Atmospheric CO_2 retrievals from GOSAT TANSO-FTS data

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Outline

Brief summary on the MicroCarb mission
(remember the full presentation of Denis Jouglet on Wed. 29 May)

4A/SWIR Radiative Transfer Code (RTM) and inversion model (1D-var) developed at NOVELTIS (NOV) in Toulouse

TANSO-FTS spectra of GOSAT used for retrievals

Retrieval of aerosols and surface pressure in band B1 of TANSO-FTS

Comparison of NOV retrieved column averaged CO_2 mixing ratio XCO_2 using band B2 with other L2 retrievals

Comparison of the XCO_2 with ground-based TCCON retrievals

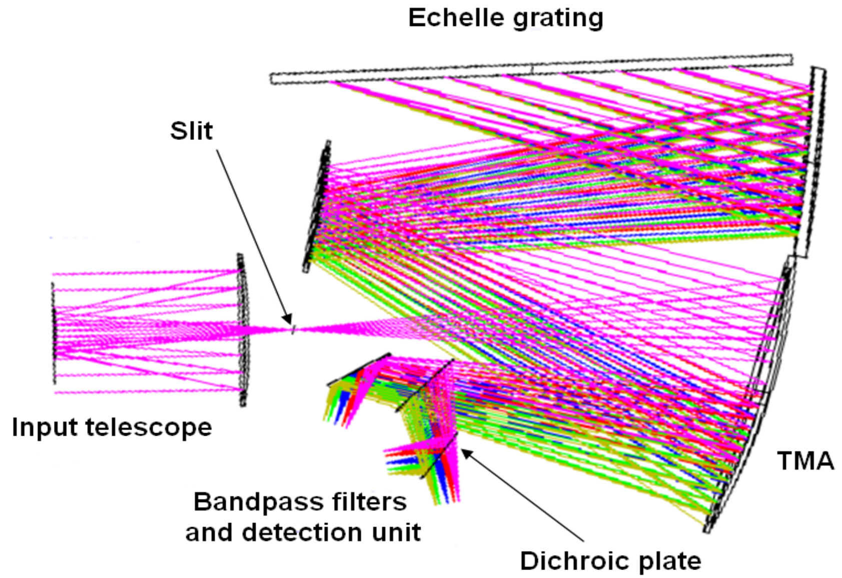
Outlook

The MicroCarb mission

- Satellite mission under phase A study at CNES
  (PI: F.-M. Bréon, LSCE)
- The main objective is to monitor natural CO_2 fluxes at global scale with a spatial resolution of ≈ 500 km
- Measurements similar to those of OCO
  - Limited swath
  - Pixel size ≈ 5 km
  - Main modes of operation are nadir and glint observations
  - Pointing capabilities
  - 3 spectral bands (O_2, weak CO_2, strong CO_2)
  - Performance on XCO_2 better than 1 ppm
- Instrument designed to fit on-board a micro-satellite platform such as Myriade Evolutions of CNES
- Reduced costs of recurrent micro-satellites make it possible to design a series of instruments for increased coverage or long-term monitoring

The MicroCarb concept

- Two industrial phase A studies (TAS and Astrium) in parallel
- Performance analyses have led to the selection of a grating spectrometer concept with a single optical aperture



- Phase A to be concluded by the end of 2013 with a PDR
- Decision to go into phase B not expected before 2014
- Depends on budgetary constraints and on the recommendations resulting from the "CNES Colloque de Prospective" in spring 2014 when priorities will be discussed
- If a positive decision to go into phase B is made, a launch in 2018 can be achieved

Rationale for the study presented here

- To be ready for a launch in 2018, the algorithms for going from level 1 (L1) spectra to retrieved level 2 (L2) products i.e. XCO_2 have to be developed, tested and « industrialized »
- Retrieval simulation studies have been supported by CNES in the framework of the MicroCarb phase A
- However, confronting to real atmospheric spectra was considered to be a priority
- Hence the use of GOSAT TANSO-FTS L1B spectra

4A/SWIR Radiative Transfer Code (RTM)

- CNES is supporting NOVELTIS for developing and maintaining the 4A/OP radiative transfer model (RTM) in cooperation with LMD (the group that initially developed STRANSAC and 4A)
- The 4A/OP model is used extensively in the TIR (absorption, emission) by CNES for IASI (hence OP for operational) and for preparing IASI-NG
- CNES has been supporting NOVELTIS to extend 4A/OP into the SWIR (including scattering and solar lines) for the preparation of MicroCarb with scientific guidance from IPSL (F.-M. Bréon and C. Camy-Peyret)
- The corresponding forward model code is known as 4A/SWIR

Inversion model (1D-var)

- NOVELTIS has developed a generic inverse model called 1D-var for atmospheric retrievals
- CNES is developing an in house retrieval code for MicroCarb called 4ARTIC based on 4A/SWIR
- Comparisons of 4A/SWIR+1D-var and 4ARTIC have been performed for the cross-validation of simulated retrievals

→ Inversions using TANSO-FTS spectra were deemed necessary as an additional check of the capabilities of 4A/SWIR+1D-var to cope with real spectra

→ Hence the use of the corresponding RTM and inverse model to test retrievals of XCO_2 from TANSO-FTS with 4A/SWIR+1D-var

Processing chain for TANSO-FTS spectra

- Direct forward Radiative Transfert Model : 4A/SWIR (version SWIR of 4A/OP) in the scalar mode (spectra and Jacobians) including scattering and appropriate ILS

- Extraction of TANSO-FTS spectra: from the GUIG or from Ether (which has a direct link with JAXA) followed by conversion from hdf to ASCII files including the necessary information (time, location, geometry for each IFOV)

- Spectral calibration : based on a best correlation method between the raw L1B TANSO-FTS (separately for P and S spectra) and a simulated spectrum using appropriate observation geometry and meteorological information

- Inversion : 1D-var tool:
  - based on the optimal estimation method (OEM) (Rodgers) for inverse non-linear problems using the Levenberg-Marquardt algorithm
  - information content analysis (DOFS, Averaging Kernels *i.e.* AK, error analysis from the uncertainties in the observation vector and propagation to the state vector)
  - Iterative retrieval for atmospheric profiles and surface properties

Parameterization of the radiatif transfer

- Band B1
  - Limitation of the band B1 to the band of MicroCarb [13000-13100] cm^{-1}
  - Rayleigh scattering taken into account
  - Need to reduce the computing time (inversions in the « scattering » mode for 3 types of aerosols)
  - Limitation of the domain of the instrument function : ±25 cm^{-1} for S spectra (±10 cm^{-1} for P spectra → this was for test purposes and sould have been changed in the systematic retrievals)
  - Computing step: 0.02 cm^{-1} (1/20 of the FWHM of the ILS)
  - Computing time for 1 spectrum : iterative inversion ~ 30 min (x3) = 1.5 hr

- Band B2
  - Rayleigh scattering effect negligible
  - Useful B2 band covered [6150-6400] cm^{-1}
  - One single inversion in the « scattering » mode with the aerosol type determined in B1
  - Limitation of the domain of the instrument function: ±25 cm^{-1} for S spectra
  - Computing step : 0.005 cm^{-1} (1/50 of the FWHM of the ILS)
  - Computing time for 1 spectrum : iterative inversion ~ 3-4 hr

Test cases for aerosols

20 spectra simulated for MicroCarb (band 1 and 2) calculated for 20 scenes obtained by combining 4 cas geophysical cases and 5 aerosol types

4 geophysical cases

Name	Description	Solar zenith angle (SZA)	Albedo	P_s	Atmosphere
Case 1	reference	30°	vegetation	standard	warm-humid
Case 2	impact of SZA	60°	vegetation	standard	warm-humid
Case 3	impact of high albedo	30°	desert	standard	warm-humid
Case 4	impact of low albedo	30°	dark surface	standard	warm-humid

5 types of aerosols

Name	Description	Altitude	AOT(0.55 µm)	AOT(0.75 µm)	AOT(1.6 µm)
A0C2	high altitude cirrus	13 km	0.4	0.40	0.41
A3C0	continental pollution mixture	1-3 km	0.5	0.32	0.09
A4C0	desert dust mixture	4-6 km	0.3	0.29	0.26
A5C0	maritime tropical mixture	0-1 km	0.3	0.30	0.25
A3C2	mixture of continental pollution + cirrus	1-3 km and 9 km	0.9	0.72	0.50

Retrieval of the aerosol optical depth (AOT) in B1 (0.75 mm)

Name	Description	Altitude
A0C1	high altitude cirrus (CIR100)	10 km
A1C0	desert dust (MITR)	5 km
A2C0	continental pollution (WASO)	1.5 km

3 types of retrieved aerosol

Tests of the AOT retrieval in B1

« true » aerosol

Name	Description	Altitude
A0C2	high altitude cirrus	13 km
A3C0	continental pollution mixture	**1-3 km**
A4C0	desert dust mixture	**4-6 km**
A5C0	maritime tropical mixture	**0-1 km**
A3C2	mixture of continental pollution + cirrus	**1-3 km et 9 km**

retrieved aerosol

Nom	Description	Altitude
A0C1	high altitude cirrus **(CIR100)**	**10 km**
A1C0	desert dust **(MITR)**	**5 km**
A2C0	continental pollution **(WASO)**	**1.5 km**

(-) ≡ non convergence
(*) ≡ slow convergence

→ The aerosol type is generally well determined using B1 whatever the geophysical case

"true" aerosol type	"true" AOT in B1	type of retrieved aerosol	AOT retrieved in B1	χ^2_y
A0C2	0.4	A0C1	0.554	1.25
		A1C0	1.550	5.074
		A2C0	-	-
A3C0	0.32	A0C1	0.072	3.299
		A1C0	0.219	1.581
		A2C0	0.468	1.260
A4C0	0.29	A0C1	0.139	2.541
		A1C0	0.329	0.974
		A2C0	0.440	2.419
A5C0	0.3	A0C1	0.037	1.681
		A1C0	-	-
		A2C0	0.180	1.243
A3C2	0.72	A0C1	0.331	2.173
		A1C0	0.900	1.544
		A2C0	-	-

case 1

"true" aerosol type	"true" AOT in B1	type of retrieved aerosol	AOT retrieved in B1	χ^2_y
AOC2	0.4	A0C1	0.521	2.145
		A1C0	-	-
		A2C0	-	-
A3CO	0.32	A0C1	0.014	0.584
		A1C0	0.048	0.531
		A2C0	1.042	0.479
A4CO	0.29	A0C1	0.107	0.990
		A1C0	0.305	0.491
		A2CO	2.258	2.256
A5CO	0.3	AOC1	-	-
		A1CO	-	-
		A2CO	0.833	0.736
A3C2	0.72	AOC1	0.367	1.037
		A1C0	0.905	4.921
		A2C0	-	-

case 2

"true" aerosol type	"true" AOT in B1	type of retrieved aerosol	AOT retrieved in B1	χ^2_y
A0C2	0.4	A0C1	0.554	1.259
		A1C0	1.560	5.153
		A2C0	-	-
A3C0	0.32	A0C1	0.074	3.354*
		A1C0	0.221	1.592
		A2C0	0.470	1.270
A4C0	0.29	A0C1	0.141	2.595
		A1C0	0.330	0.983
		A2C0	0.444	2.433
A5C0	0.3	A0C1	0.037	1.700
		A1C0	-	-
		A2C0	0.179	1.238
A3C2	0.72	A0C1	0.331	2.238
		A1C0	0.902	1.540
		A2C0	-	-

case 3

"true" aerosol type	"true" AOT in B1	type of retrieved aerosol	AOT retrieved in B1	χ^2_y
A0C2	0.4	A0C1	0.514	0.927
		A1C0	-	-
		A2C0	-	-
A3C0	0.32	A0C1	0.022	0.265
		A1C0	-	-
		A2C0	1.048	2.926
A4C0	0.29	A0C1	0.128	0.550
		A1C0	0.314	0.256
		A2C0	-	-
A5C0	0.3	A0C1	-	-
		A1C0	-	-
		A2C0	-	-
A3C2	0.72	A0C1	0.382	0.497
		A1C0	0.756	2.304
		A2C0	-	-

case 4

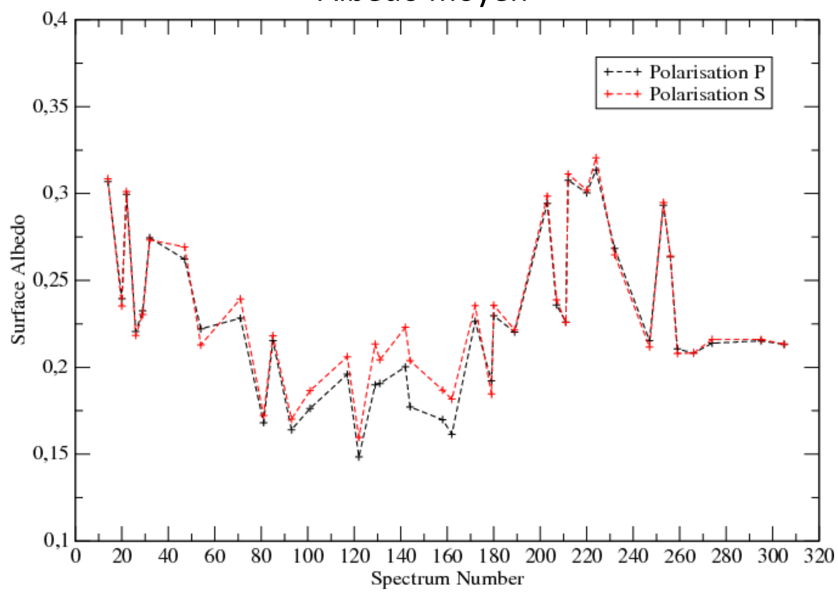
Detection method in B1 for the aerosols

- Based on the analysis of the inversion retrievals : test of χ^2_y
- Reference inversion (Ref) without aerosol AOT : simultaneous inversion of surface albedo (mean + slope) and of surface pressure
- The *a priori* surface pressure is extracted from NCEP (GFS model) : *a priori* error fixed to 5 hPa
- Inversion of the AOT for 3 types of aerosol (cirrus, desert dust and continental pollution) $\rightarrow$ 3 separate inversions
- If χ^2_y is reduced (as compared to Ref) $\rightarrow$ aerosol detected
- The smallest χ^2_y is determining the aerosol type
- The corresponding retrieved AOT is used (transported through the RTM model) for the retrieval of CO_2 in B2

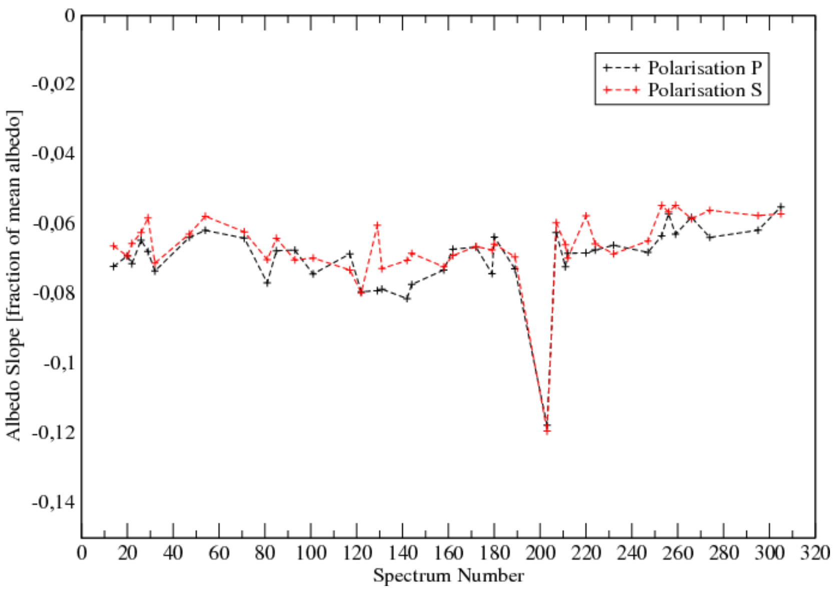
Mean albedo and slope in B1

- IFOVs around the Orléans TCCON site (distance < 130 km)
- Reference inversion
- Differences between P and S spectra
- Significant variations of the surface albedo in space and time

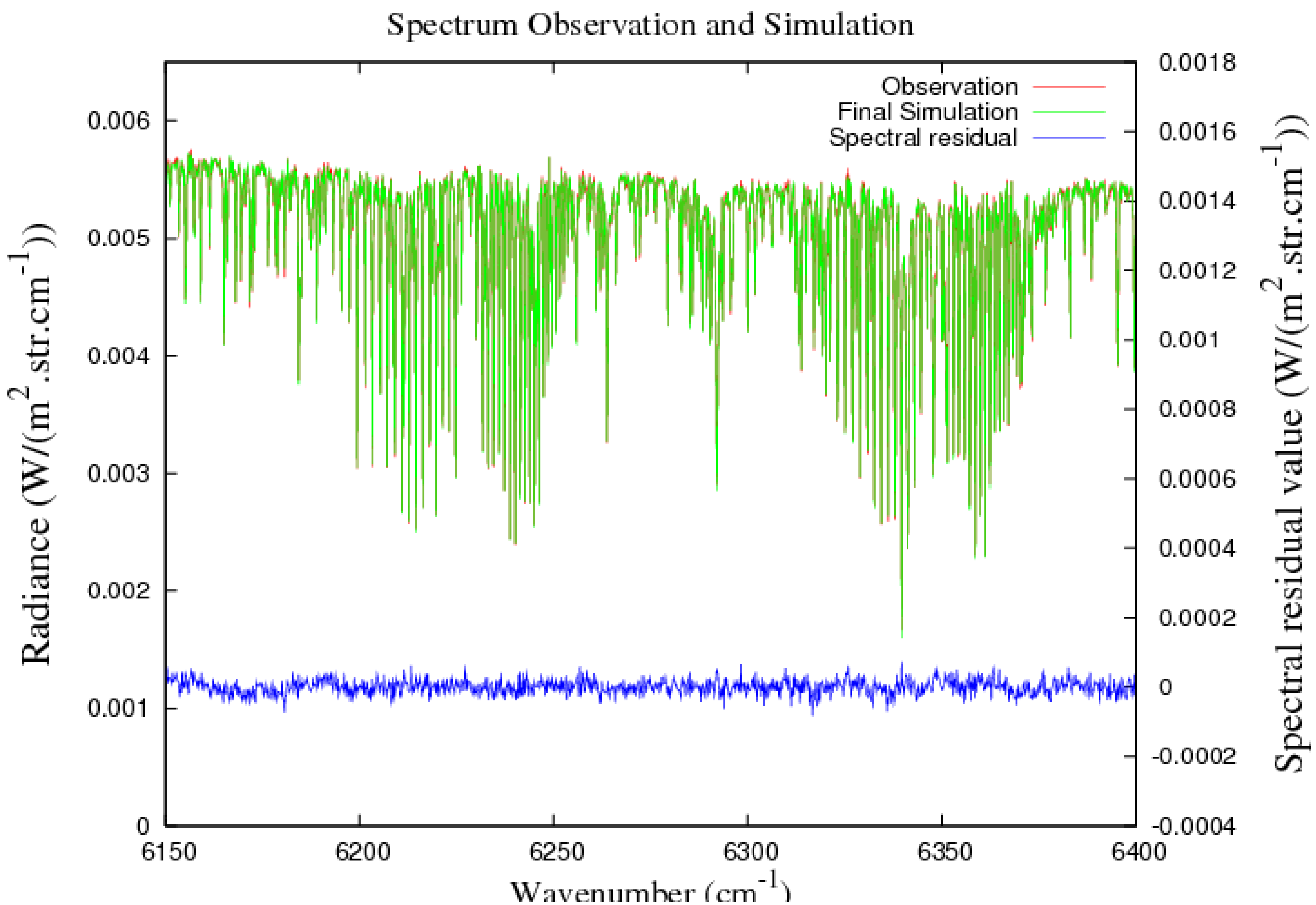
Albédo moyen



Pente



Retrievals in B2 using the tools developed at NOVELTIS: 4OP/SWIR+1D-var



Inter-comparison of the XCO_2 products

Selection and filtering of the different data sets used for the retrievals

Spectra/data used for the comparaison : TCCON and NOV, ULe EOS, SRON/KIT, NIES, ACOS (initially chosen within the SCORE-MIP exercise)

TCCON

time of GOSAT overpass ± 10 min
errorr < 1.5 ppmv, flag_quality = 0

NOV

Prefiltering with simple B4 cloud/aerosol detection scheme (J. Bureau /C. Camy-Peyret)

Nb of iterations ≤ 3

Error on CO_2 < 2 ppmv, $\chi^2_y < 0.8$

Correction with proxy < 1 % ($\Delta P_{surf} \leq 10$ hPa)

ULe EOS v3.0

AOT < 0.06

flag_quality = 0 ($\chi^2_y < 1$, # iter ≤ 3, AOT+COD < 0.3, error CO_2 < 1.2 ppmv)

SRON/KIT (RemoTeC) v2.0

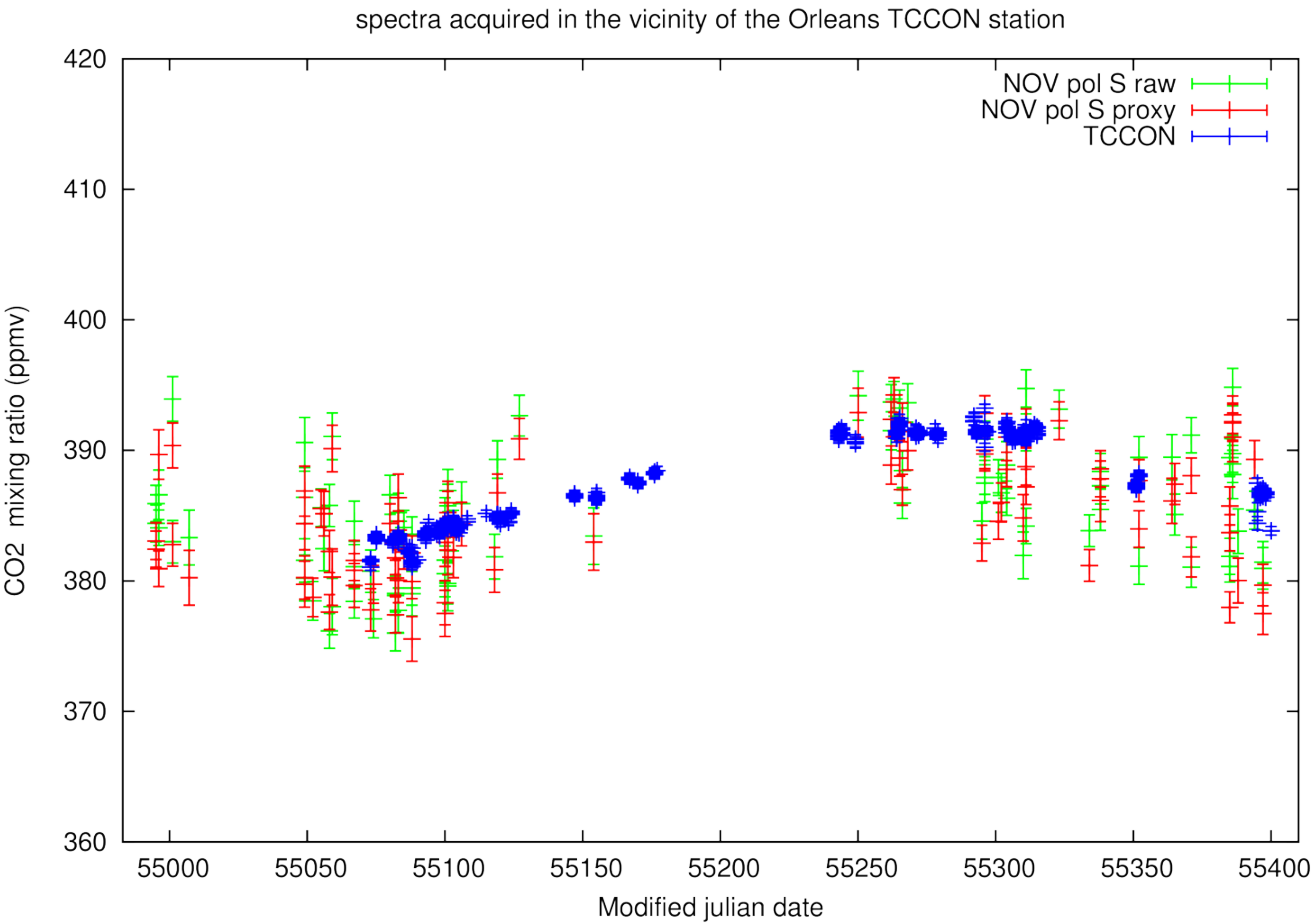
flag_quality = GOOD

NIES L1B v140.141 for spectra and L2, v2.00 for XCO_2

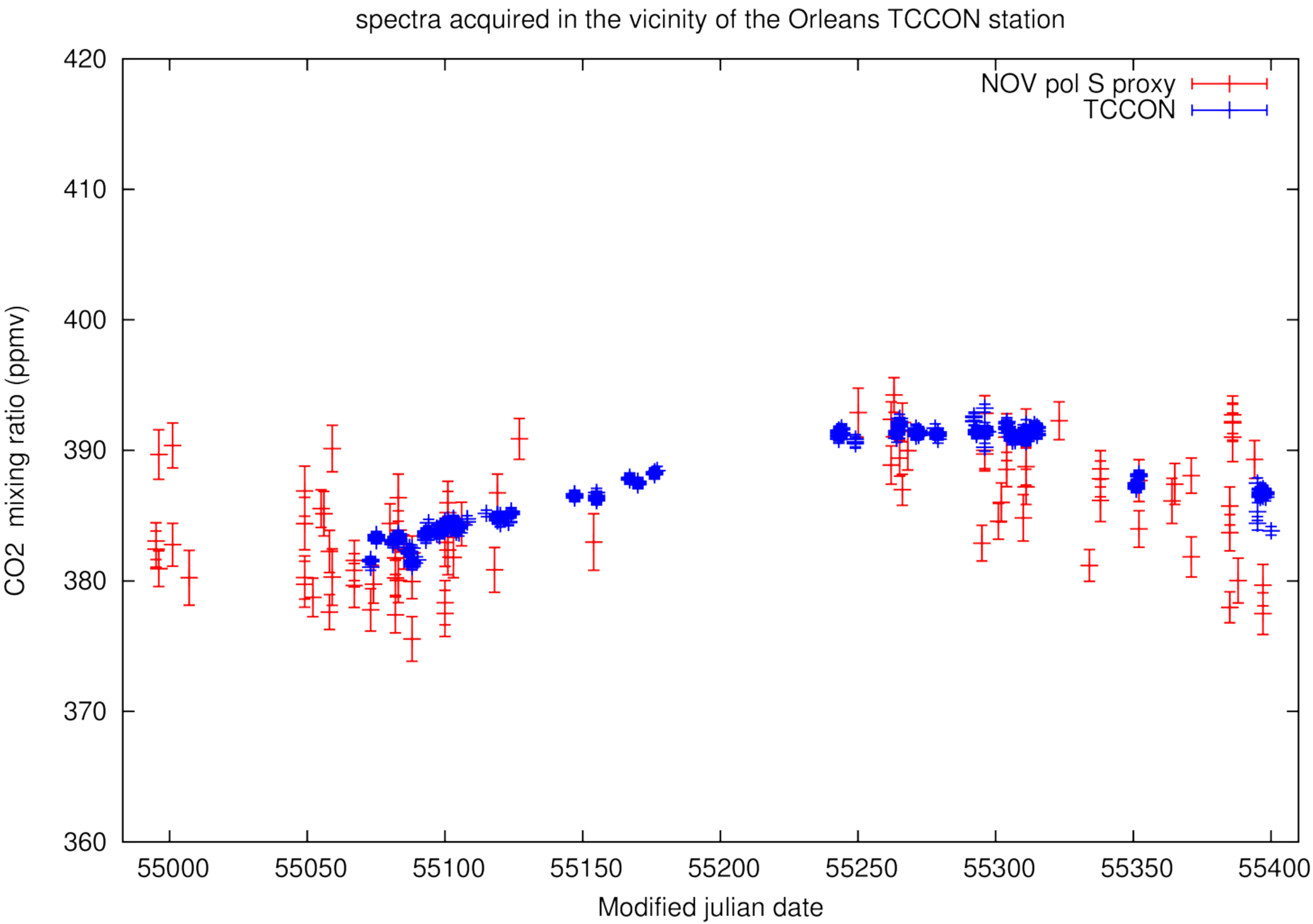
in the vicinity of the TCCON sites, extracted from GUIG and/or ETHER

ACOS vB2.9

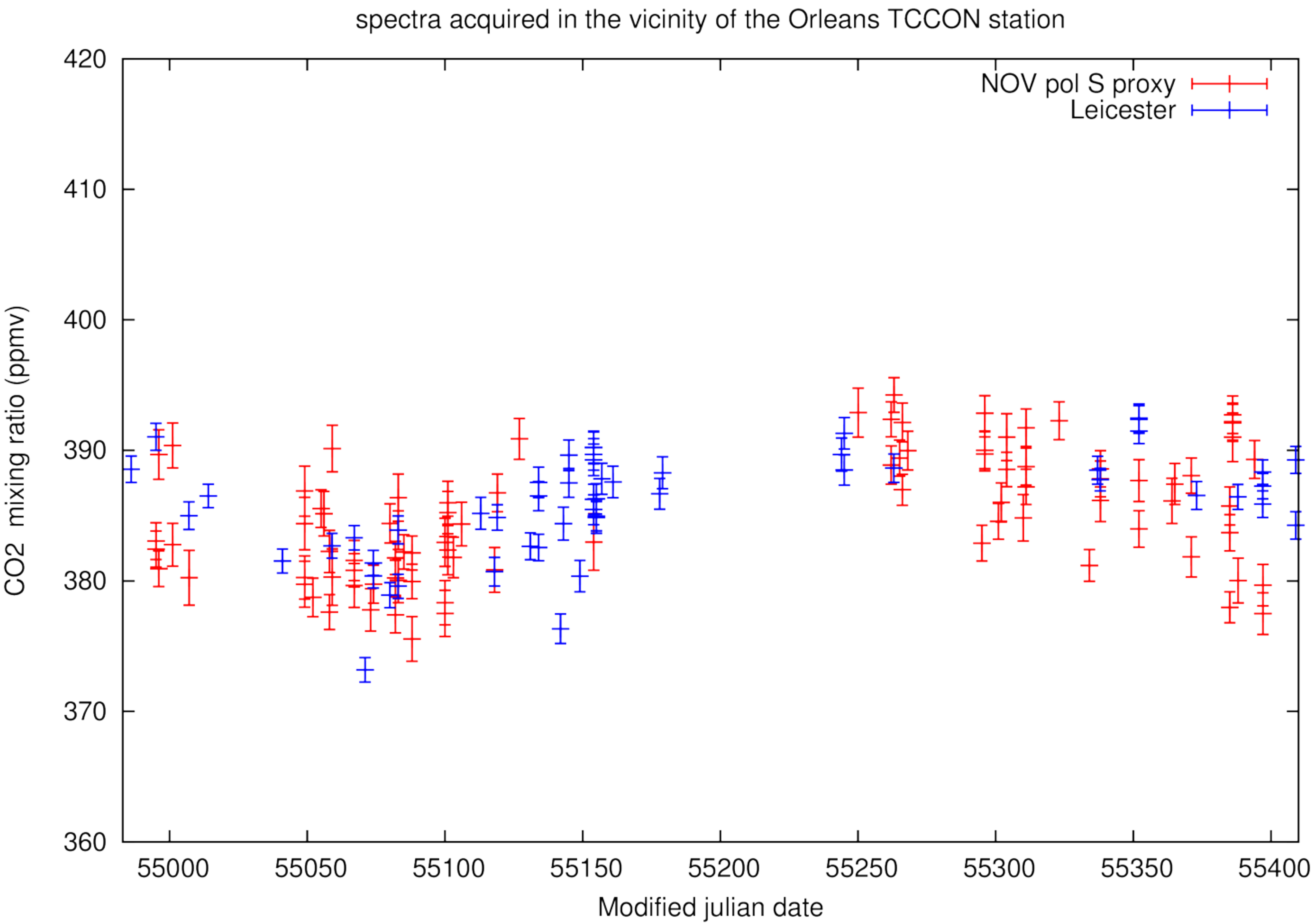
flag_quality =0



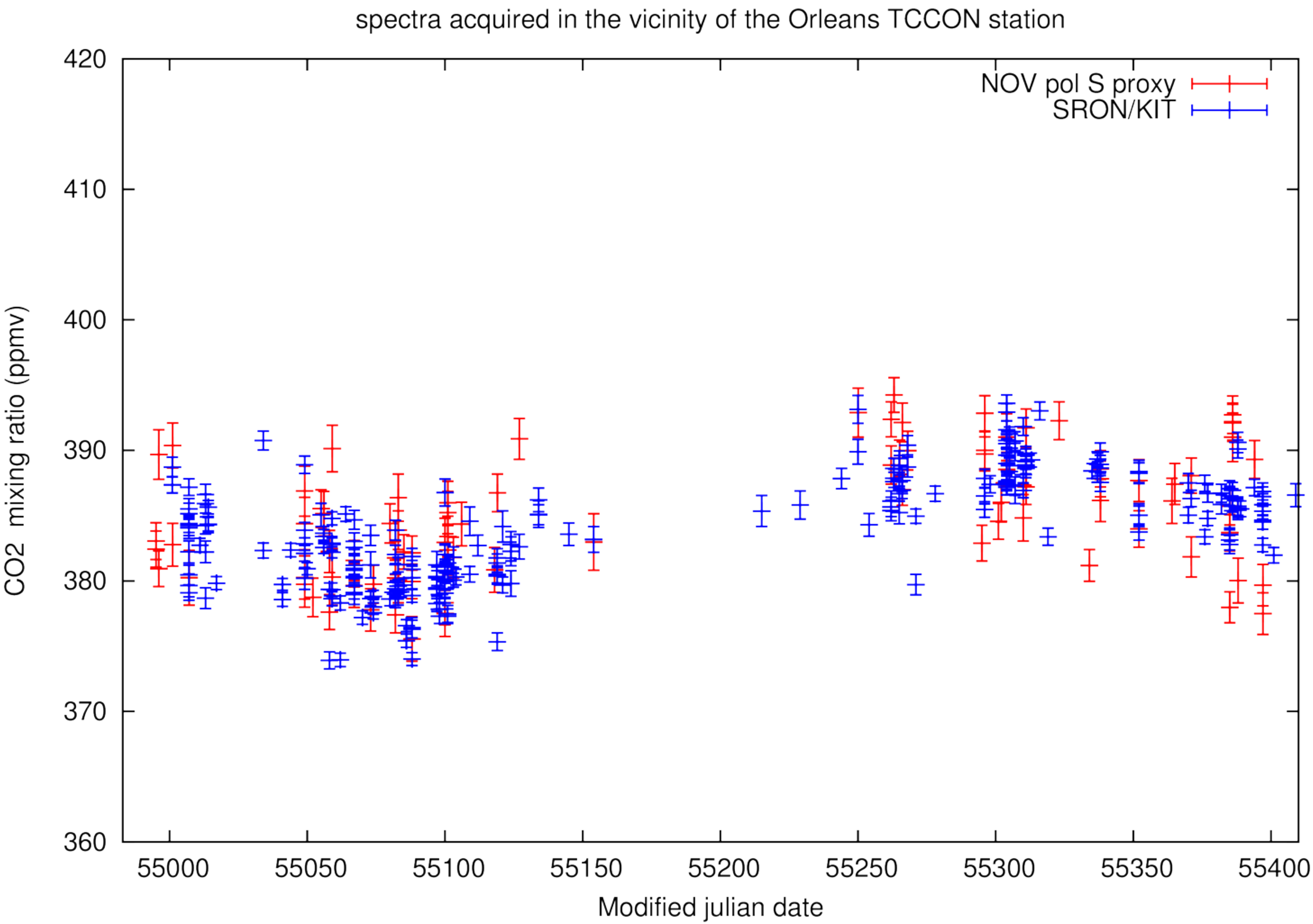
spectra acquired in the vicinity of the Orleans TCCON station
NOV pol S raw
NOV pol S proxy
TCCON
CO2 mixing ratio (ppmv)
Modified julian date
420
410
400
390
380
370
360
55000
55050
55100
55150
55200
55250
55300
55350
55400



spectra acquired in the vicinity of the Orleans TCCON station
NOV pol S proxy
TCCON
CO2 mixing ratio (ppmv)
420
410
400
390
380
370
360
55000
55050
55100
55150
55200
55250
55300
55350
55400
Modified julian date



spectra acquired in the vicinity of the Orleans TCCON station
NOV pol S proxy
Leicester
CO2 mixing ratio (ppmv)
Modified julian date
420
410
400
390
380
370
360
55000
55050
55100
55150
55200
55250
55300
55350
55400


spectra acquired in the vicinity of the Orleans TCCON station
NOV pol S proxy
SRON/KIT
CO2 mixing ratio (ppmv)
Modified julian date
420
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55150
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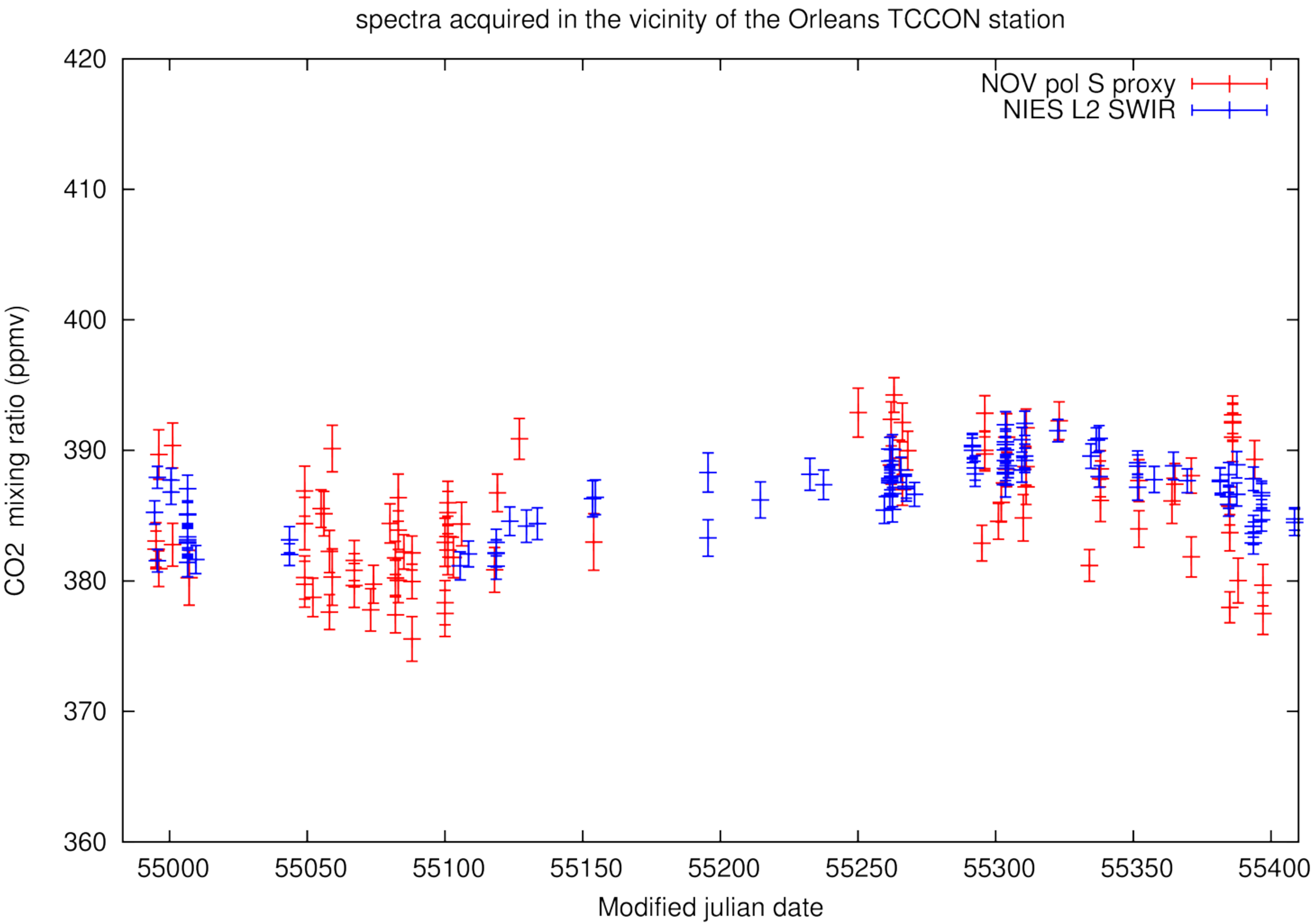
spectra acquired in the vicinity of the Orleans TCCON station
NOV pol S proxy
NIES L2 SWIR
CO2 mixing ratio (ppmv)
Modified julian date
420
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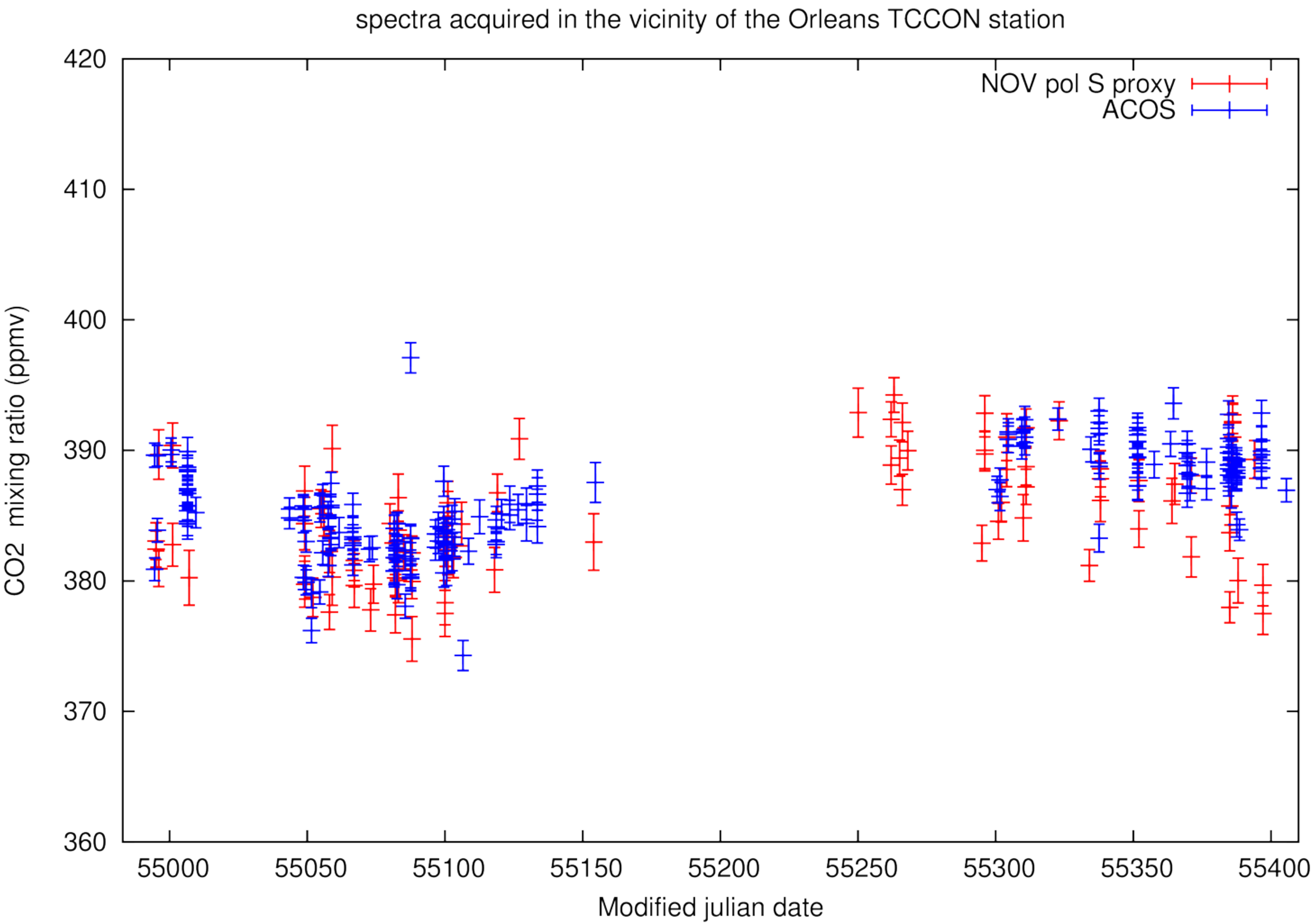
390
380
370
360
55000
55050
55100
55150
55200
55250
55300
55350
55400



spectra acquired in the vicinity of the Orleans TCCON station
NOV pol S proxy
ACOS
CO2 mixing ratio (ppmv)
Modified julian date
420
410
400
390
380
370
360
55000
55050
55100
55150
55200
55250
55300
55350
55400

Differences in the XCO_2 retrievals (all in ppm)

nb= number of coincident retrievals (IFOVs in the vicinity of TCCON stations the same day/time)
bias=mean(retrieval – NOVELTIS) for **NOV S spectra**
stdev=standard deviation around the mean

Orléans

```
Leicester - NOV nb= 15 bias= 1.24 stdv=4.64
SRON/KIT  - NOV nb= 85 bias= 0.41 stdv=2.27
NIES(L2)  - NOV nb=  9 bias= 2.03 stdv=3.31
ACOS B2.9 – NOV nb= 19 bias= 2.69 stdv=4.13
```

Lamont

```
Leicester - NOV nb= 27 bias=-0.73 stdv=4.75
SRON/KIT  - NOV nb=153 bias= 0.22 stdv=1.98
NIES(L2)  - NOV nb= 10 bias= 1.91 stdv=2.76
ACOS B2.9 – NOV nb= 15 bias= 2.19 stdv=3.71
```

Darwin

```
Leicester - NOV nb= 45 bias=-1.98 stdv=2.13
SRON/KIT  - NOV nb=150 bias= 0.27 stdv=1.80
NIES(L2)  - NOV nb= 52 bias=-2.16 stdv=2.53
ACOS B2.9 – NOV nb= 86 bias=-0.62 stdv=2.42
```

NOVELTIS S spectra retrievals are in very good agreement with SRON/KIT

All retrievals are quite consitent (no bias correction applied)

Standard deviation of the mean differences consistent with the RSS of the *a posteriori* retrieval errors of each retrieval

<bias>=0.43
<stdv>=3.04

Differences of the retrieved XCO_2 (5 algorithms) with respect to TCCON (all in ppm)

nb= number of coincident retrievals (IFOVs in the vicinity of TCCON stations the same day)
bias=mean(retrieval – TCCON) for **S spectra**
stdv=standard deviation around the mean

Orléans

Leicester	- TCCON	nb= 7	bias=-0.89	stdv=1.94
SRON/KIT	- TCCON	nb= 25	bias=-1.63	stdv=1.72
NIES(L2)	- TCCON	nb= 9	bias=-1.86	stdv=1.64
NOV	- TCCON	nb= 14	bias=-2.54	stdv=2.55
ACOS B2.9	– TCCON	nb= 14	bias= 0.17	stdv=1.50

Lamont

Leicester	- TCCON	nb= 27	bias=-1.48	stdv=3.77
SRON/KIT	- TCCON	nb= 96	bias=-0.75	stdv=1.64
NIES(L2)	- TCCON	nb= 28	bias=-2.41	stdv=1.21
NOV	- TCCON	nb= 44	bias=-1.06	stdv=2.71
ACOS B2.9	– TCCON	nb= 26	bias=-1.22	stdv=2.04

Darwin

Leicester	- TCCON	nb= 18	bias=-0.97	stdv=2.70
SRON/KIT	- TCCON	nb= 20	bias=-1.13	stdv=1.52
NIES(L2)	– TCCON	nb= 10	bias=-2.94	stdv=0.93
NOV	- TCCON	nb= 11	bias= 0.89	stdv=2.60
ACOS B2.9	– TCCON	nb= 13	bias=-1.19	stdv=0.68

Negative bias for (almost) all GOSAT retrievals with respect to TCCON

The stdv is consistent with the combined RSS of the retrieval errors and of those of TCCON data

<bias>=-1.27
<stdv>= 1.94

To understand better the (small) differences

One should compare more precisely the effect of the different filters on the retrieved XCO_2 applied by each group → choose IFOVs common to all retrievals

The comparison of retrieved XCO_2 should be performed on exactly the same IFOVs
Exact time (in s) was used but one has to be careful: difference between the time of the beginning of IGM acquisition and the ZPD time

NOVELTIS will have to confirm the origin of the small negative bias on XCO_2 (~1 ppm) for P spectra with respect to S spectra (ILS on a domain +/- 10 cm^{-1} for P instead of +/-25 cm^{-1} for S)

NOV retrievals using S spectra are very consistent with the 4 other retrievals

NOVELTIS has not performed a full aerosol retrieval in B2 (information from the aerosols retrieved in B1 was used) and the proxy method was applied

Retrievals from the (possibly) « true » combination of P&S spectra should be used by NOVELTIS after proper application of the Müller matrices

Summary

- For preparing the MicroCarb L1 → L2 algorithm, inversions with real data from TANSO-FTS have been performed for GOSAT IFOVs in the vicinity of 3 TCCON sites using 4A/SWIR+1D-var from NOVELTIS
- Comparison of NOV retrievals has been possible with 4 other retrieval algorithms (NIES, ULe, SRON/KIT, ACOS) with in addition TCCON as « truth »
- NOV values of XCO_2 were derived from TANSO-FTS S spectra only accounting for the aerosol type determined in B1 and transferring the AOT from B1 to B2 through the aerosol model
- A proxy method for a residual airmass correction (always smaller than 1%) has been applied
- As much as possible, a careful selection of identical TANSO-FTS IFOVs (or spectra) has been attempted
- Overall good agreement found between the 5 retrievals
- Already identified bias with respect to TCCON
- 4A/SWIR+1D-var (hence 4ARTIC) well validated for further MicroCarb studies

Acknowledgments

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