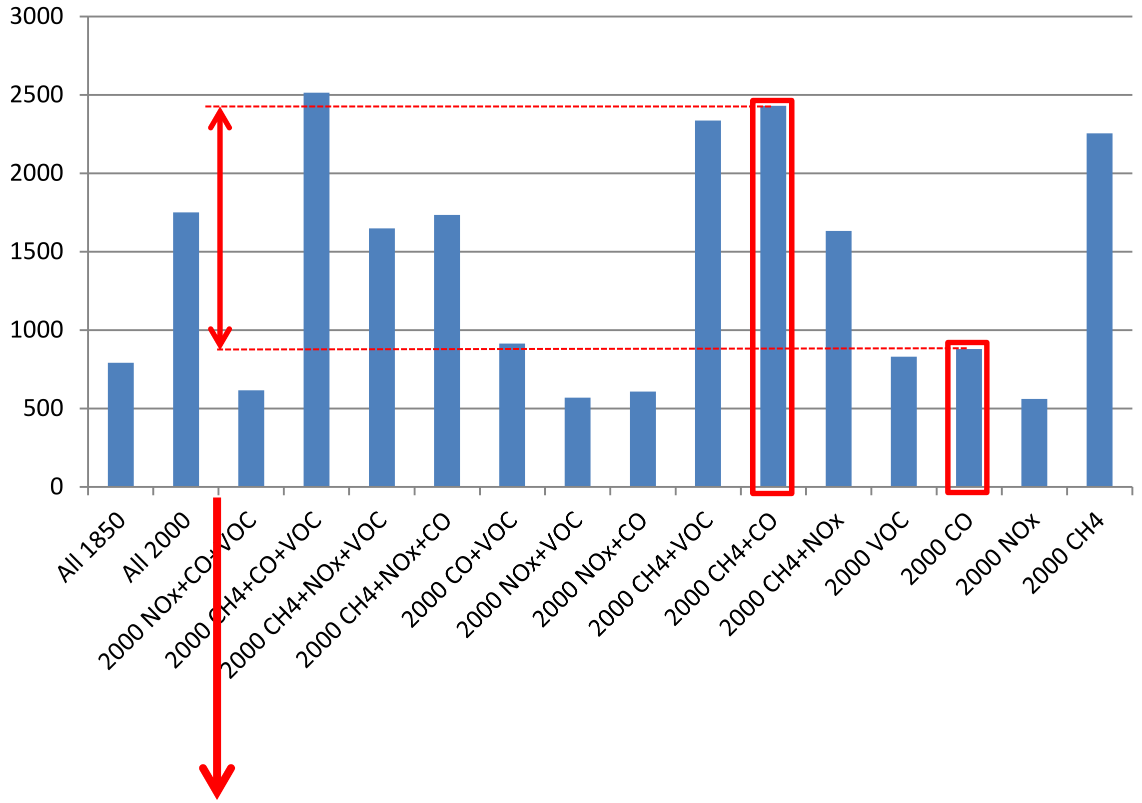
1850 VOC + 2000 NOx, CO, CH_4 emissions
minus
1850 CH_4, VOC + 2000 NOx, CO emissions
→ $\Delta[CH_4]$ = 1126 ppb

Impact of CH_4 emissions on $\Delta[CH_4]$



1850 NOx, CO + 2000 CH_4, VOC emissions
minus
1850 CH_4, NOx, CO + 2000 VOC emissions
→ $\Delta[CH_4]$ = 1506 ppb

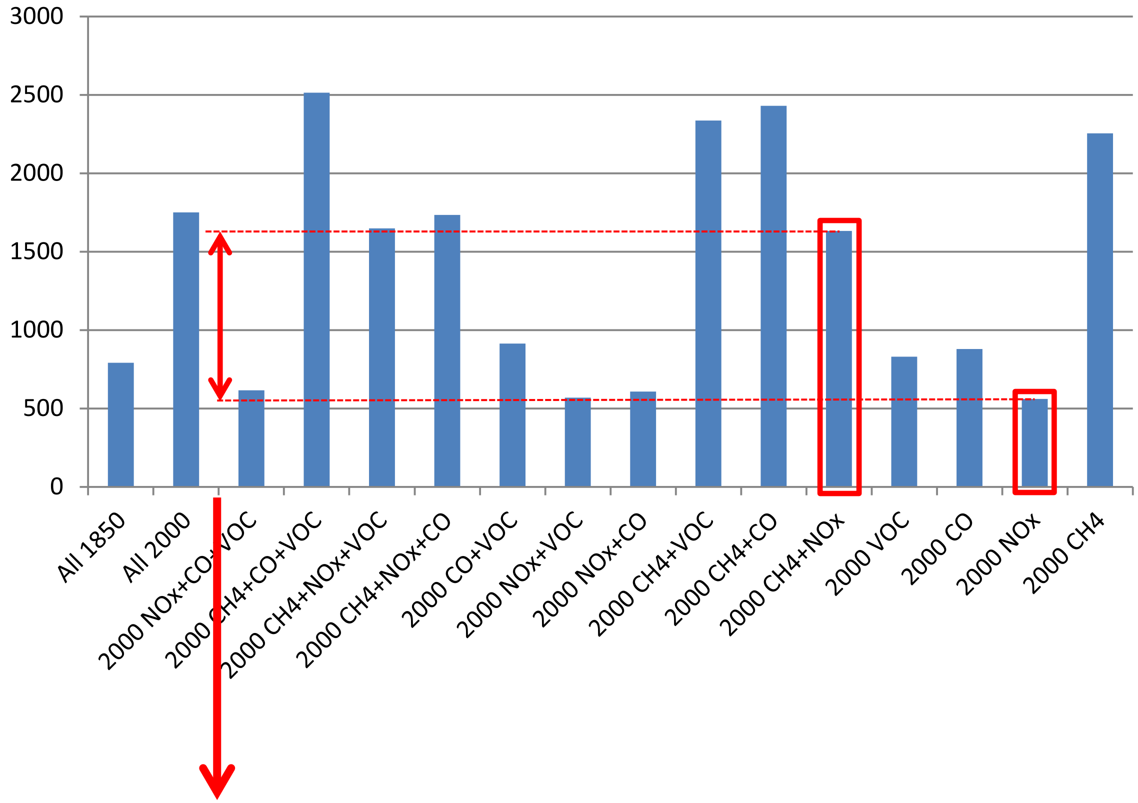
Impact of CH_4 emissions on $\Delta[CH_4]$



Estimate of ΔCH_4 #6

1850 NOx, VOC + 2000 CH_4, CO emissions
minus
1850 CH_4, NOx, VOC + 2000 CO emissions
→ $\Delta[CH_4]$ = 1553 ppb

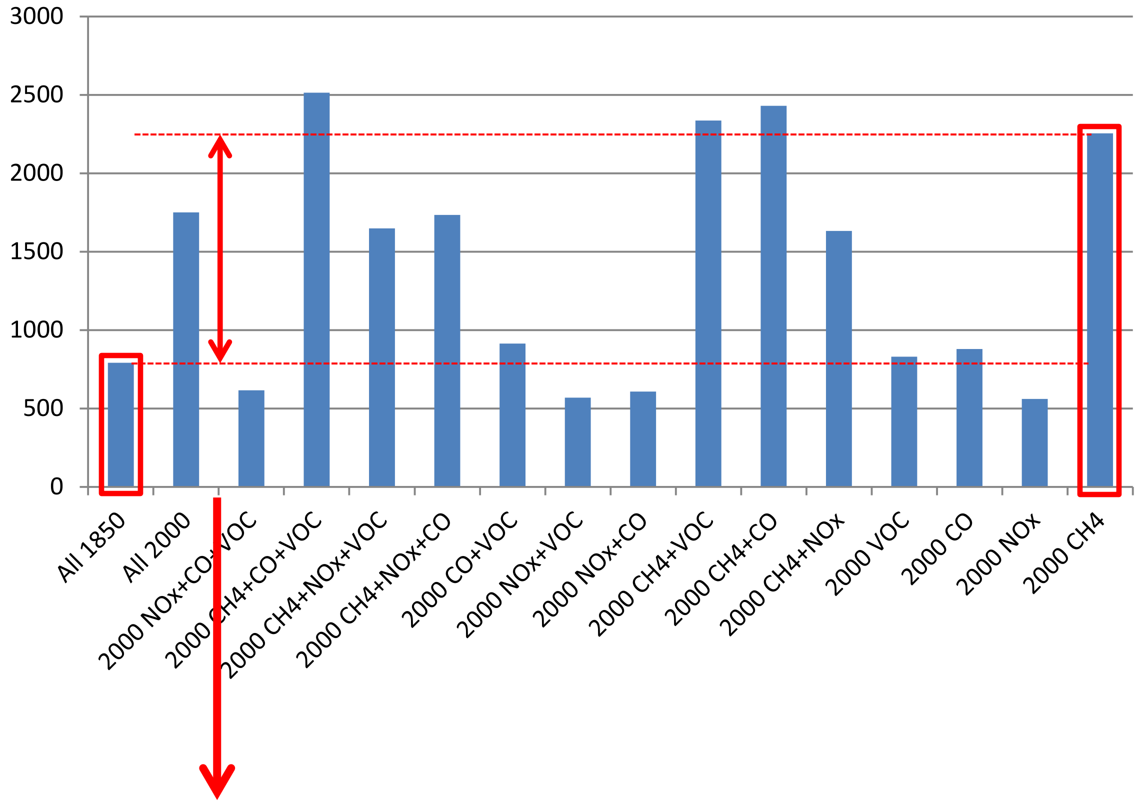
Impact of CH_4 emissions on $\Delta[CH_4]$



Estimate of ΔCH_4 #7

1850 CO, VOC + 2000 CH_4, NOx emissions
minus
1850 CH_4, CO, VOC + 2000 NOx emissions
→ $\Delta[CH_4]$ = 1072 ppb

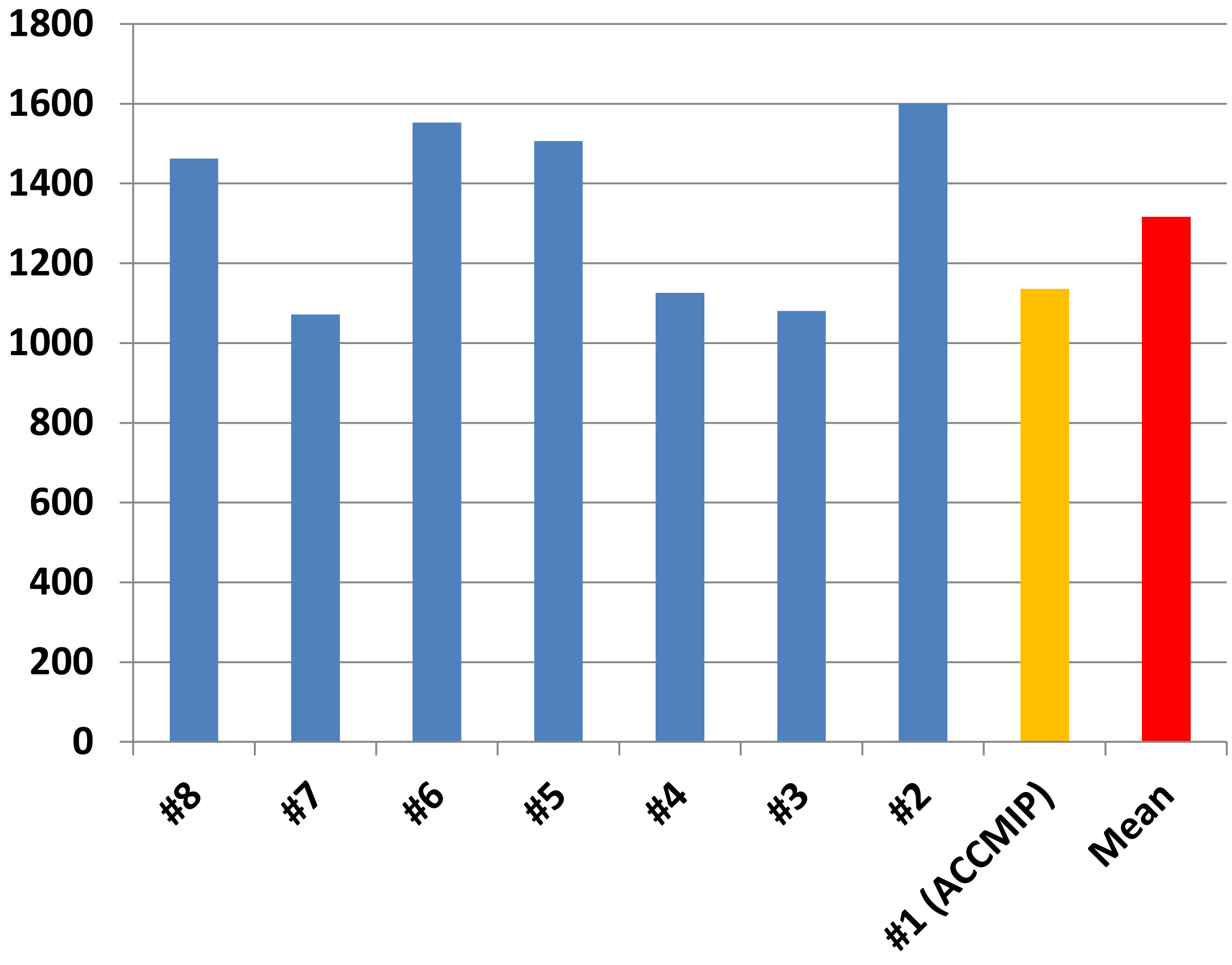
Impact of CH_4 emissions on $\Delta[CH_4]$



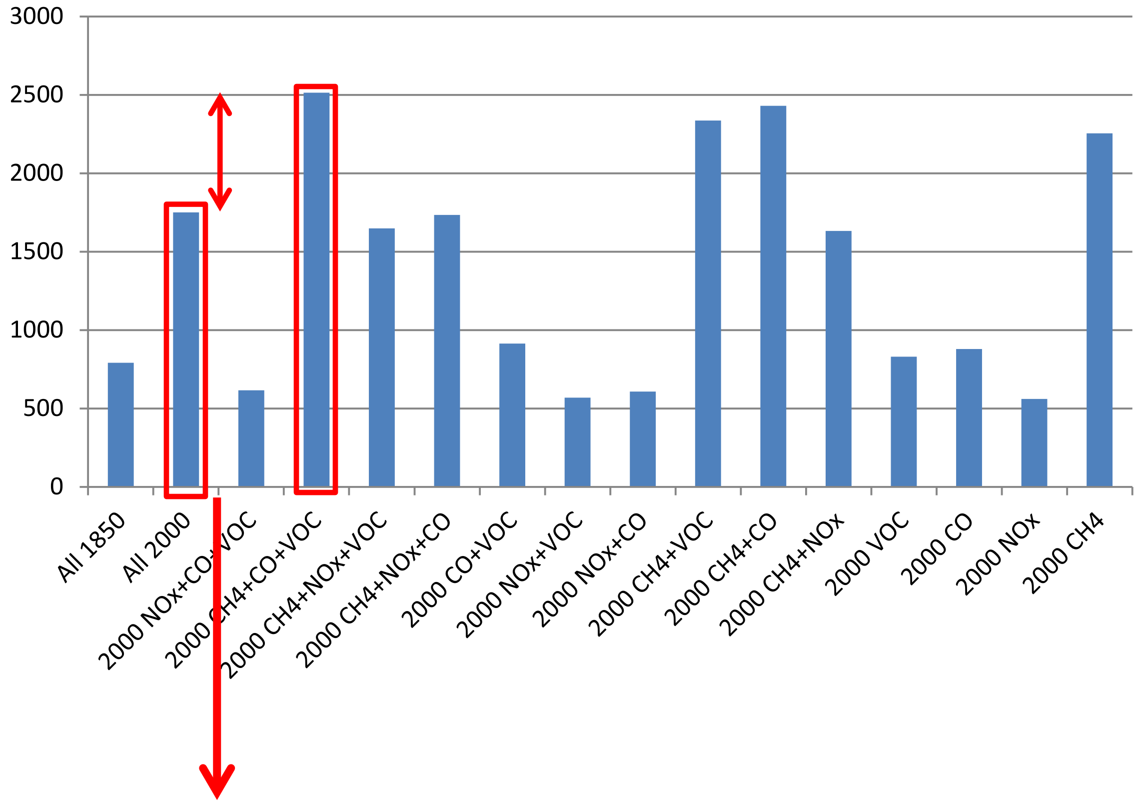
Estimate of ΔCH_4 #8

1850 NOx, CO, VOC + 2000 CH_4 emissions
minus
All 1850 emissions
→ $\Delta[CH_4]$ = 1462 ppb

Impact of CH_4 emissions on $\Delta[CH_4]$: 8 different estimates



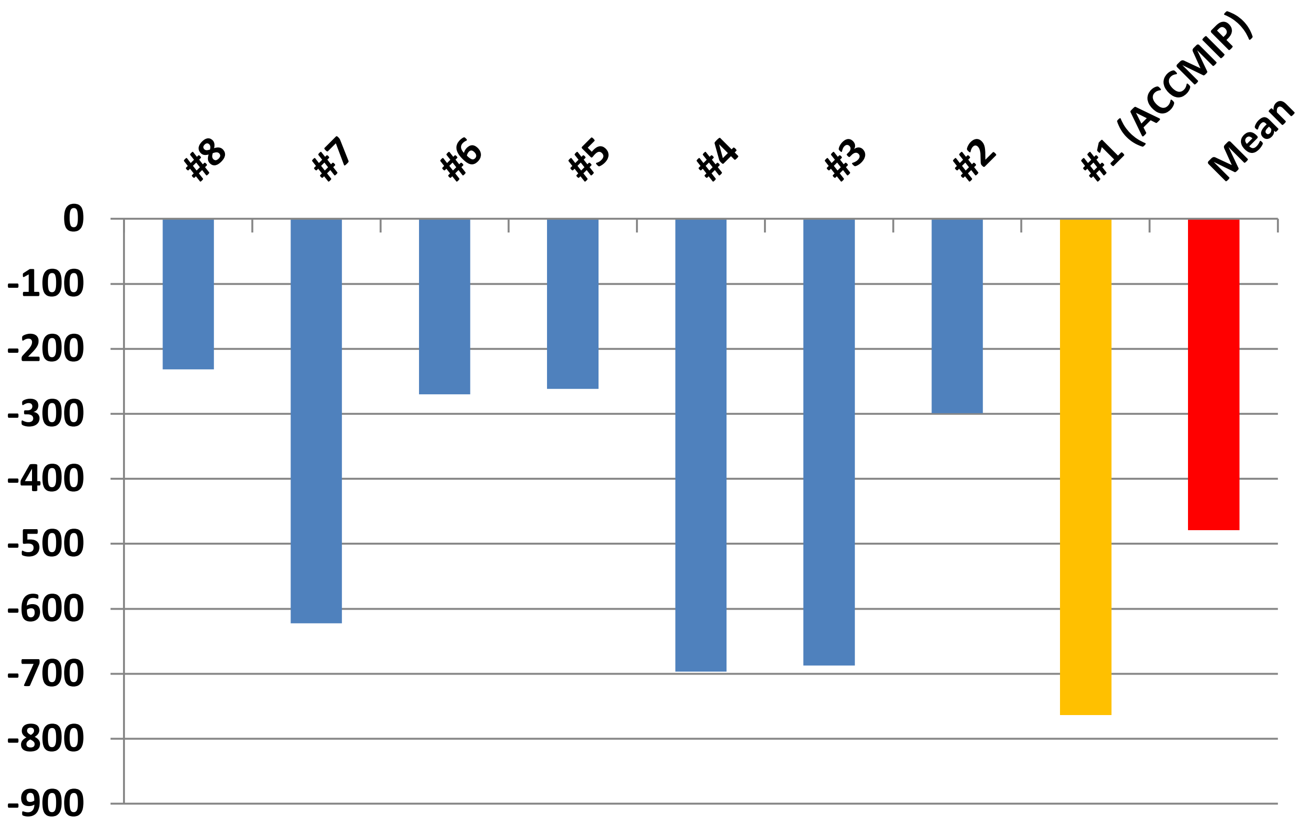
Impact of NO_x emissions on $\Delta[CH_4]$



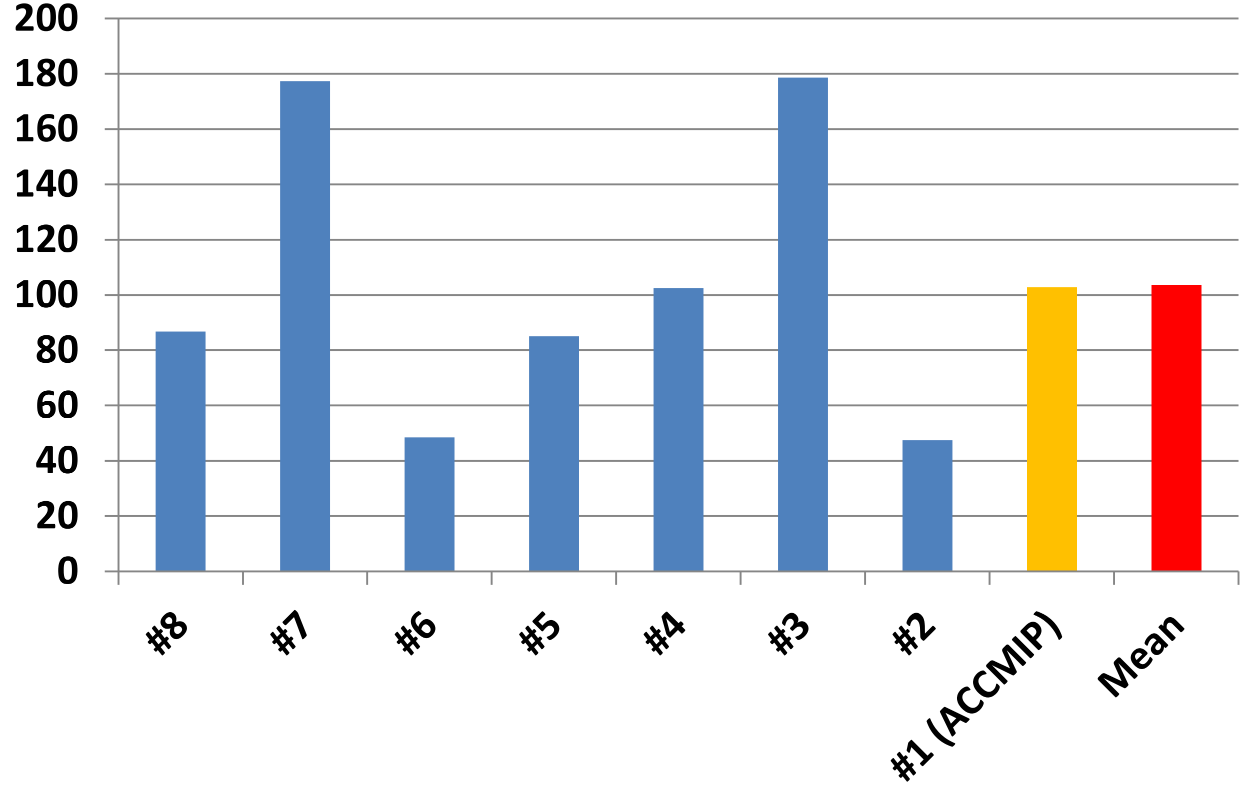
Estimate of ΔCH_4 #1 (this was the ACCMIP method)

All 2000 emissions
minus
1850 NOx, 2000 CH_4, CO, VOC emissions
→ $\Delta[CH_4]$ = -763 ppb

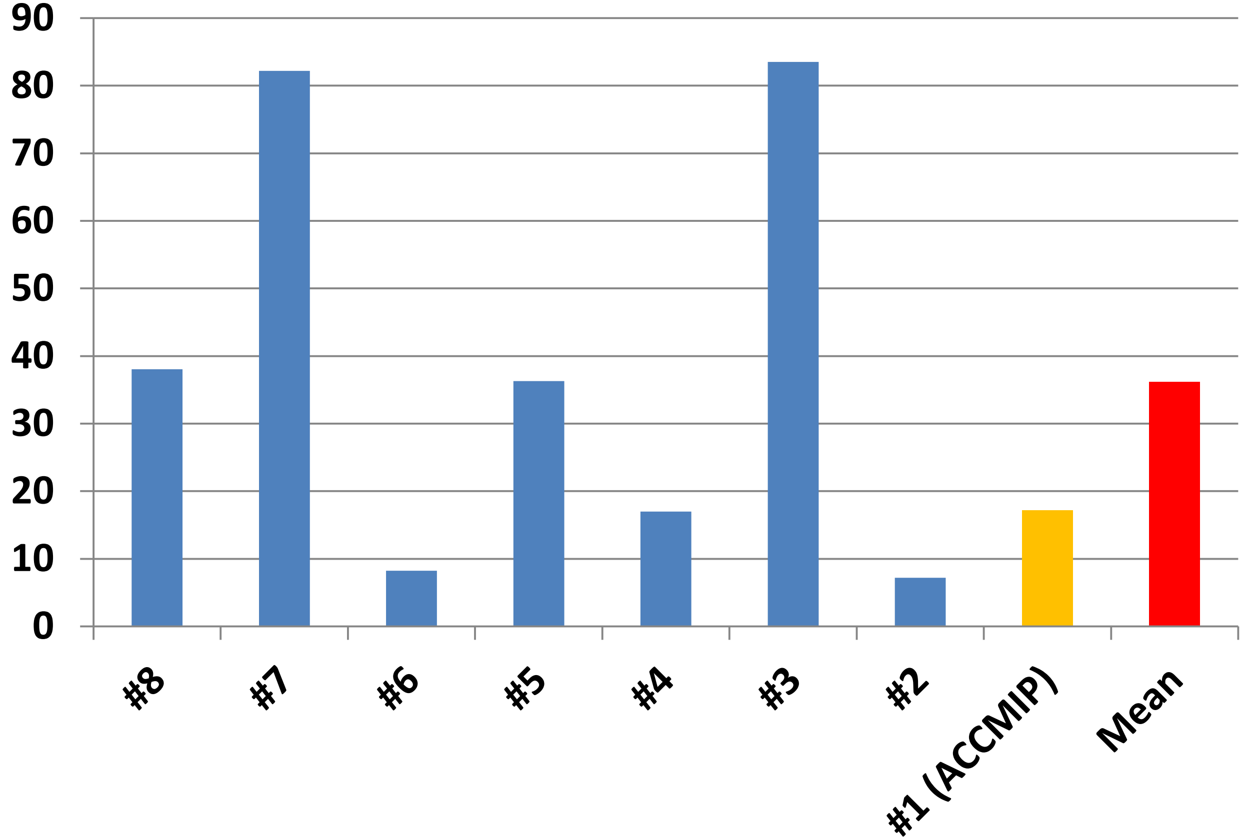
Impact of NO_x emissions on $\Delta[CH_4]$: 8 different estimates



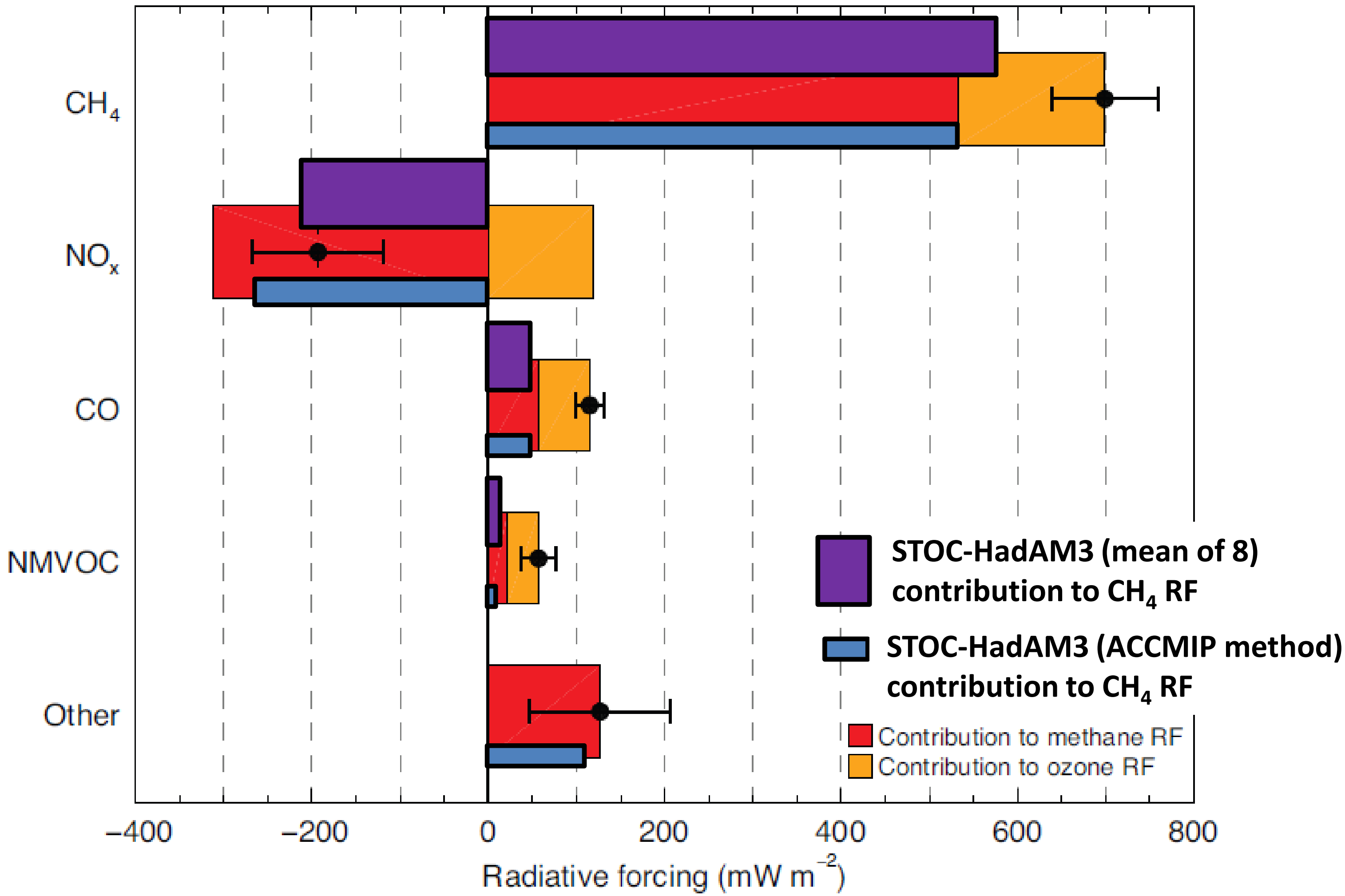
Impact of CO emissions on $\Delta[CH_4]$: 8 different estimates



Impact of VOC emissions on Δ[CH_4]: 8 different estimates



Revised CH_4 attribution summary (based on mean results from STOC-HadAM3 runs)



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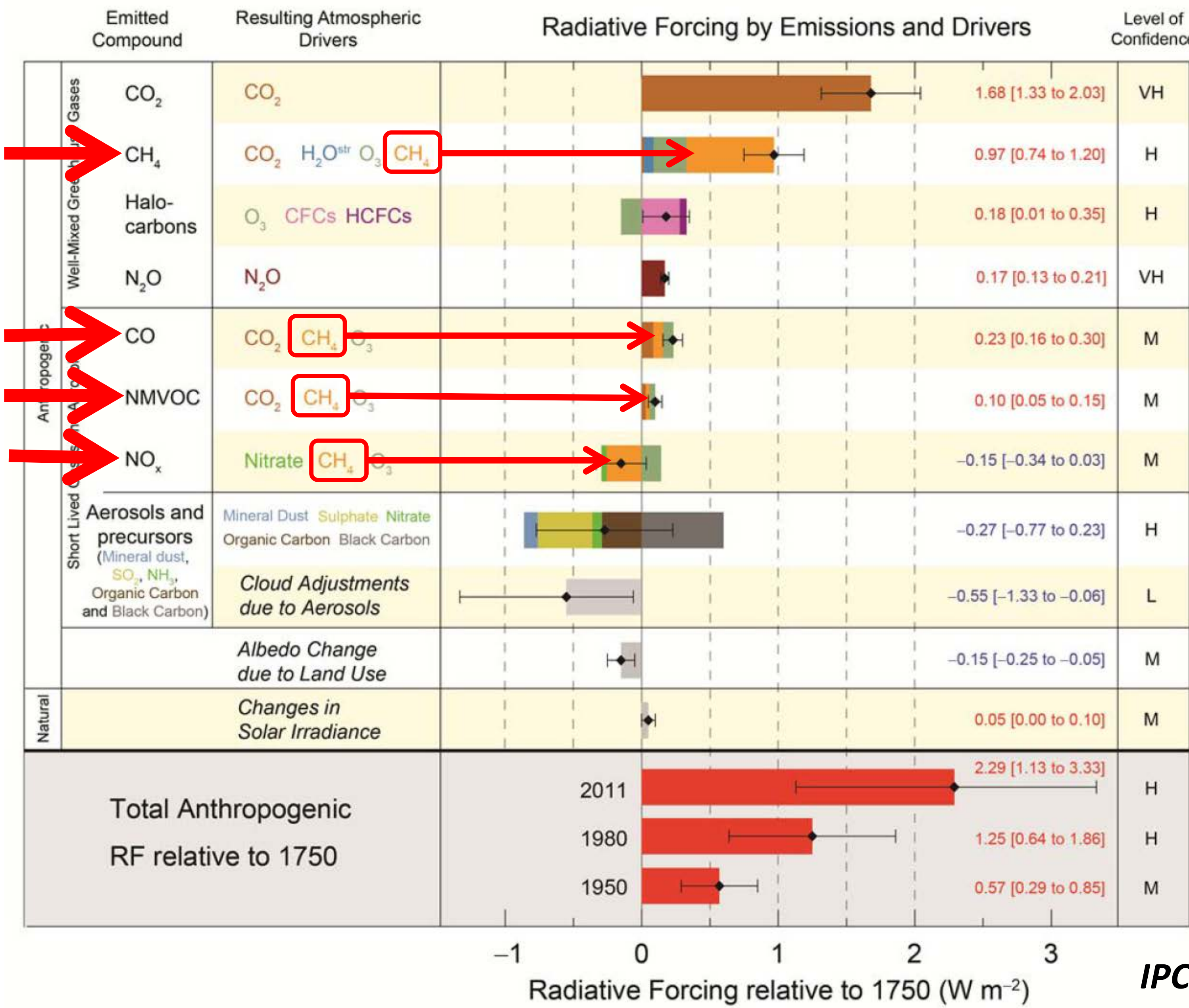

IPCC (2013)

Summary

- Methane attribution is quite non-linear: it matters how you set up your experiment
- The main reason is how NOx interacts with everything else – background NOx level is important (for OH and O_3)
- Accounting for the transient response of CH_4 is important
- Using the mean of all 8 combinations makes the non-linearity go away – fortuitous?