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Satellite-borne greenhouse gas retrievals in the Arctic: ongoing research at the FMI

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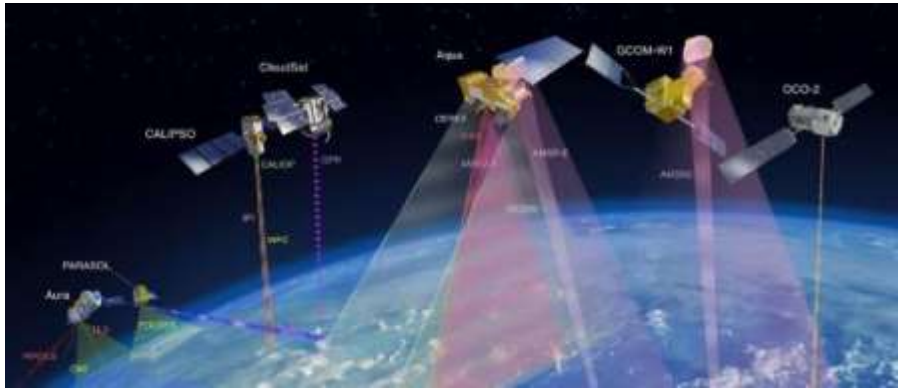
Outline

- Space-based CO_2 and CH_4 retrievals from GOSAT and OCO-2
- Validation against ground-based retrievals at Sodankylä
- Methane profile retrieval
- XCH_4 observations and their connection to fluxes in the Arctic

Currently operating GHG satellites

GOSAT

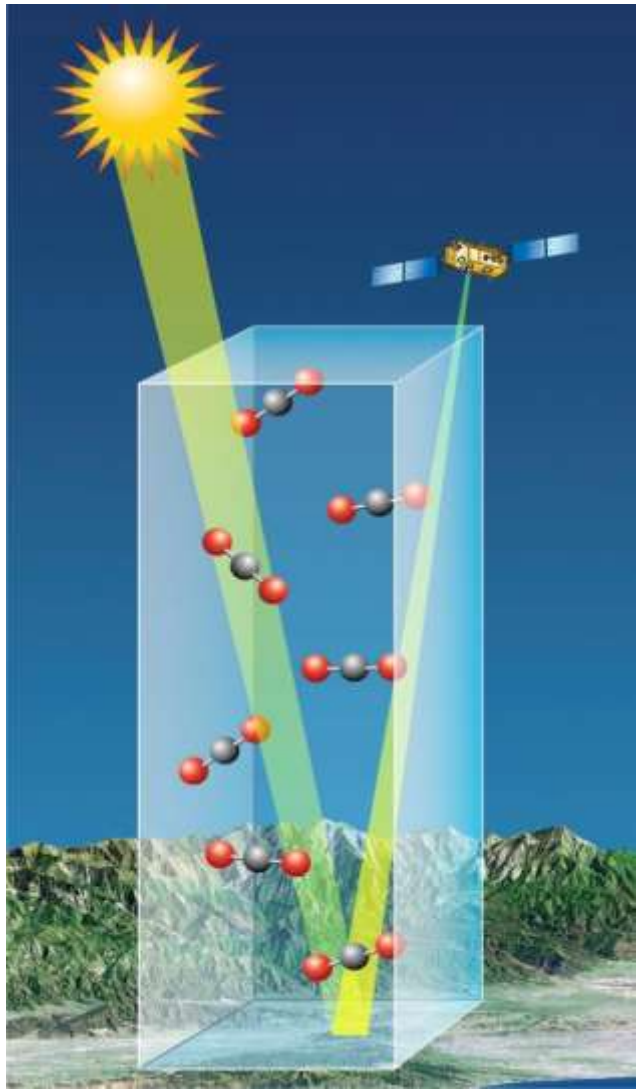
- 2009 April →
- Footprint diameter 10 km
- Sun-synchronous polar orbit; repeat cycle 3 days
- Both CO_2 and CH_4



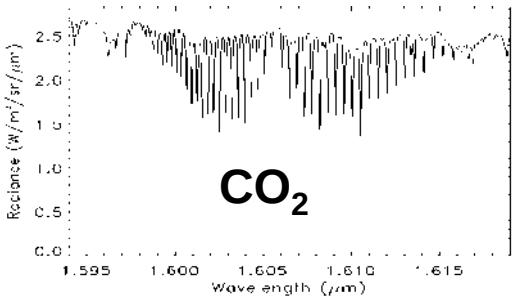
OCO-2

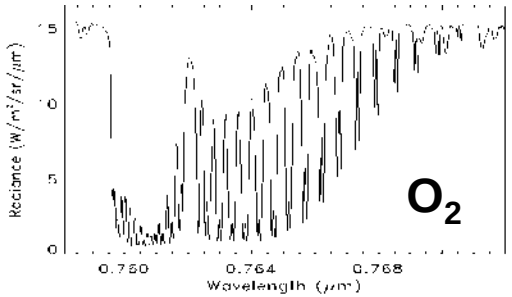
- 2014 September →
- Only CO_2
- Footprint size 2 km x 1 km; 8 footprints; swath 10 km
- Sun-synchronous polar orbit; head of the A-train
- Repeat cycle 16 days
- About 1 million soundings per day; 6% processed

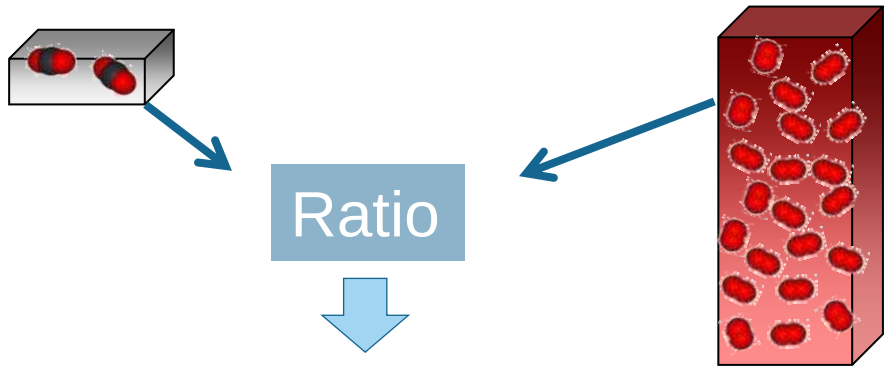
Retrieving CO_2 (and CH_4) from space



- Satellite measures spectra of CO_2 and O_2 absorption from reflected sunlight

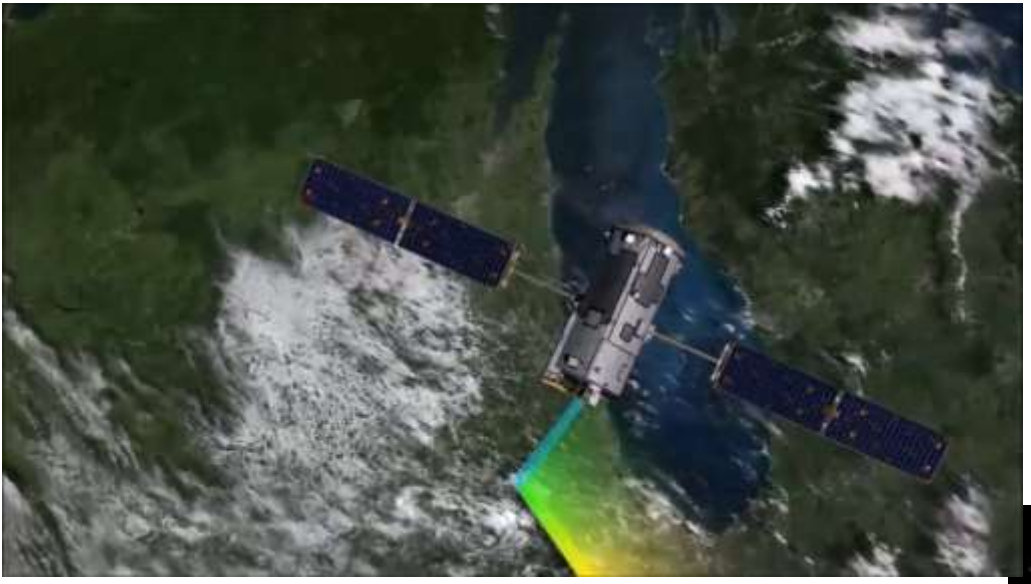




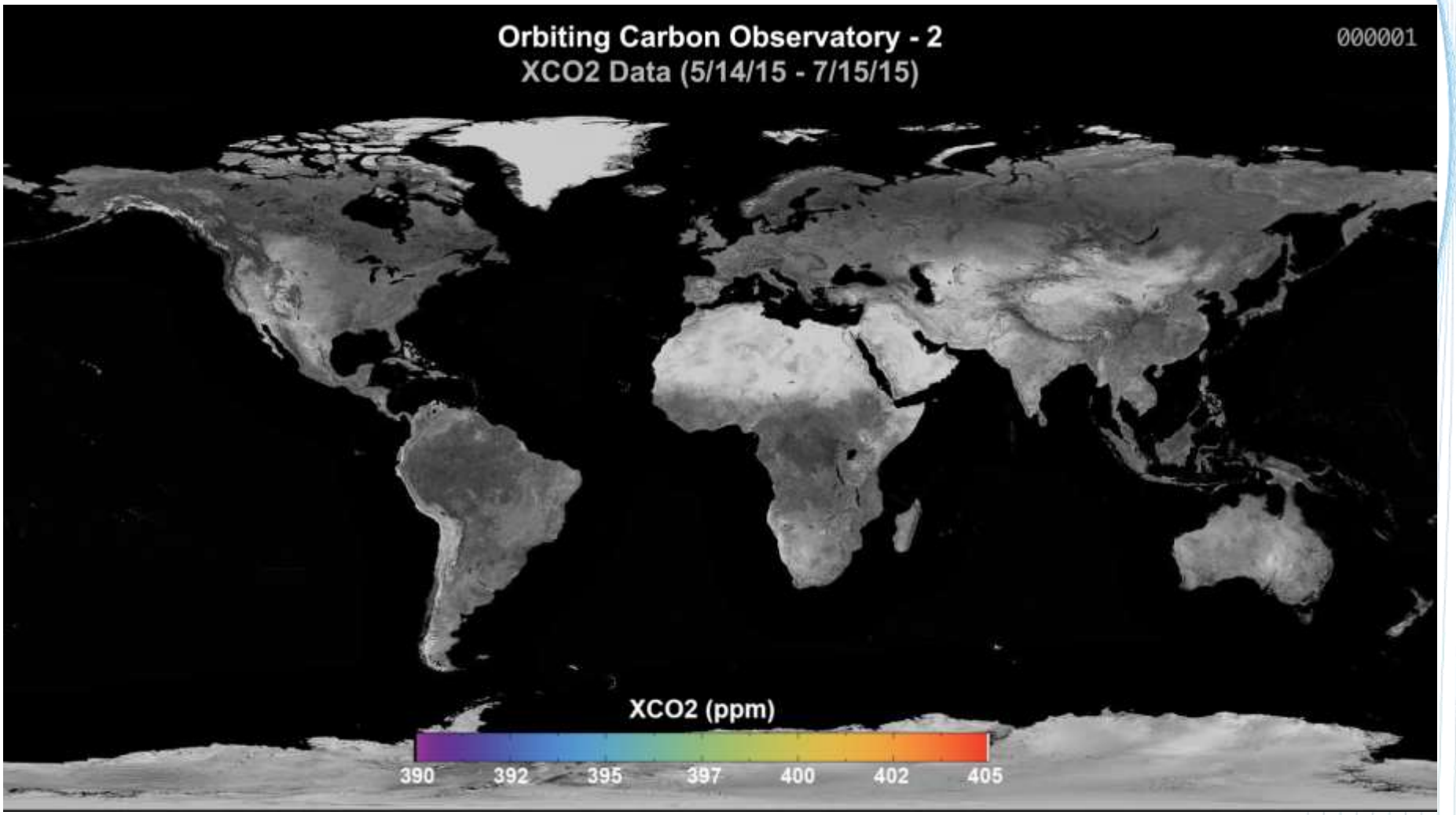


Column-averaged CO_2 dry air mole fraction **XCO_2**

Nadir and glint modes



Example: OCO-2 sees the spring drawdown



OCO-2 target mode

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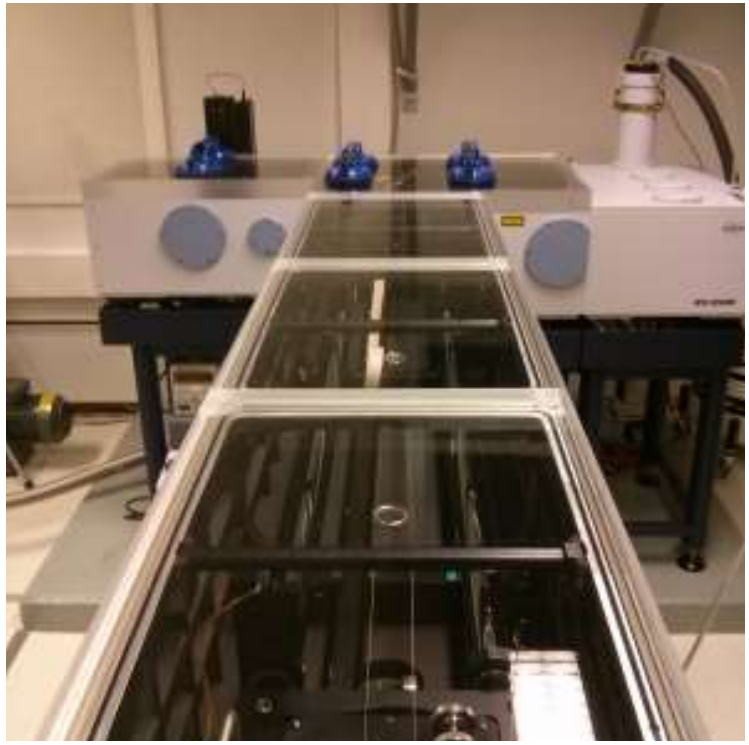
Sodankylä FTS

67.3668N, 26.6310E

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

Detectors:

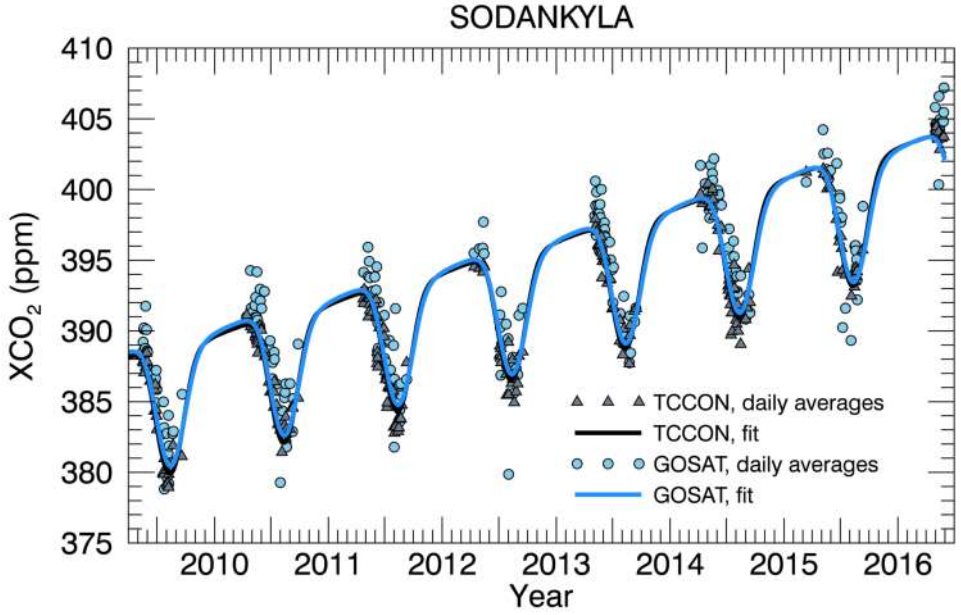
RT-InGaAs:	*12800 - 4000 cm^{-1}*
RT-Si:	*25000 - 9000 cm^{-1}*
LN-InSb:	*10000 - 1850 cm^{-1}*



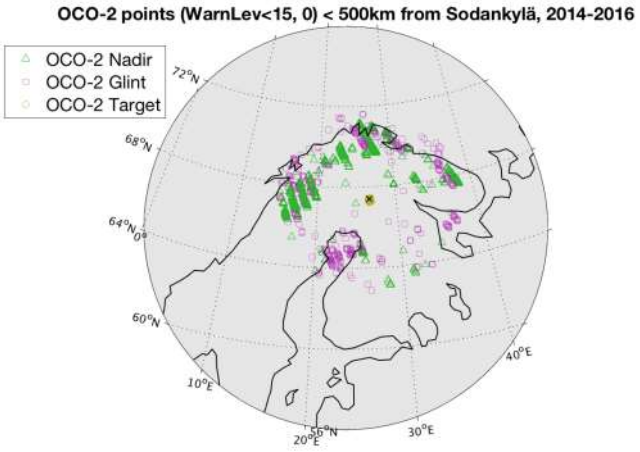
- In operation since February 2009
- Part of TCCON network
- Used extensively for GOSAT methane and carbon dioxide validation at high latitudes
- Target site for OCO-2 validation

GOSAT XCO_2 evaluation at Sodankylä

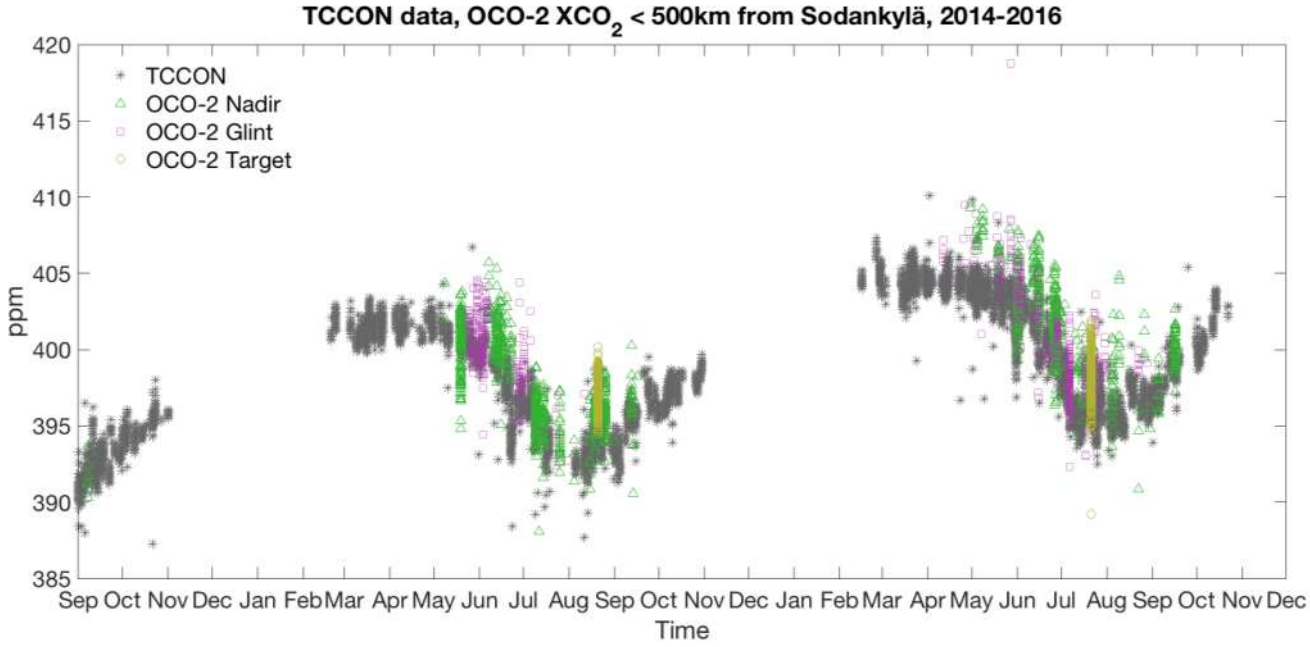
- GOSAT observations co-located with TCCON dynamically using model simulations
- Mostly no co-locations between October-March (large solar zenith angles, snow)
- Daily averages of co-located data agree very well
- Seasonal cycle is captured by GOSAT: amplitude to within 0.2 ppm, phase within days.



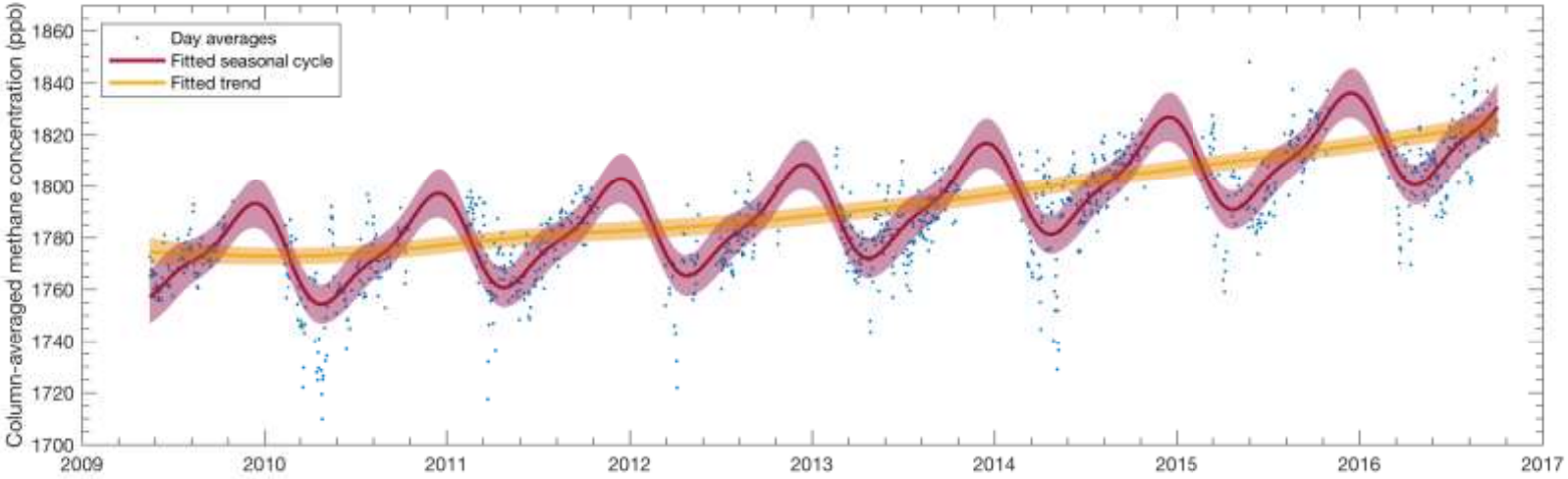
OCO-2 XCO_2 evaluation at Sodankylä



- 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

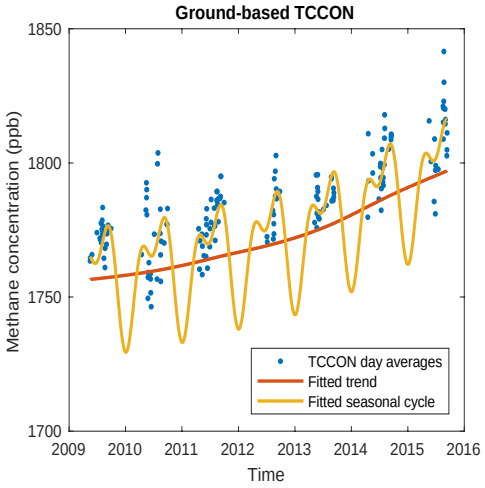


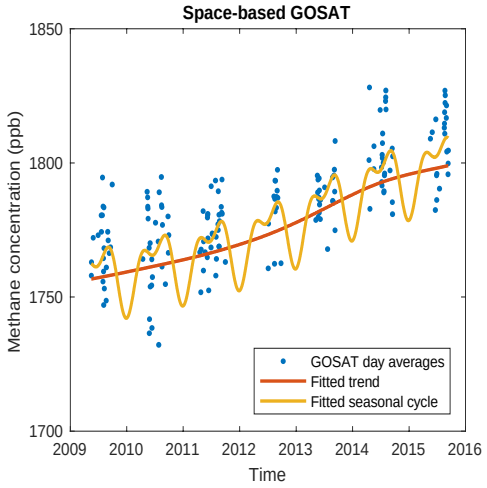
XCH_4 evaluation at Sodankylä

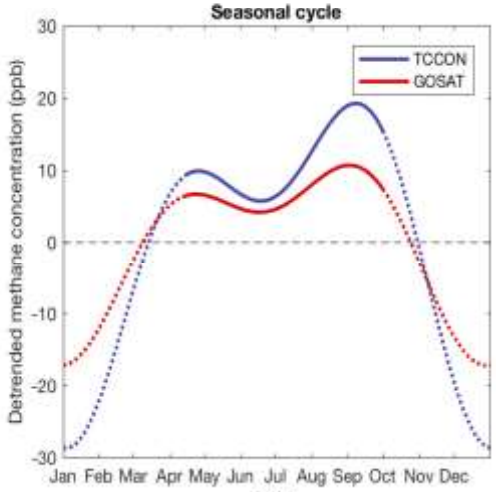


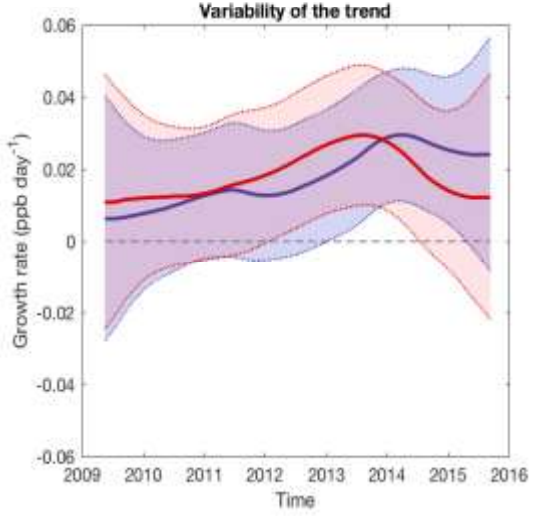
- TCCON XCH_4 time series at Sodankylä shows a nonlinear trend and a seasonal cycle.
- Sources and sinks of methane not fully known/understood

GOSAT XCH_4 at Sodankylä









- GOSAT soundings co-located with TCCON dynamically.
- We fit a seasonal cycle and a trend to the daily averages using DLM.
- TCCON XCH_4 higher than GOSAT, trends somewhat agree.
- Work in progress.

TCCON profile retrieval using dimension reduction method

(Tukiainen et al., 2016, JGR)

- 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 when the prior is far from the truth.

Prior:

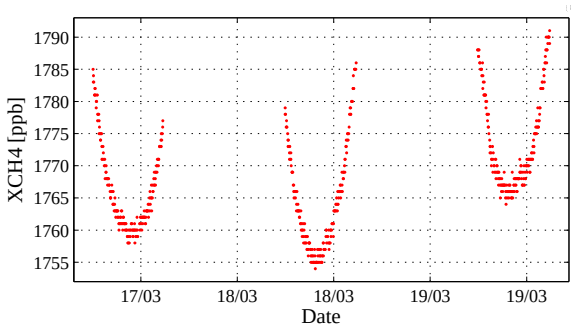
$$\boldsymbol{x} \sim \mathcal{N}(\boldsymbol{x}_0, \boldsymbol{C})$$

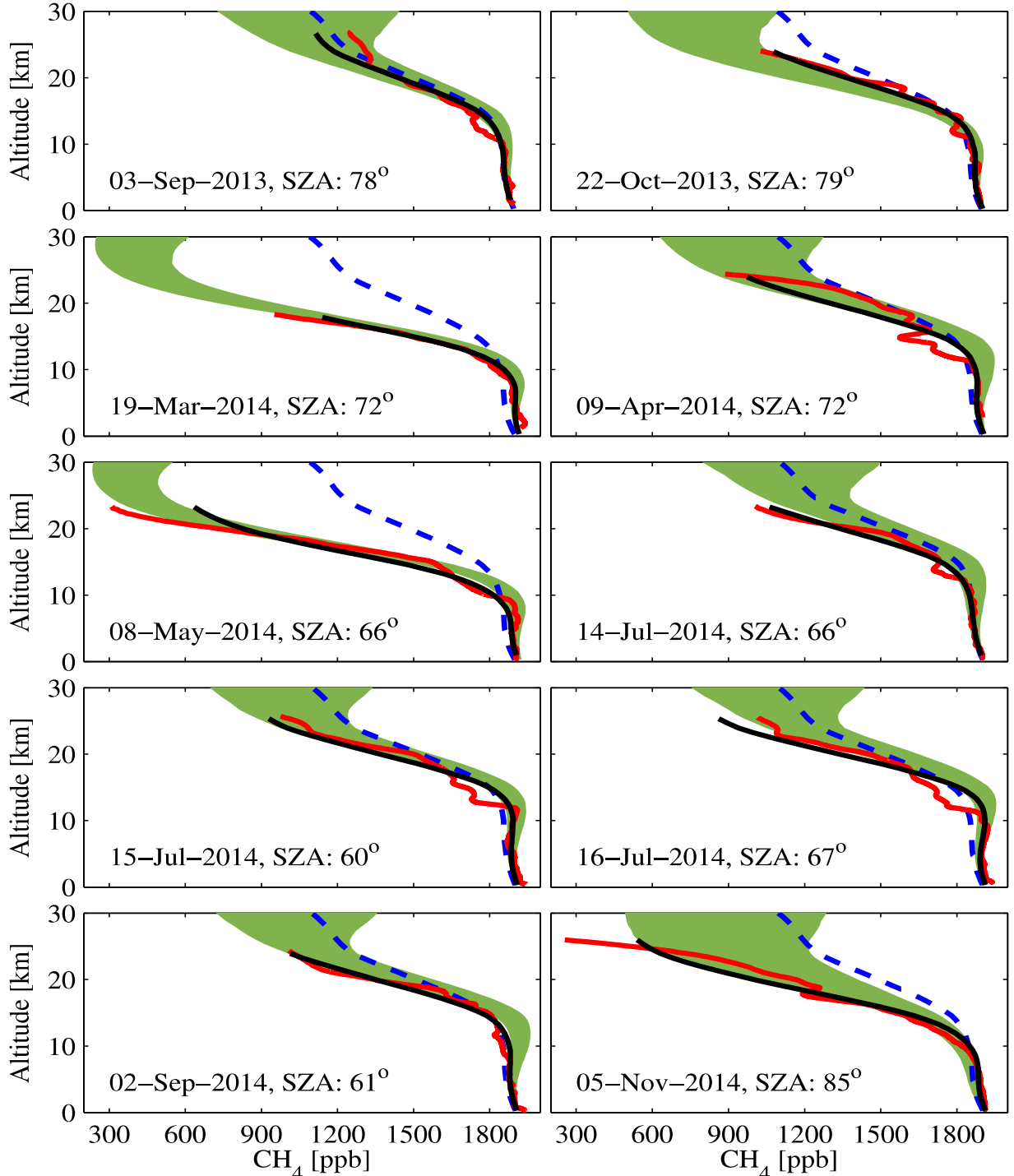
Low rank approximation of the prior covariance using SVD:

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

Low-dimensional representation:

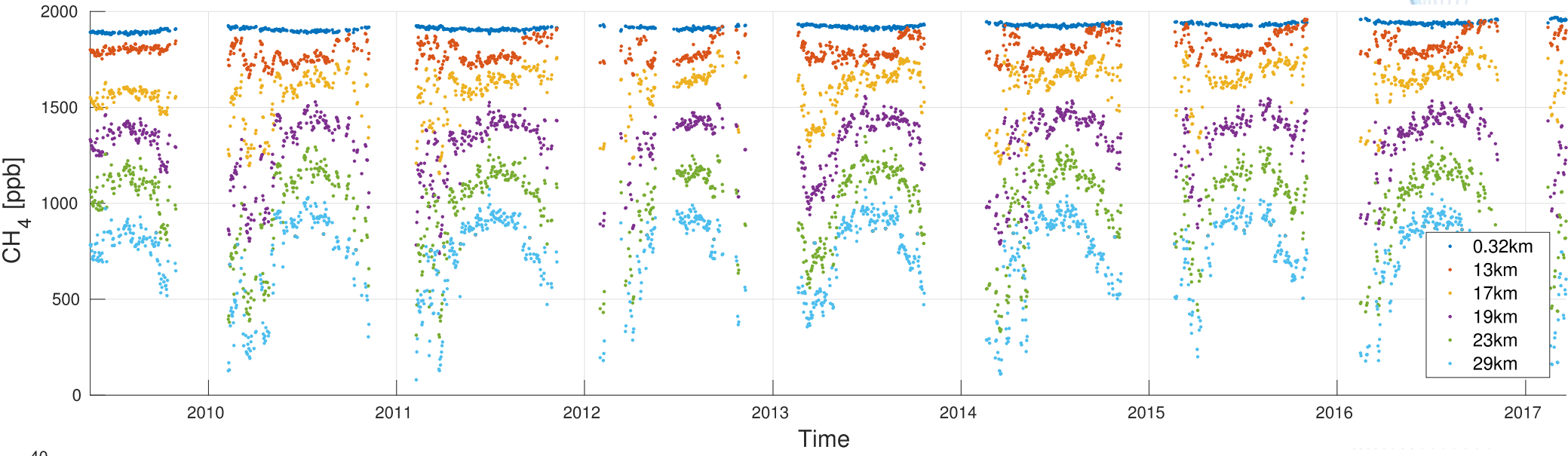
$$\boldsymbol{x} = \boldsymbol{x}_0 + \boldsymbol{P}_k \boldsymbol{\alpha}_k,$$

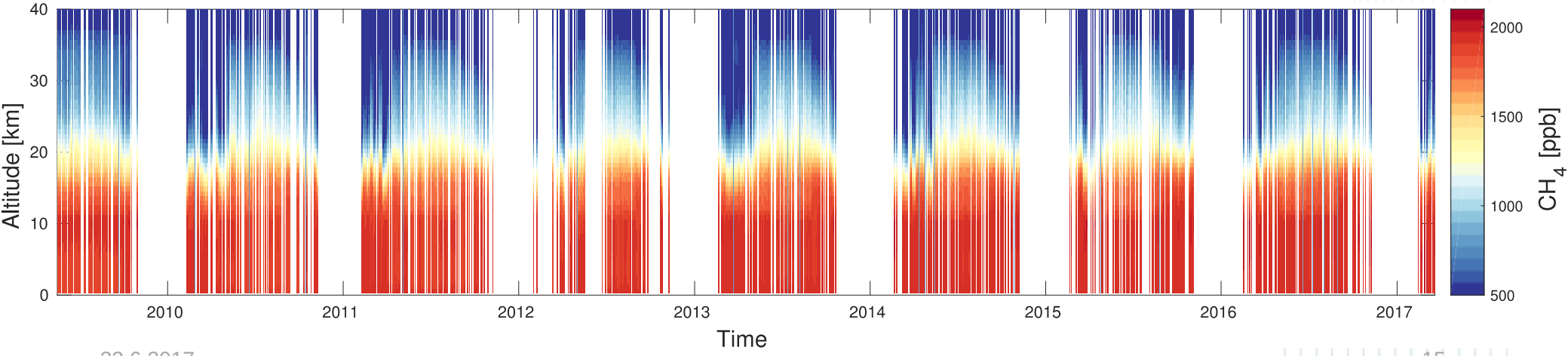




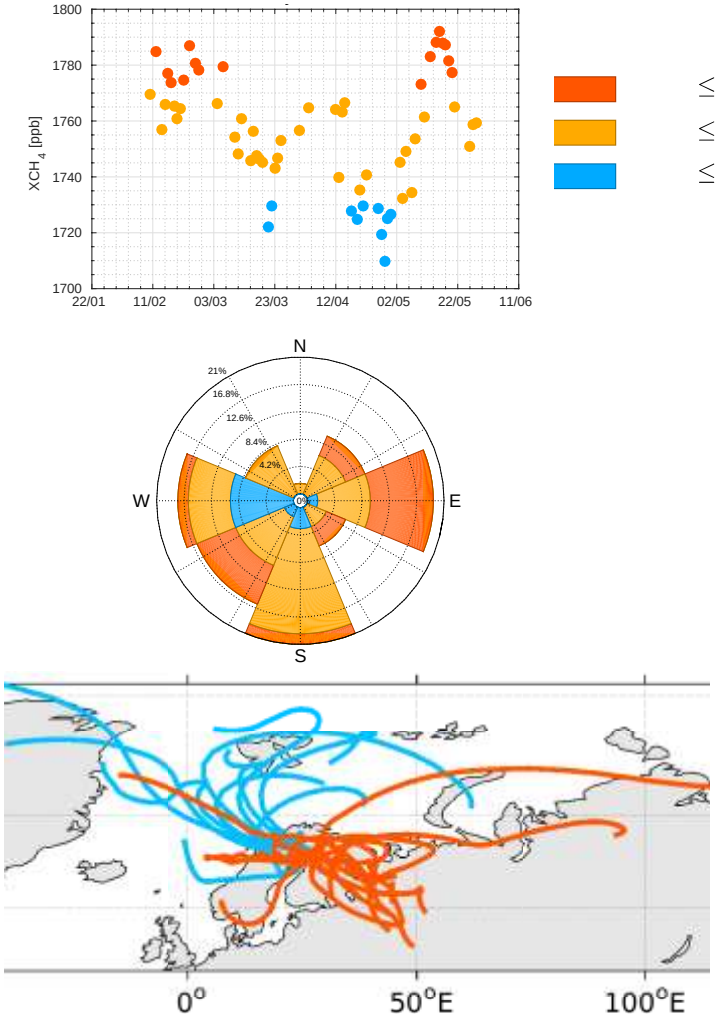
95% Posterior
Prior mean
AirCore
AirCore (smoothed)

TCCON profile retrieval





Methane variability at Sodankylä – the effect of transport



- TCCON retrievals at Sodankylä during spring 2010 show large day-to-day variability.

- Wind direction correlates with the variability: overall, on “low” XCH_4 days the wind is from the west, and on high XCH_4 days, from the east/southeast.

- Backward in time trajectories: low XCH_4 air from the North, high XCH_4 air from Eastern Europe or Russia.

Conclusions

- GOSAT and OCO-2 provide XCO_2 and XCH_4 retrievals also in the Arctic regions.
  - Validation against the Sodankylä TCCON gives promising results.
  - Dimension reduction technique developed for XCH_4 profile retrieval – fully applicable to other gases and satellite retrievals.
- Large solar zenith angles and snow-covered surfaces are problematic in the GHG satellite retrievals in the Arctic.
- Estimation of fluxes is of crucial importance. What can be learned directly from XCO_2 or XCH_4?