Methane retrieval from mid-infrared FTIR

Improved strategy optimized for profile information

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- Motivation
- FTIR trace gas retrieval
- Optimization for profiles
- Summary and Outlook

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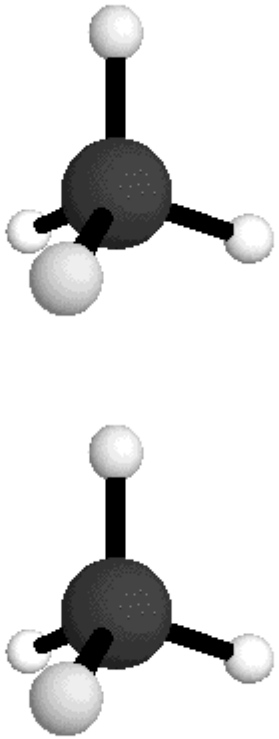
REGIONAL CLIMATE SYSTEMS – Atmospheric Variability and Trends

Why look at Methane? (1)

IR-active vibrations



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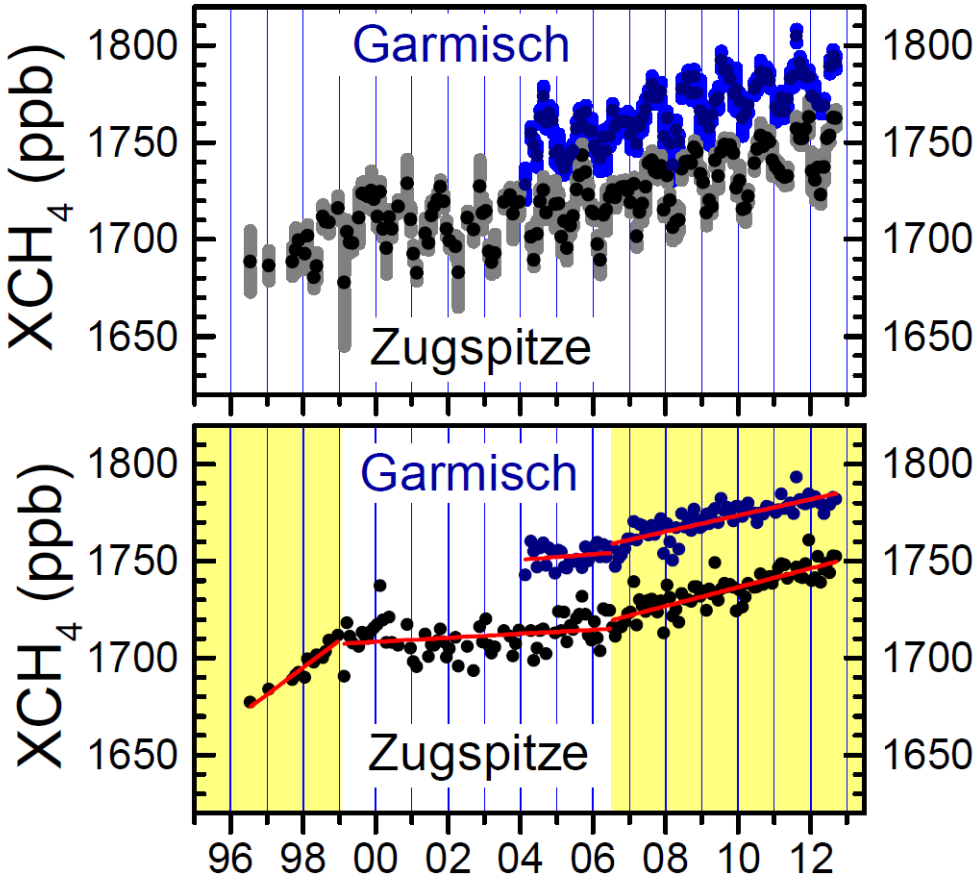
Long-term increase



Sussmann 2012, updated

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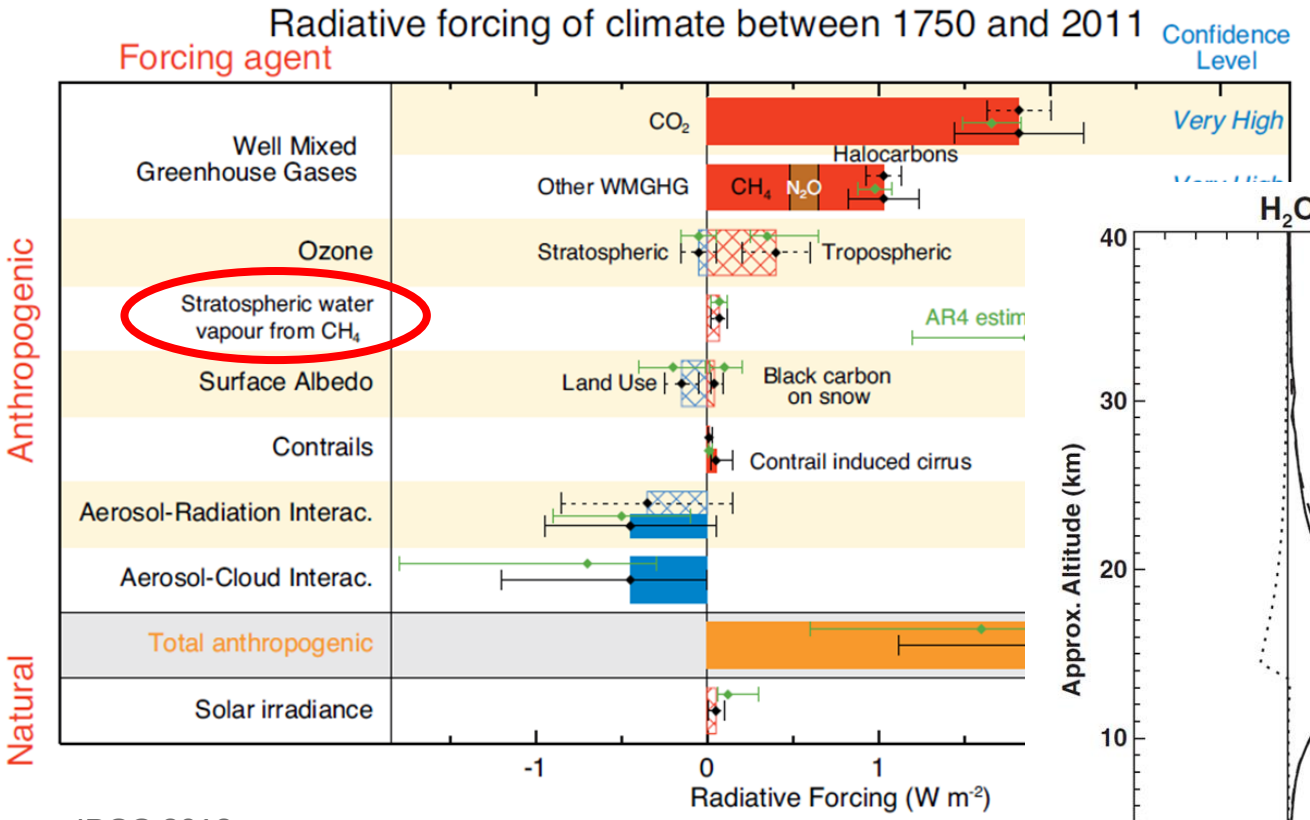
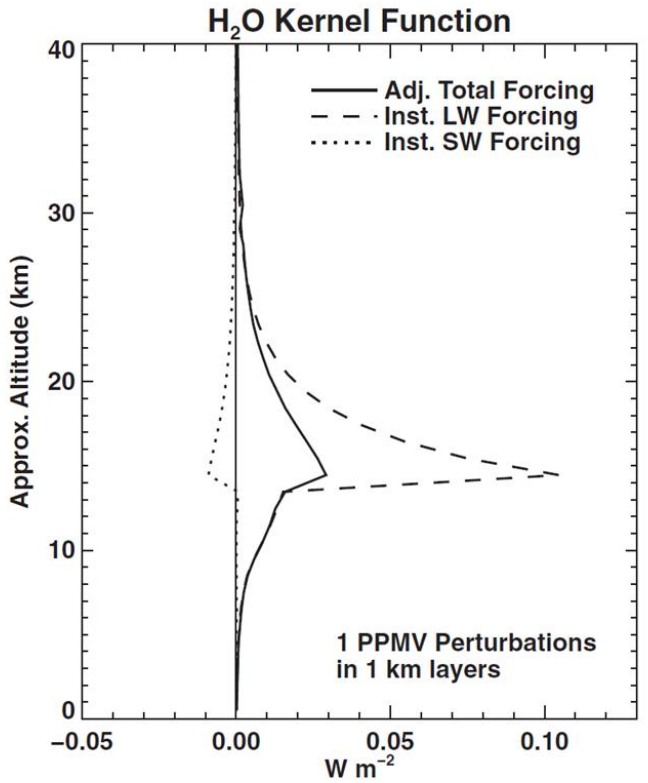
Why look at Methane? (2)



IPCC 2013



Solomon 2010

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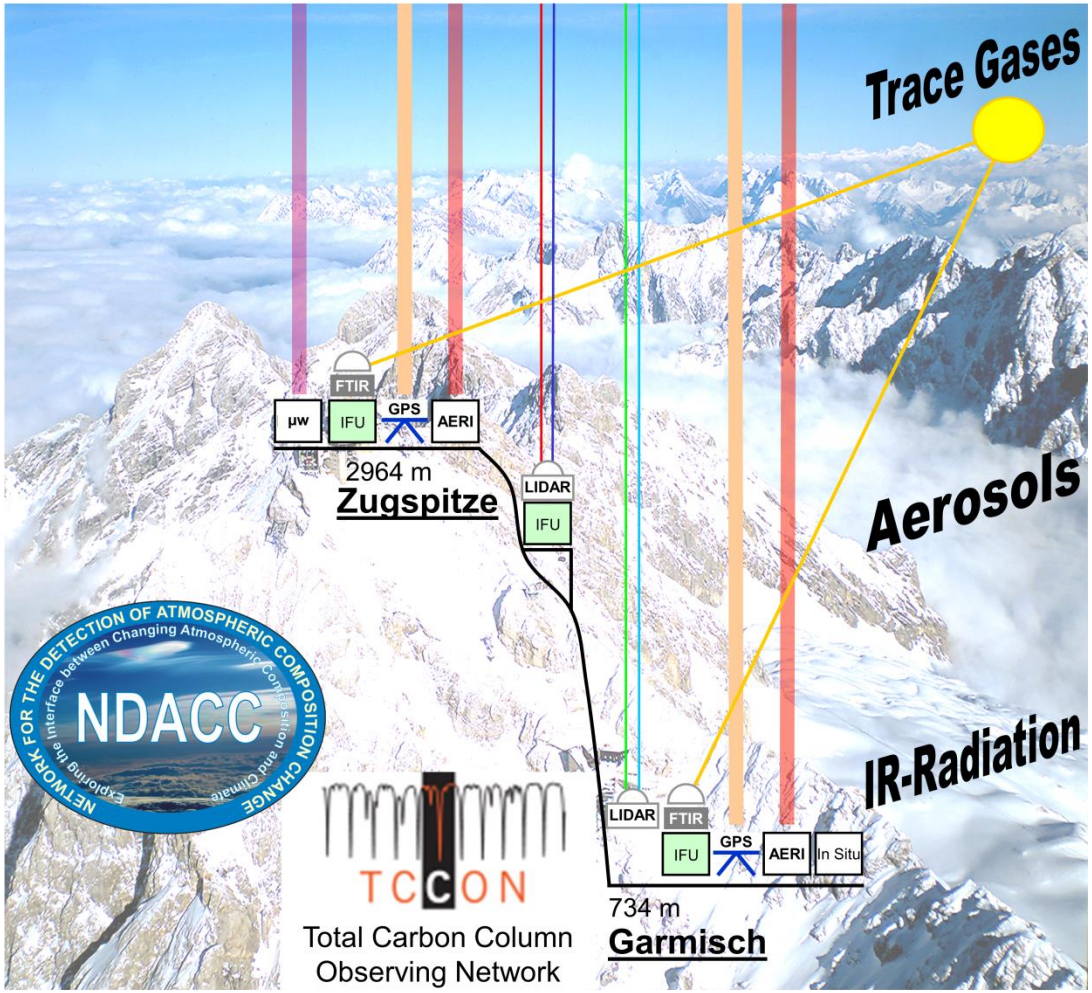
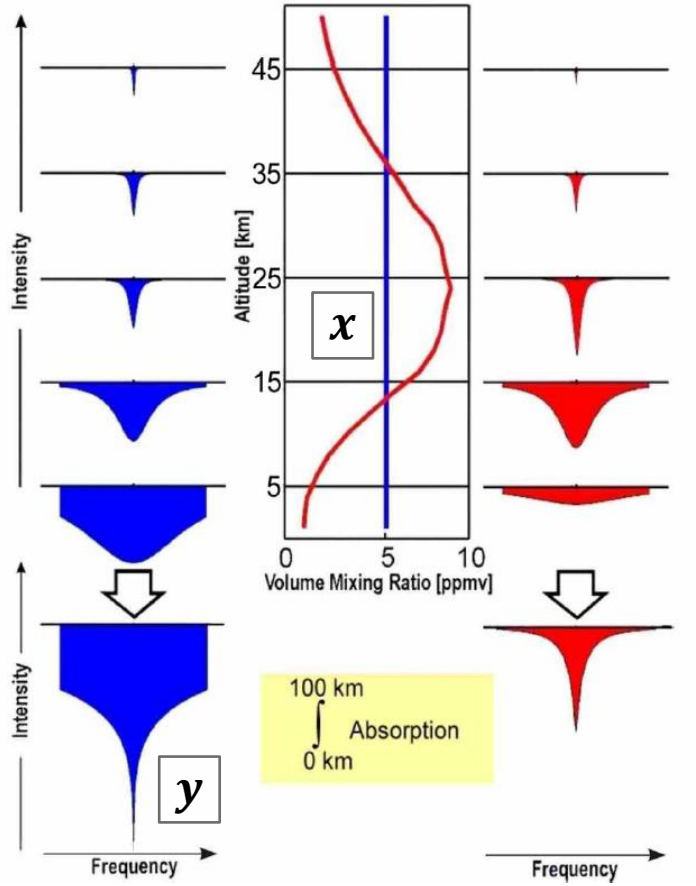
FTIR spectrometry – Zugspitze observatory



- Ground-based solar absorption FTIR measurements at Zugspitze (2964 m)
- Spectral resolution: ~ 0.005 cm^{-1}
- Mid-Infrared region: CH_4 retrieval within 2600 - 2900 cm^{-1}

FTIR spectrometry – trace gas retrieval



x - trace gas vertical profile
y - measured spectrum

Forward model $y = F(x)$

Inverse model $x = F^{-1}(y)$

→ non-linear, ill posed problem

Minimize cost function:

$$\underbrace{\|y - F(x)\|^2_{S_\varepsilon}}_{\text{spectral error cost}} + \underbrace{(x - x_a)^T R\,(x - x_a)}_{\text{regularization cost}}$$

→ 1st order Tikhonov $R = \alpha L_1^T L_1$

- constraint on profile slope
- $\alpha \to \infty$ profile scaling
- $\alpha \to 0$ perfect fit, but oscillations

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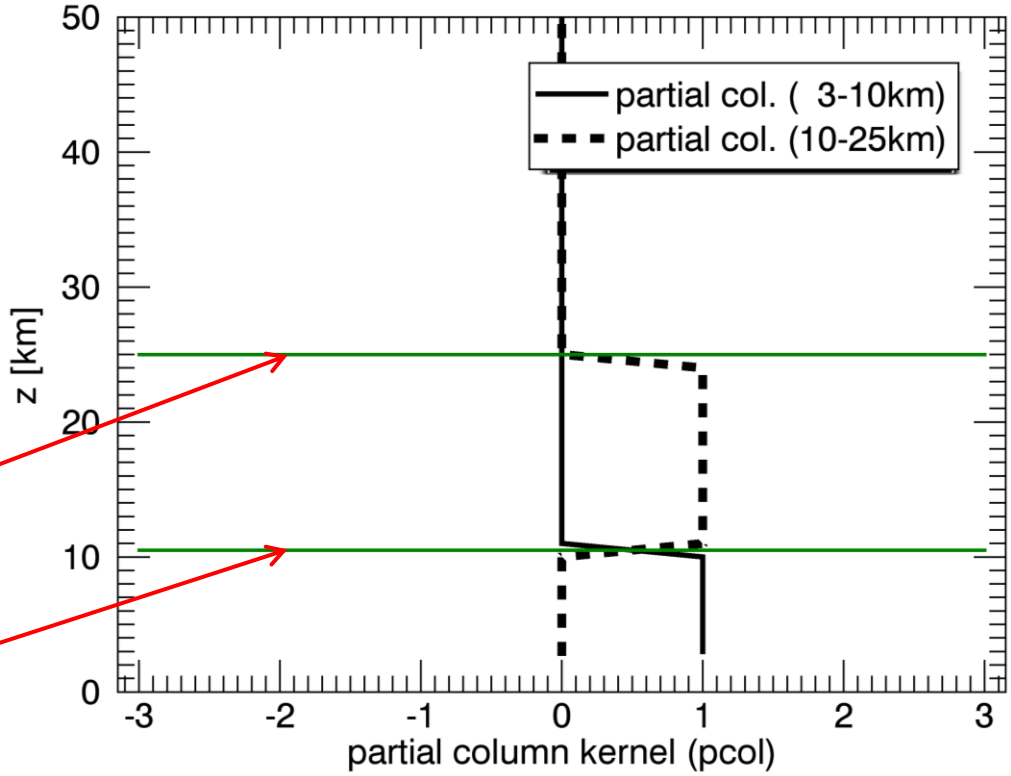
FTIR spectrometry – vertical resolution

- Averaging kernel matrix A $\quad x - x_a = A(x_{true} - x_a)$
- Independent partial columns $\quad DOFS = trace(A)$
- Ideal separation of two partial columns:



level of $DOFS = 2$

level of $DOFS = 1$ = tropopause

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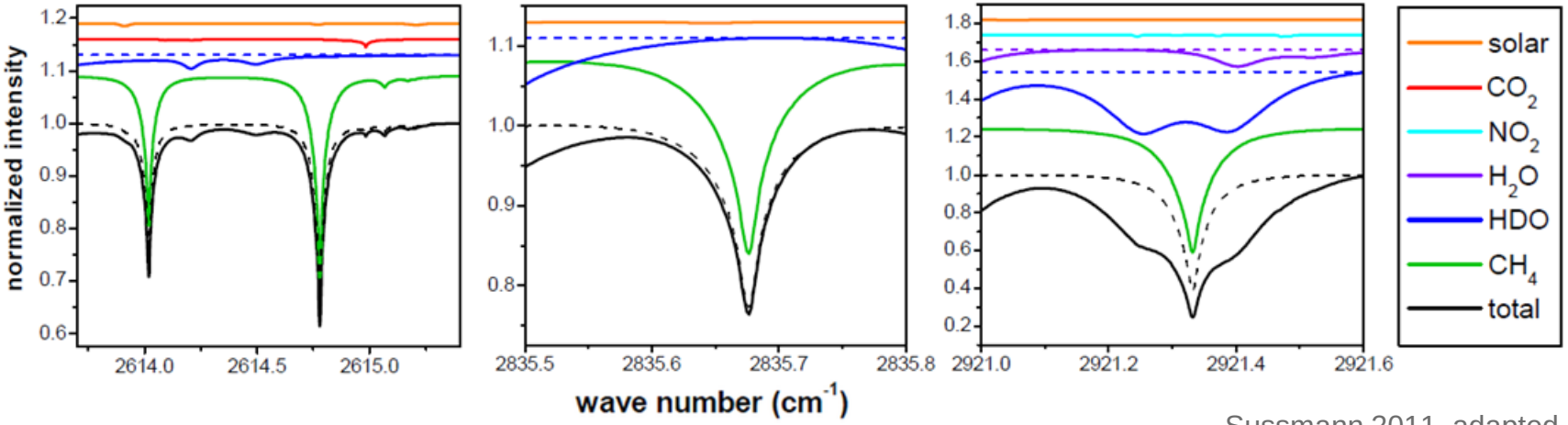
Methane retrieval – starting point

Retrieval Strategy MIR-GBM (Sussmann, 2011):

- optimized for total column precision < 0.3% (1-σ diurnal variation)
- minimized H_2O/HDO-CH_4 interference error (seasonal bias < 0.14%)

- altitude-constant Tikhonov-L_1 constraint
- spectroscopy: HITRAN 2000 + updates

$$R' = \alpha L_1^T T L_1$$
$$DOFS \approx 2$$



Sussmann 2011, adapted

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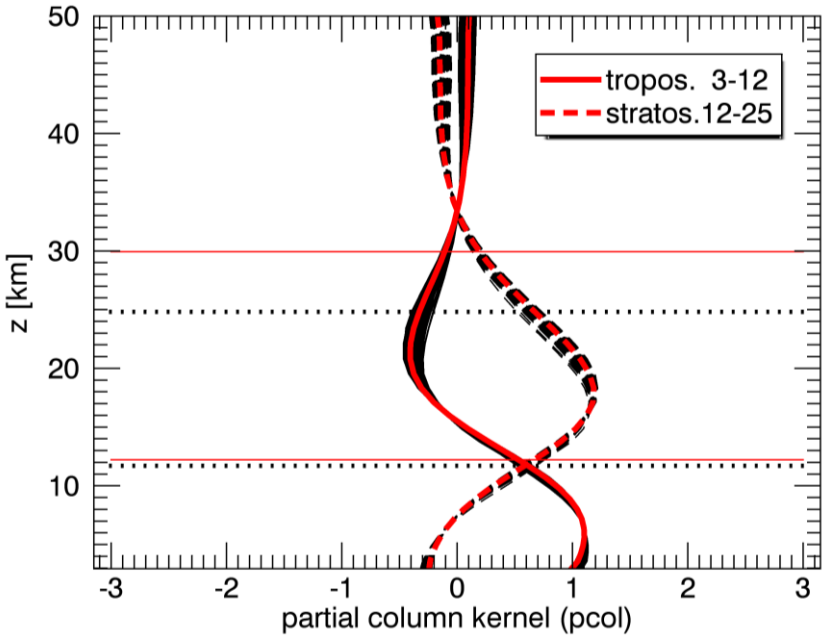
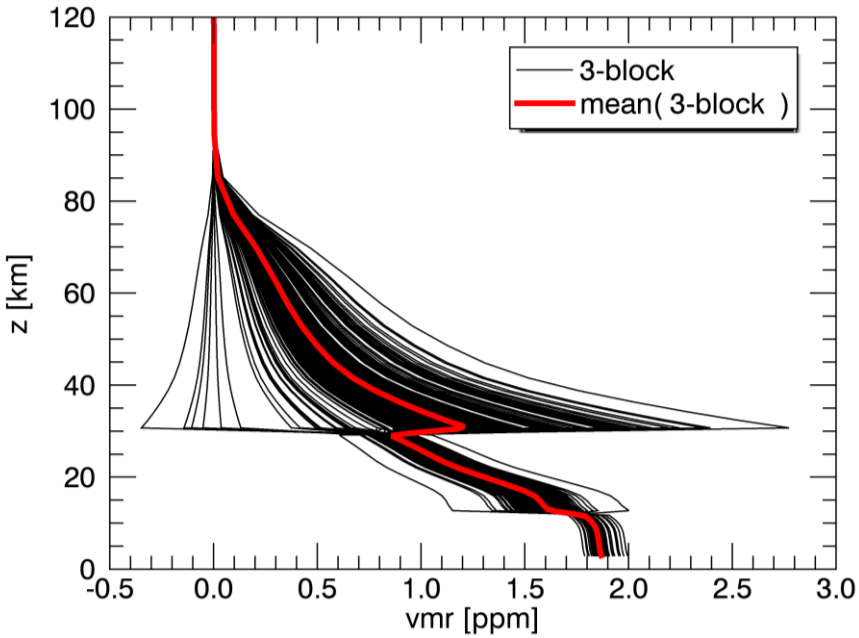
Methane retrieval – optimizing for profiles

- 3-block Tikhonov: free scaling of 3 profile-parts ($\alpha \to \infty$, $DOFS = 3$)
  blocks: 3 - 12 km, 12 - 30 km, 30 - 120 km
- partial columns: 3 - 12 km, 12 - 25 km





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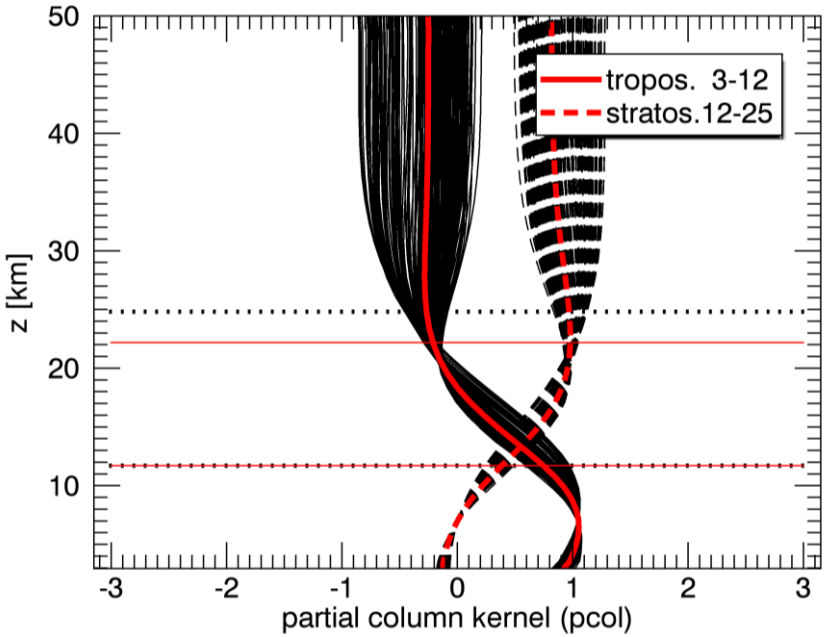
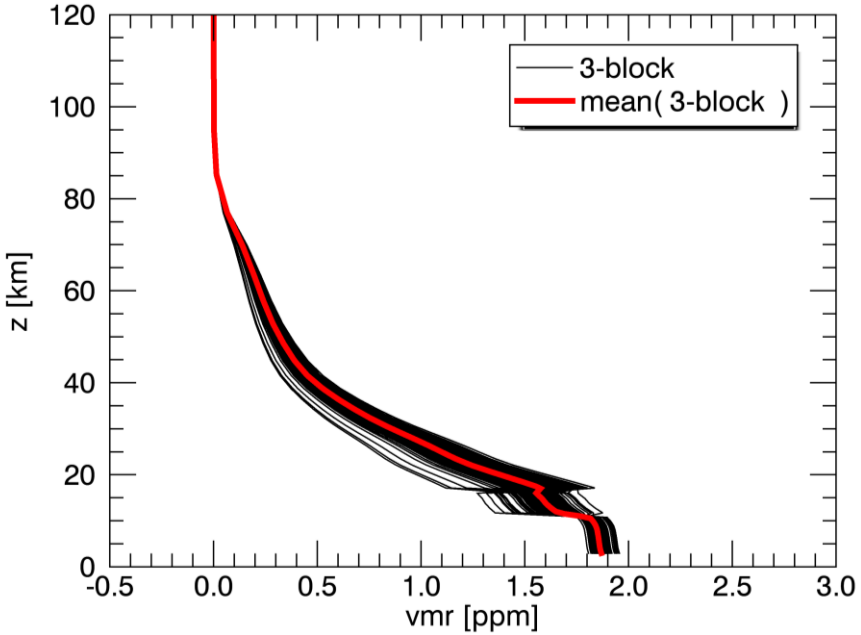
Methane retrieval – refined 3-block Tikhonov

- only free scaling of first + third block ($\alpha_1 \rightarrow \infty$)
- add weak absolute constraint in second block (α_0 small):

$$R'_{3B} = \alpha_0 \, L_0^T L_0 + \alpha_1 \, L_1^T L_1$$

- refined 3-block Tikhonov (3 - 11 km, 11 - 16 km, 16 - 120 km)





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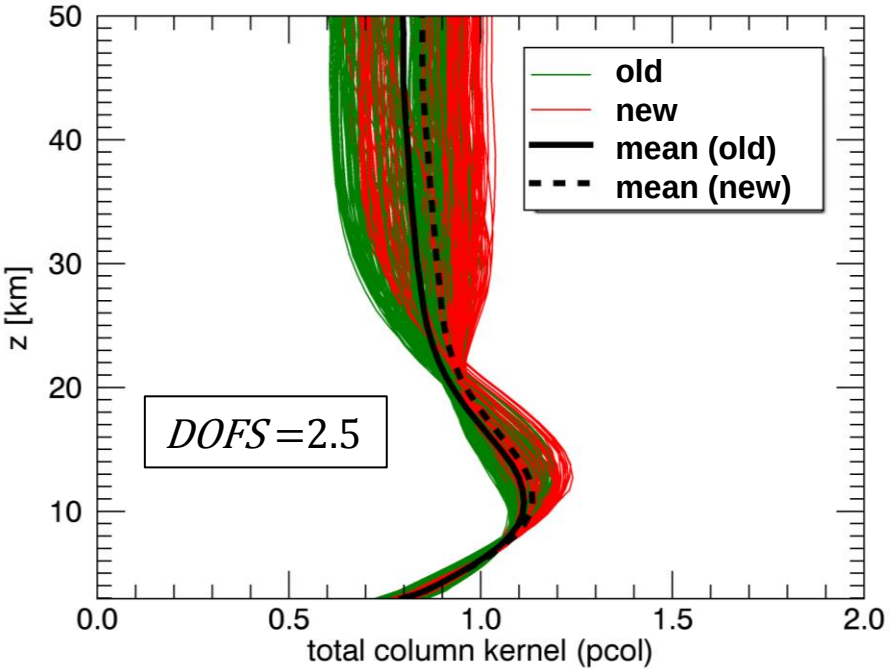
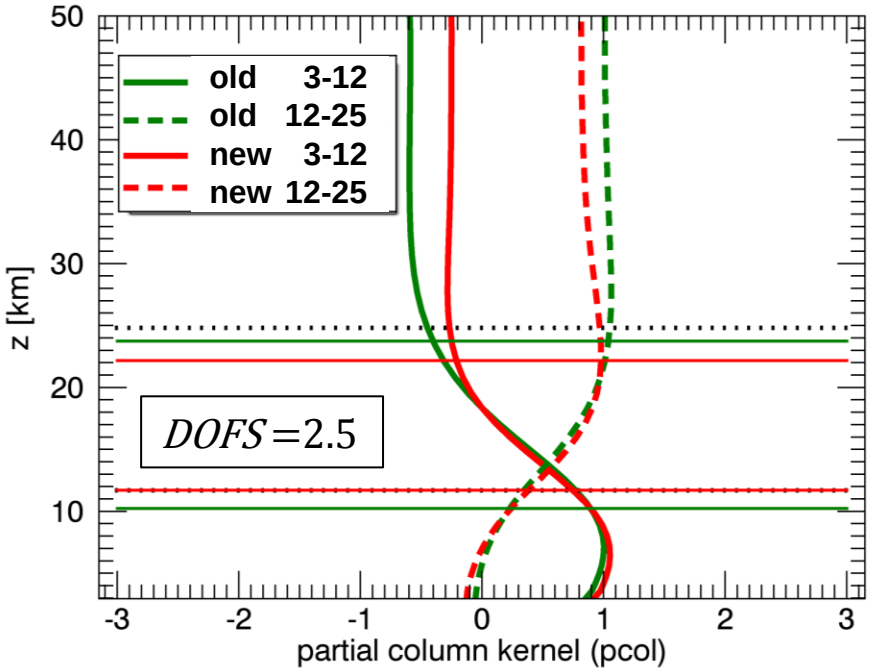
Methane retrieval – strategy comparison

Compare 2 regularization schemes:

- old: optimized for total column precision (Sussmann, 2011)
- new: optimized for profile information





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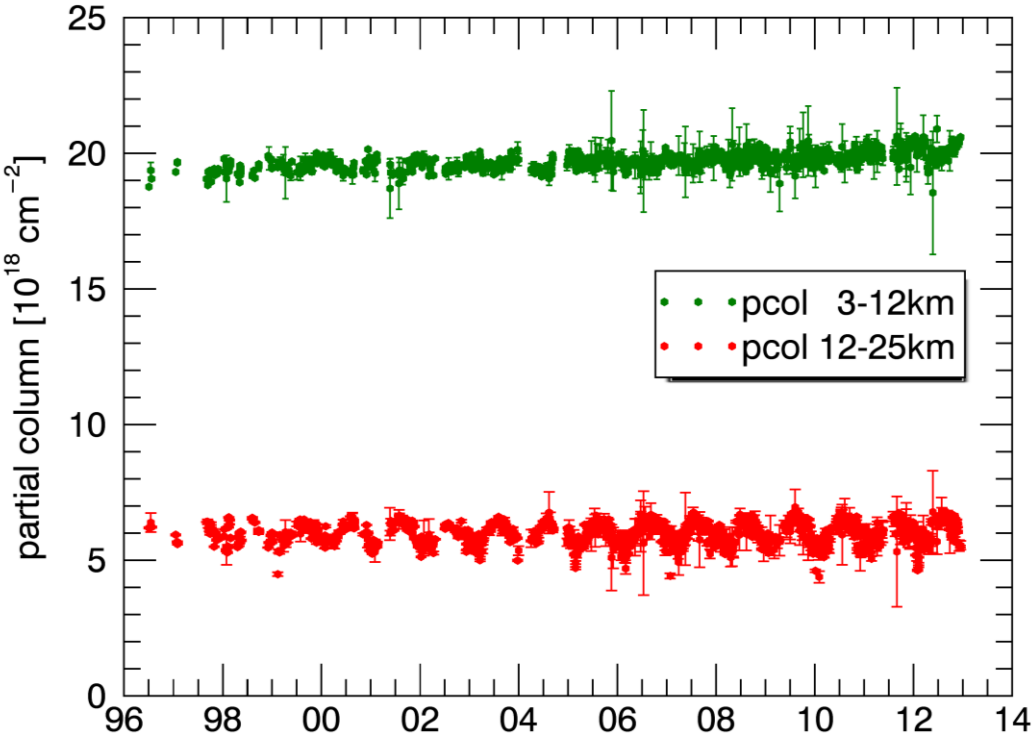
Methane retrieval – partial column time series



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Summary

- Retrieval of atmospheric methane from solar FTIR spectrometry
- Strategy optimized for profile information
  → tropospheric and stratospheric methane partial columns

- Outlook:
  - Methane trend analysis (3 - 12 km, 12 - 25 km)
  - Combine with water vapor trend analysis