Overview of activities related to remote sensing of greenhouse gases at the Finnish Meteorological Institute and plans for TanSat validation

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Sodankylä satellite validation site

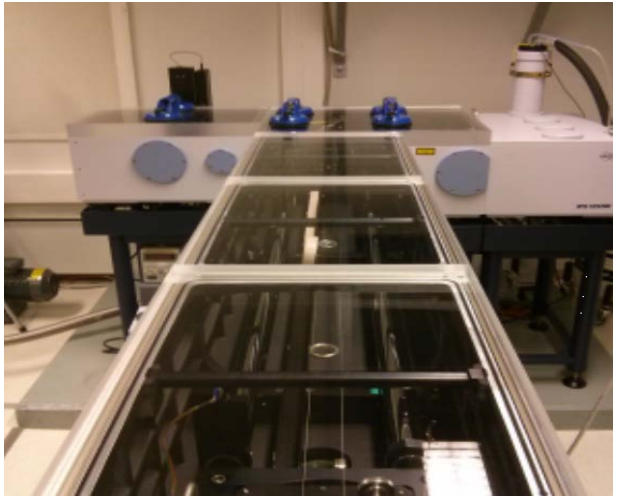
- Sodankylä area is included in the boreal region
- With regard to stratospheric meteorology, it can be classified as an Arctic site, often lying beneath the middle or the edge of the stratospheric polar vortex and in the zone of polar stratospheric ozone depletion.
- Continuous weather records since 1908.
- Satellite validation super site used as a reference for various satellite measurements of atmosphere composition, meteorological parameters, cryosphere observations.
- Related to carbon cycle research, Sodankylä hosts observations concerning atmosphere-vegetation-snow-soil interaction, including CO_2 fluxes.

Sodankylä high latitude site

TCCON Total Carbon Column Observing Network

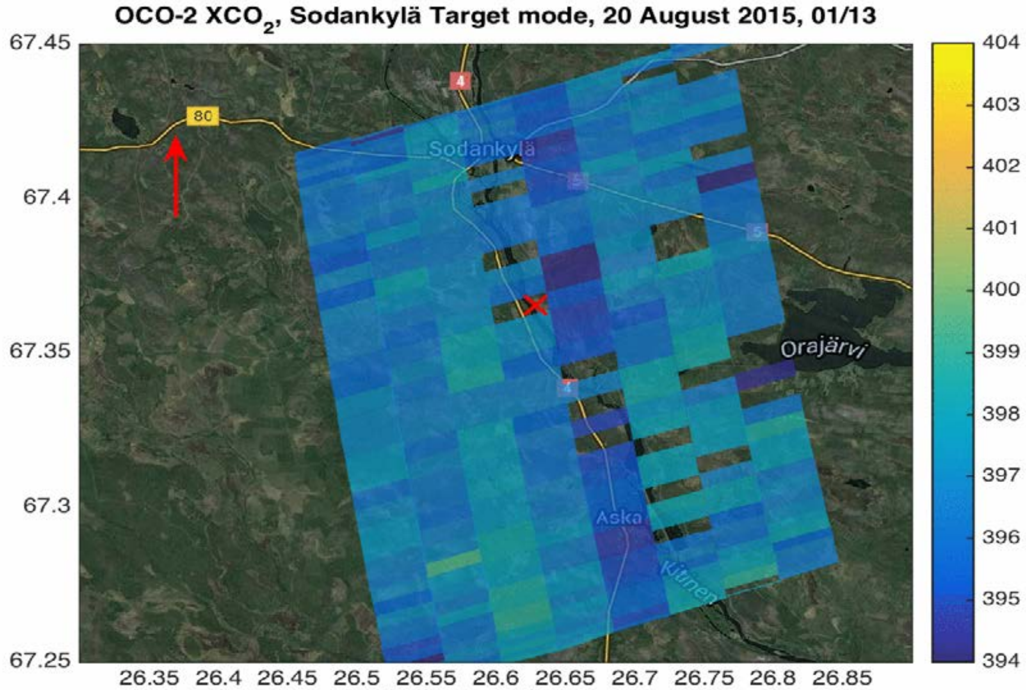
Satellite validation of greenhouse gas column observations using Sodankylä FTS

Bruker *IFS 125HR* with *A547N* solar tracker.

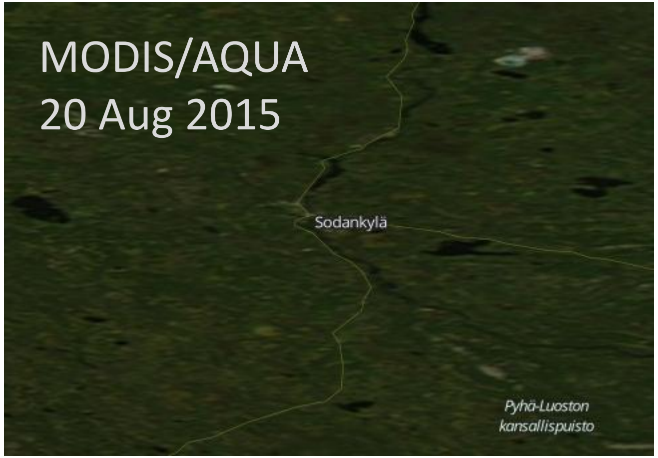


- In operation since February 2009
- Part of TCCON network
- Observations March - October.
- Used extensively for GOSAT methane and carbon dioxide validation at high latitudes
- Used as target site for OCO-2 CO_2 validation
- Will be used for TanSat CO_2 validation, nadir and target observations
- Validation site for TROPOMI / S5P

Sodankylä validation – target 20.08.2015

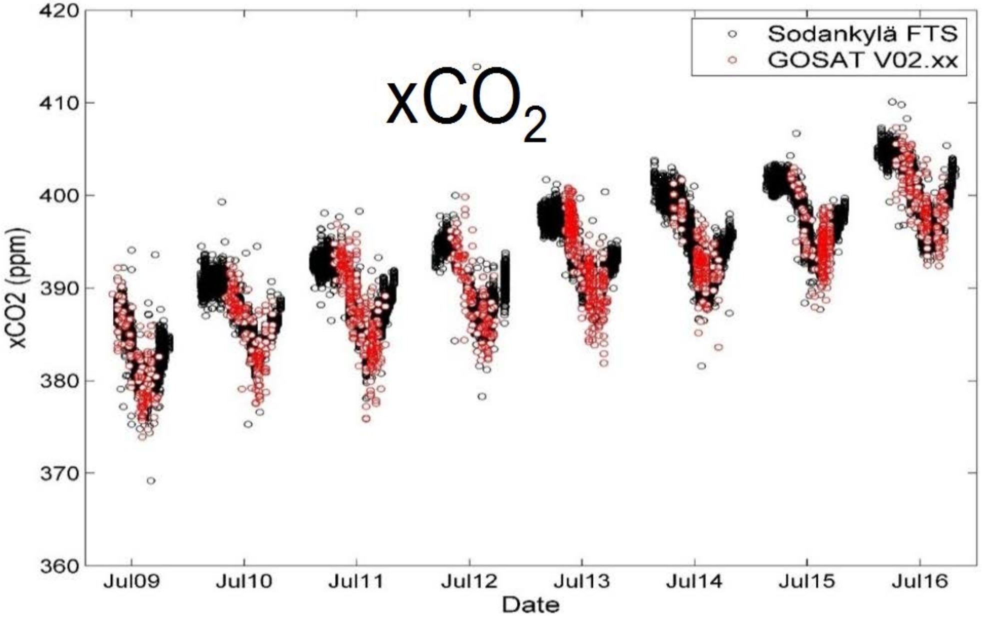


TCCON ~394.5 ppm



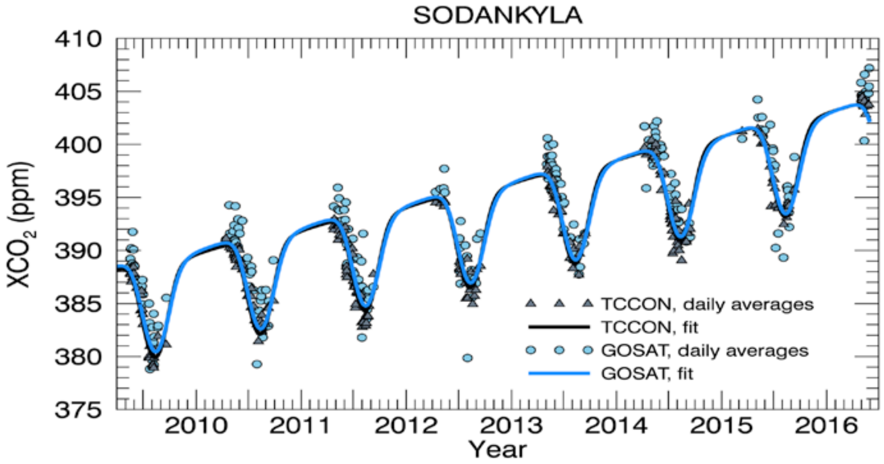
GOSAT XCO_2 validation

Spatial coverage	1000 km radius	500 km radius	250 km radius
Time window	± 3 h	± 2 h	± 1 h
Number of coincident measurements	2492	1040	338
Absolute difference, GOSAT – Sodankylä FTS [ppm]:			
Mean	0.1	0.1	0.4
StdDev	2.5	2.4	2.2
StdErr	0.1	0.1	0.1
Relative difference, (GOSAT – Sodankylä FTS) / Sodankylä FTS [%]:			
Mean	0.02	0.04	0.09
StdDev	0.64	0.61	0.56
StdErr	0.01	0.02	0.03



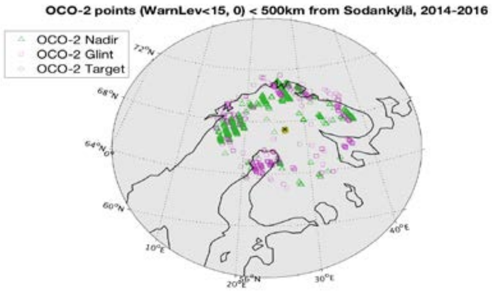
GOSAT XCO_2 evaluation at Sodankylä

- GOSAT (ACOS) observations co-located with TCCON dynamically using model simulations
- Mostly no co-locations between October-March (large solar zenith angles, snow)
- Daily averages of co-located data agree very well
- **Seasonal cycle is captured by GOSAT: amplitude within 0.2 ppm, phase within days.**

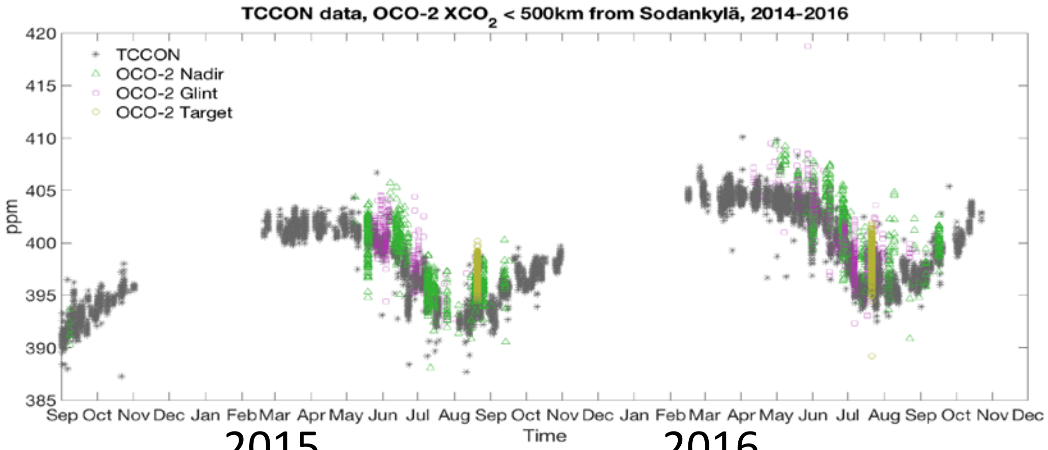


OCO-2 XCO_2 evaluation at Sodankylä

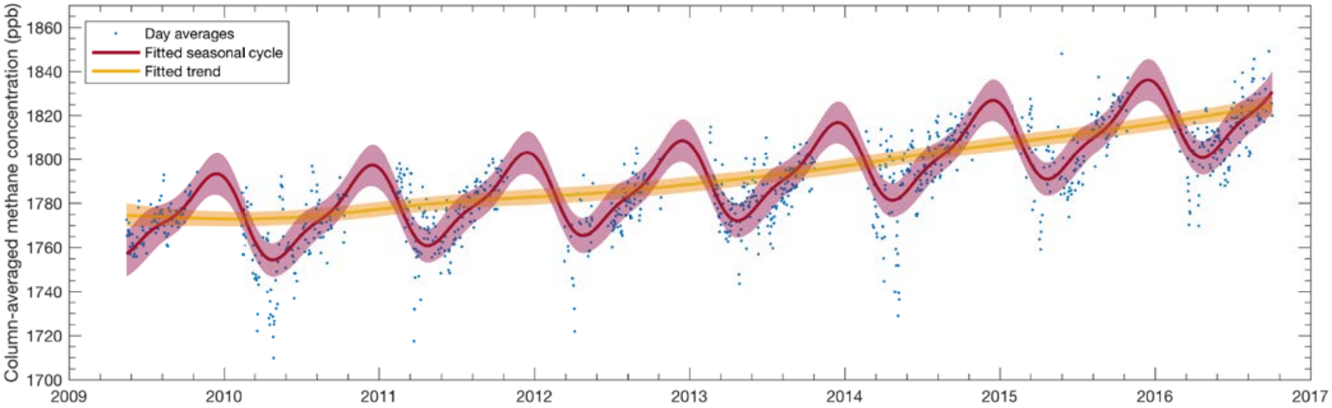
- OCO-2 data < 500 km from Sodankylä agrees well with the seasonality of TCCON XCO_2
- OCO-2 gives about 2-3 ppm higher values than TCCON in all modes → bias correction, stratospheric aerosols



Sodankylä FTS
OCO-2 Nadir
OCO-2 Glint
OCO-2 Target



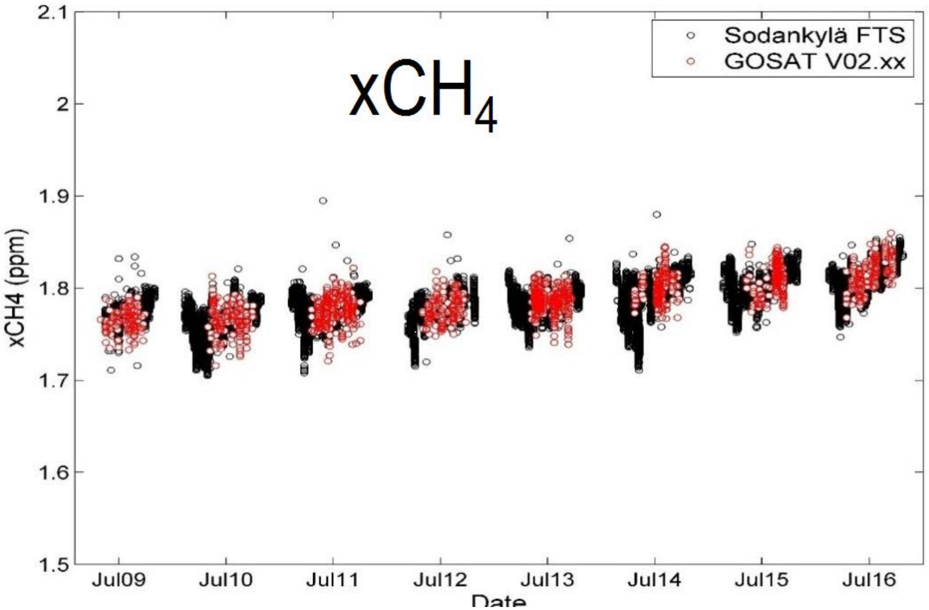
XCH_4 evaluation at Sodankylä



- TCCON XCH_4 time series at Sodankylä shows a nonlinear trend and a seasonal cycle.
- Sources and sinks of methane not fully known/understood

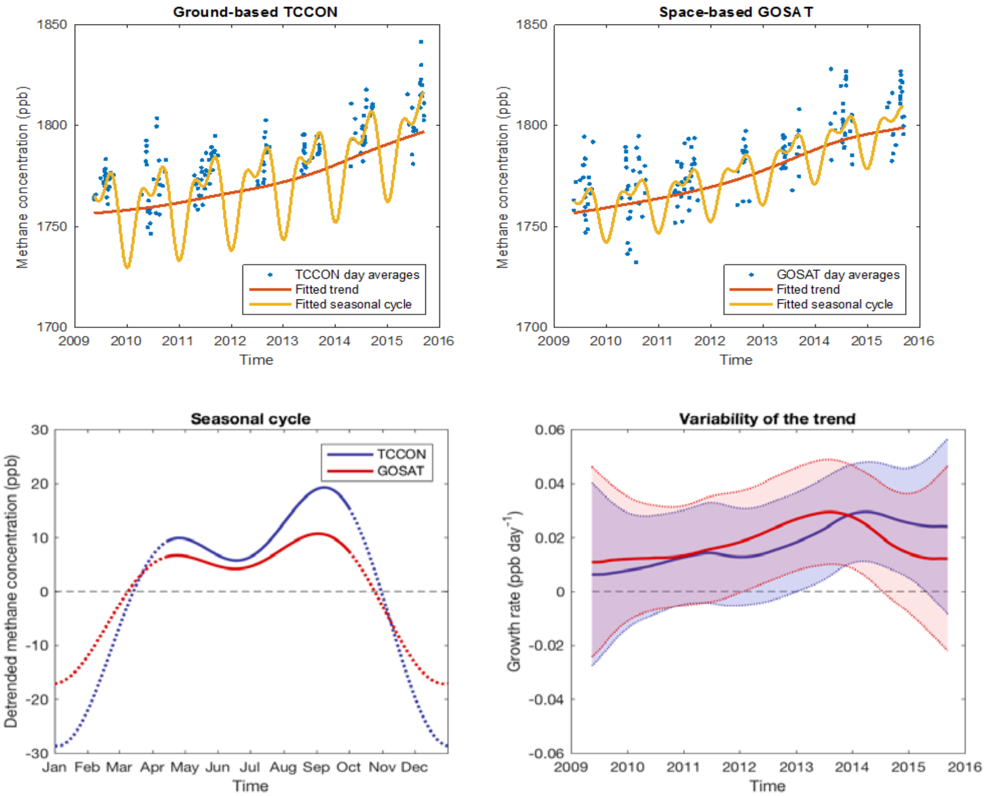
GOSAT XCH_4 validation

Spatial coverage	1000 km radius	500 km radius	250 km radius
Time window	± 3 h	± 2 h	± 1 h
Number of coincident measurements	2492	1040	338
Absolute difference, GOSAT – Sodankylä FTS [ppm]:			
Mean	0.0012	-0.0012	0.0002
StdDev	0.0155	0.0138	0.0116
StdErr	0.0003	0.0004	0.0006
Relative difference, (GOSAT – Sodankylä FTS) / Sodankylä FTS [%]:			
Mean	0.07	-0.07	0.01
StdDev	0.87	0.77	0.65
StdErr	0.02	0.02	0.04



GOSAT XCH_4 at Sodankylä

- GOSAT soundings co-located with TCCON dynamically.
- We fit a seasonal cycle and a trend to the daily averages using Dynamic linear model (DLM) time series method (Laine et.al.)
- TCCON XCH_4 higher than GOSAT, trends somewhat agree.
- Work in progress.



ESA funded FRM4GHG project

Fiducial Reference Measurements for Ground-Based Infrared Greenhouse Gas Observations

(led by University Bremen and BIRA)

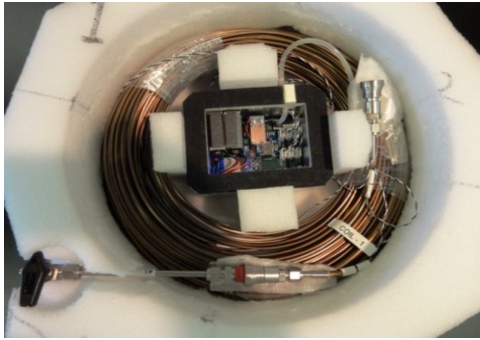
- Intercomparison of instruments and harmonization of retrievals and products from collocated new and established GHG observation ground based Infrared instrumentations to get Fiducial Reference Measurements (FRMs) for Greenhouse Gases (GHGs) and validation of satellite missions targeting including carbon dioxide and methane.

- **Comparison campaign with several new portable spectrometers taking place at Sodankylä 2017 - 2018.**

- Results of the campaign will support validation of TROPOMI and TanSat.

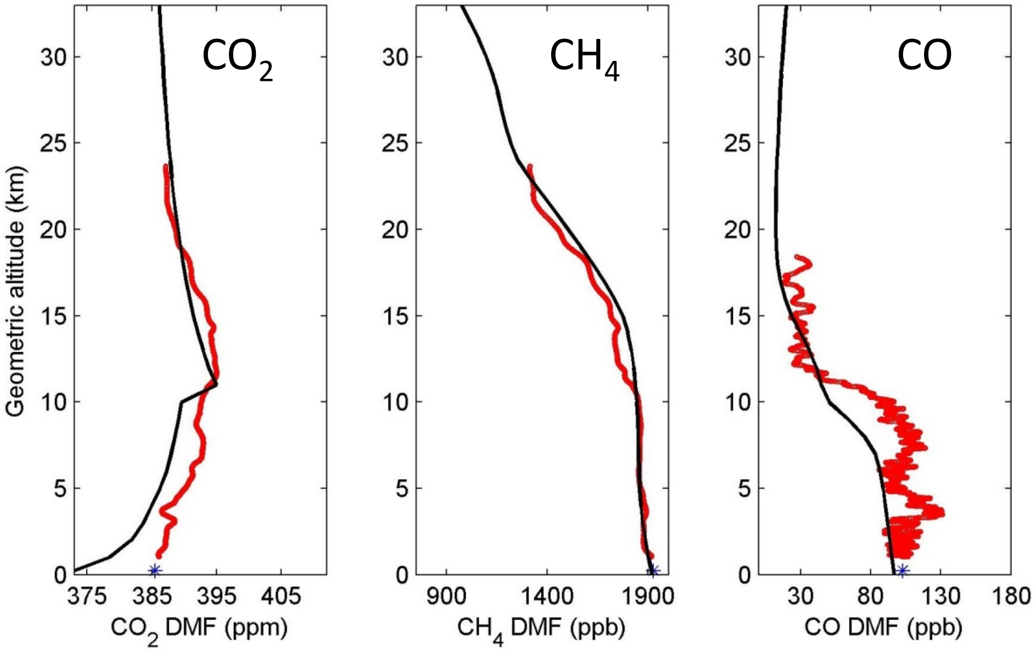
Validation using AirCore profile observations of CH_4 and CO_2 at Sodankylä

- Profile observations of CO2 and CH4 from ground up to the stratosphere with AirCore are used to support satellite validation of XCO2 and XCH4
- Vertical resolution of 5 mb in the stratosphere and 15 mb in the troposphere obtained.
- AirCore measurements started in fall 2013.
- Regular, year around measurements since then.
- So far 30 AirCore profiles obtained.
- The AirCore work is ongoing, including the ESA funded campaign FRM4GHG in 2017-2018.



AirCore instrument with an open cover

AirCore profile observations

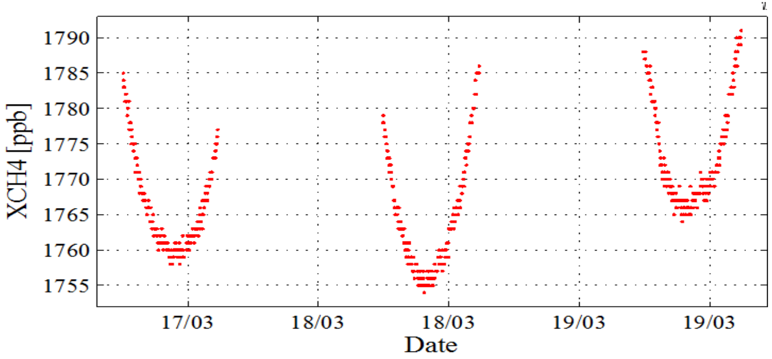


AirCore

Climatology

Using AirCore profiles to validate/improve TCCON retrieval at Sodankylä

- Standard optimal estimation retrieval algorithm is based on scaling climatological prior profile to get the best fit.
- In polar 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 is observed when the prior is far from the truth.
- The shape is largely explained by the averaging kernels. However, varying averaging kernels are problematic when interpreting the data.



FTS profile retrieval using dimension reduction method

(Tukiainen et al., 2016, JGR)

- We have developed FTS profile retrieval algorithm for methane retrieval.
- Instead of retrieving 70 dimensional profile only 3-4 parameters describing the profile are retrieved.
- Similar approach is applicable for other gases and satellite retrievals as well.
- Advantage for CO_2 retrieval?

Prior: $\boldsymbol{x} \sim \mathcal{N}(\boldsymbol{x}_0, \boldsymbol{C})$

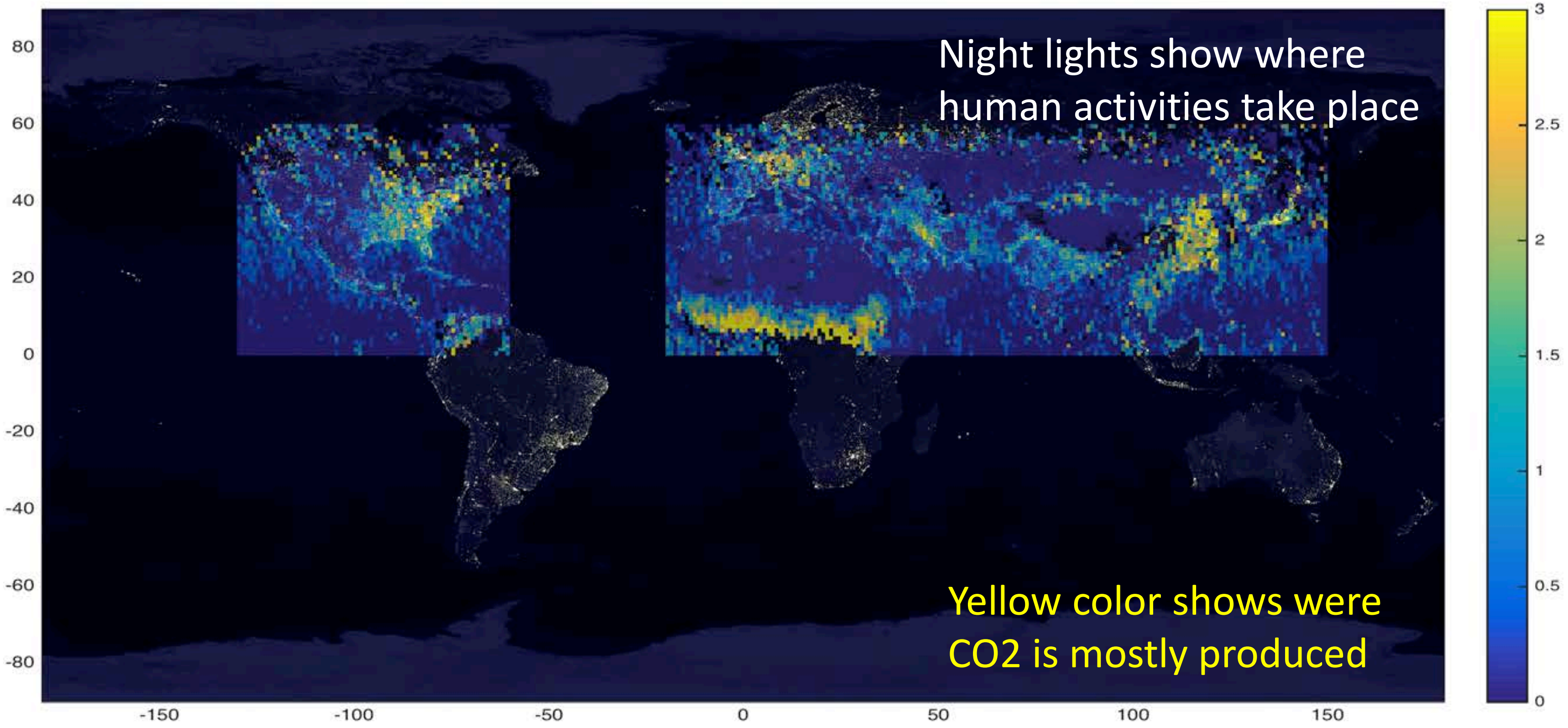
Low rank approximation of the prior covariance using SVD:

$$\widetilde{\boldsymbol{C}} = \sum_{i=1}^{k} \lambda_i \boldsymbol{u}_i \boldsymbol{u}_i^T = \boldsymbol{P}_k \boldsymbol{P}_k^T,$$

Low-dimensional representation:

$$\boldsymbol{x} = \boldsymbol{x}_0 + \boldsymbol{P}_k \boldsymbol{\alpha}_k, \qquad \boldsymbol{\alpha}_k \sim \mathcal{N}(0, \boldsymbol{I}_k).$$

Map of carbon dioxide emission areas based on NASA's OCO-2 satellite by analysing XCO_2 anomalies



Methodology introduced in Hakkarainen et. al, GRL, 2016, see also Poster by Hakkarainen et.al.

Summary and way forward

TanSat validation at high latitudes using TCCON and AirCore

- Tools exist for validation
- Target mode will be very interesting

TROPOMI / S5P validation

Data analysis

- Anomaly method developed for detecting emission areas from OCO-2 data
- Applicable for analysing TanSat CO_2 data also