FTIR methane profile retrieval using dimension reduction method

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Motivation

• Develop alternative retrieval algorithm for remote sensing of greenhouse gases that would allow studying non-linearities in the retrieval - GOSAT RA project.

• We aim to improve Sodankylä Fourier Transform Spectrometer methane retrieval by using Dimension Reduction method, in particular, observations in polar vortex conditions.

• Bayesian framework for detailed characterization of the posterior distribution and the uncertainties are obtained by applying Markov chain Monte Carlo (MCMC) technique.
Sodankylä FTS

67.3668N, 26.6310E

Bruker IFS 125HR with A547N solar tracker.

Detectors:

- **RT-InGaAs**: 12800 - 4000 cm\(^{-1}\)
- **RT-Si**: 25000 - 9000 cm\(^{-1}\)
- **LN-InSb**: 10000 - 1850 cm\(^{-1}\)

- In operation since February 2009
- Part of TCCON network
- Used extensively for GOSAT methane and carbon dioxide validation at high latitudes
- Target site for OCO-2 validation
FTIR retrievals at high latitudes

- Standard FTIR retrieval algorithm is based on scaling climatological prior profile to obtain the best fit.

- In vortex conditions there can be large discrepancy between the true and the prior profile.

- Large solar zenith angle dependency in XCH$_4$ during polar vortex when the prior is far from the truth.

- The U-shape largely explained by the averaging kernels.

- However, varying averaging kernels are problematic when interpreting the data.
**CH$_4$ profile retrieval using dimension reduction**

- FTIR measurements contain some profile information but to retrieve a full profile (100 layers between 0-70 km) is a strongly ill posed problem.
- We reduce the effective dimension of the unknown methane profile using a low dimensional representation of the prior covariance.

- Prior: $x \sim \mathcal{N}(x_0, C)$

- Low rank approximation of the prior covariance using SVD

$$\tilde{C} = \sum_{i=1}^{k} \lambda_i u_i u_i^T = P_k P_k^T,$$

- Computationally easy to solve the low dimensional representation:

$$x = x_0 + P_k \alpha_k, \quad \alpha_k \sim \mathcal{N}(0, I_k)$$
Dimension reduction prior

- Covariance for the original prior is developed using ACE-FTS observations and information on FTIR instrument sensitivity.

- Large variability allowed at UTLS, some variability below 10 km and very little above 35 km.

- Main characteristics obtained using three largest singular vectors.

- Draws from the prior show smooth profiles
Improvement in the residual

- Overall fit is better.
- Largest residual peaks are removed
Tukiainen et al., 2016, submitted to JGR.
MCMC samples of the posterior distribution

• Dimension reduction allows computation of the full posterior distribution using Markov chain Monte Carlo technique

• 100,000 samples from the posterior distribution computed

• Adaptive MCMC by Haario et al. 2004 and Haario et al. 2006 applied.
Posterior distribution

• 2D pairwise marginal distributions show slight non-Gaussian features

• Strong correlation in two methane parameters
Averaging kernels

SWIRLAB (Dim. red., column)

March 19, 2014

SWIRLAB (Dim. red., profile)

Altitude [km]

One profile

0 km
10 km
20 km
30 km
40 km

0
0.02
0.04
0.06
Summary and discussion

- Dimension reduction technique is developed for retrieving methane profiles from FTIR observations.
- The methodology is applied to Sodankylä FTIR observations.
- The retrieved profiles are in good agreement with AirCore profiles.
- Low dimensional problem allows computing posterior distributions using the adaptive MCMC methods.
- The developed method is generic and can be applied to other gases and satellite data retrievals.

* Tukiainen et al, submitted to JGR, 2016
Comparison of daily observations with averaging kernels

19-Mar-2014

XCH$_4$ [ppb]

Hour of the day
AirCore profile observations at Sodankylä

• Started in fall 2013.

• Regular flights since then. Good flight conditions needed.

• Campaigns in summer 2014 and 2015

Chen et al, in preparation