Use of FORUM for several aspects of atmospheric spectroscopy and climate change issues: link with IASI and IASI-NG

C. Camy-Peyret

IPSL (UPMC/UVSQ) Paris, France <claude.camy-peyret@upmc.fr>

with reference and acknowledgement to the presentation on Wednesday 24 October of Carmine Serio

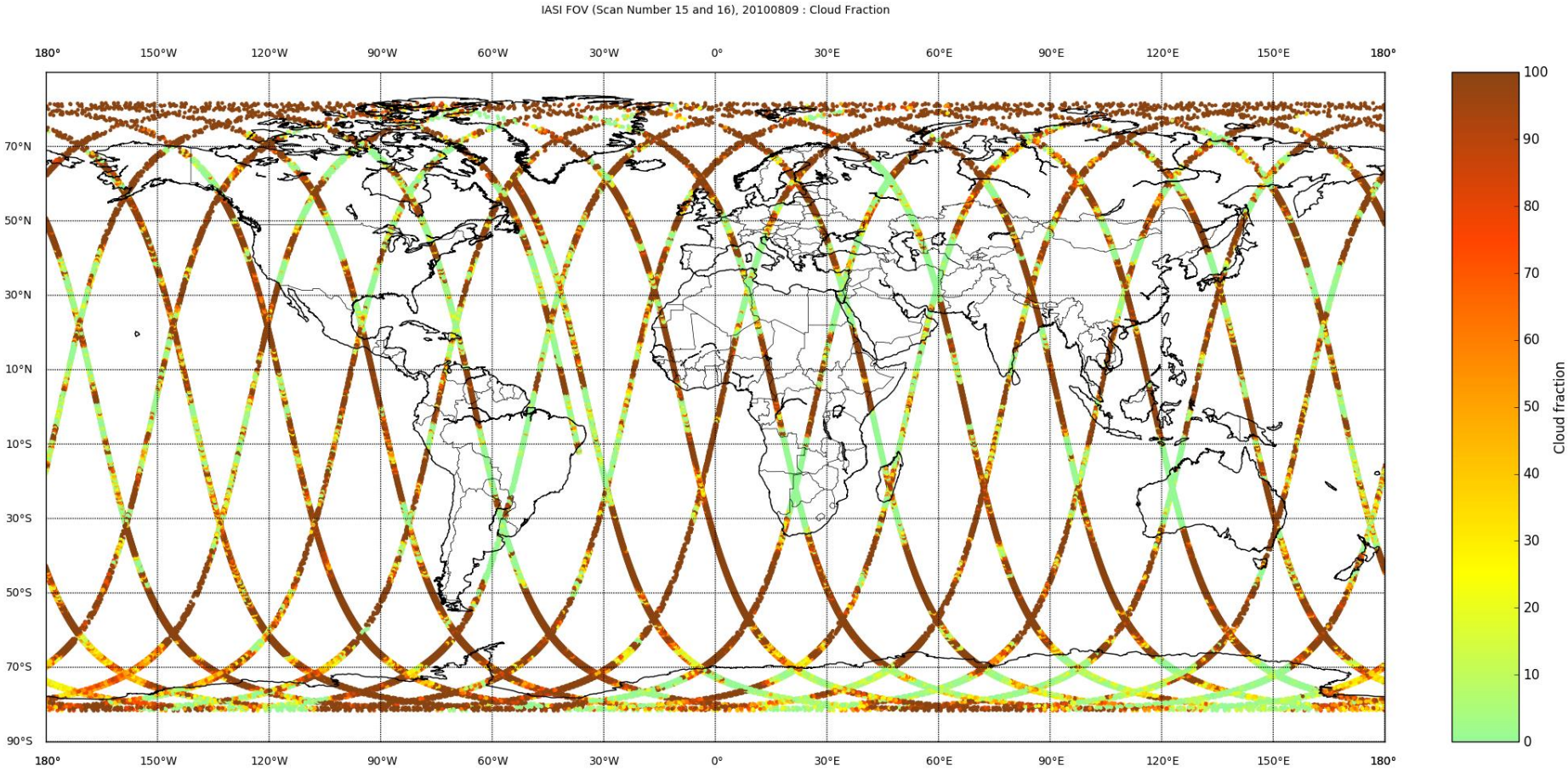
Outline

- Characterisation of IFOVs
- Spectroscopy of species relevant to FORUM
- Arctic Ocean studies in summer with IASI
- Retrieval scheme and sensitivity study as a function of T(z)
- Monthly climatology of XCO_2 and XSF_6 for the 3 summer months using IASIA (2010 to 2017) and IASIB (2013-2017)
- Impact of FIR and TIR sounders for climate studies

Characterisation of the IFOVs
Use of IASI in the context of FORUM

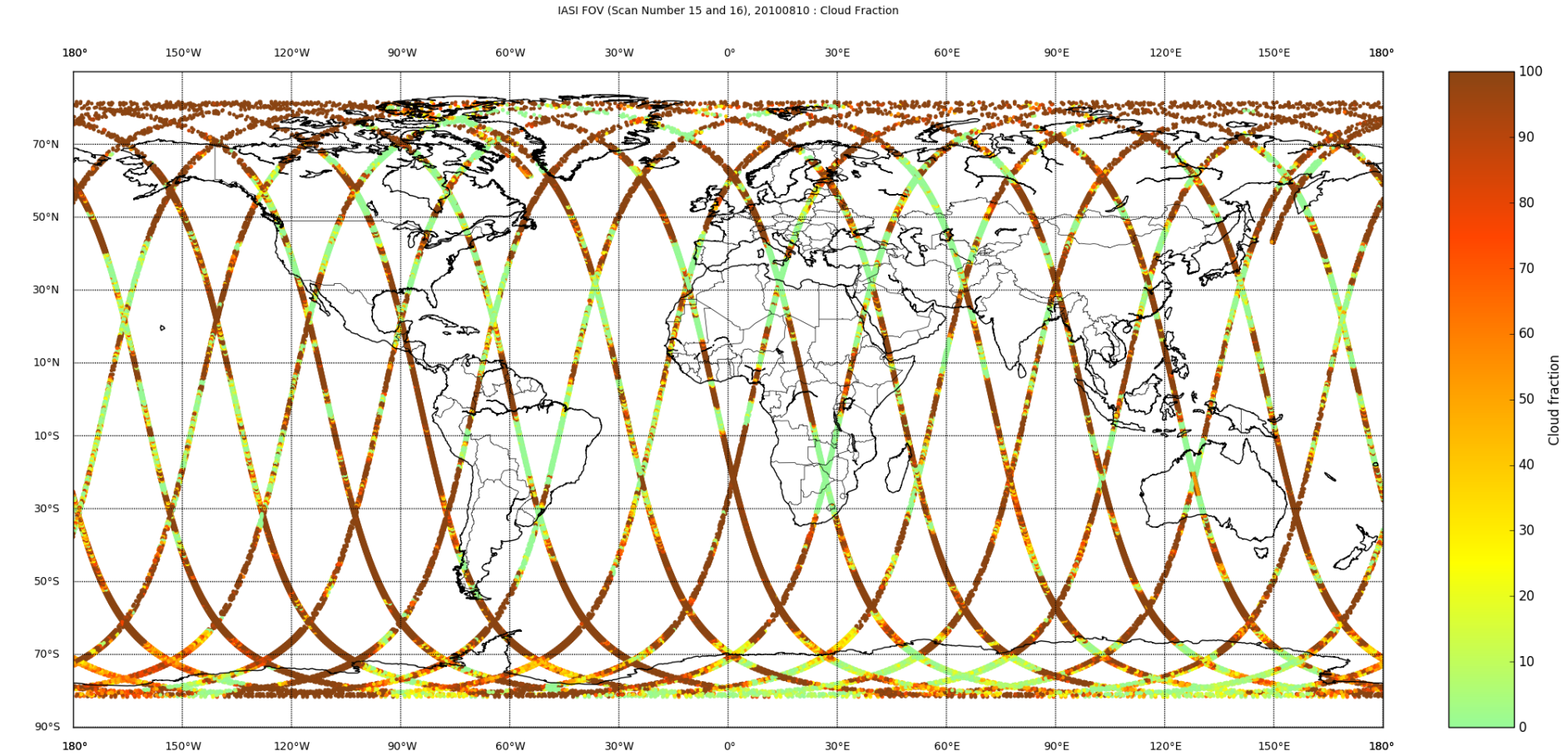
- Exemple of IASI for the cloud fraction statistics
- Fraction of « clear » and (fully) « overcast » IFOVs
- Link with FORUM

Cloud fraction within the IFOVs of IASI-A for nadir SP=[15,16], PN=[1,2,3,4], yyyymmdd=20100809

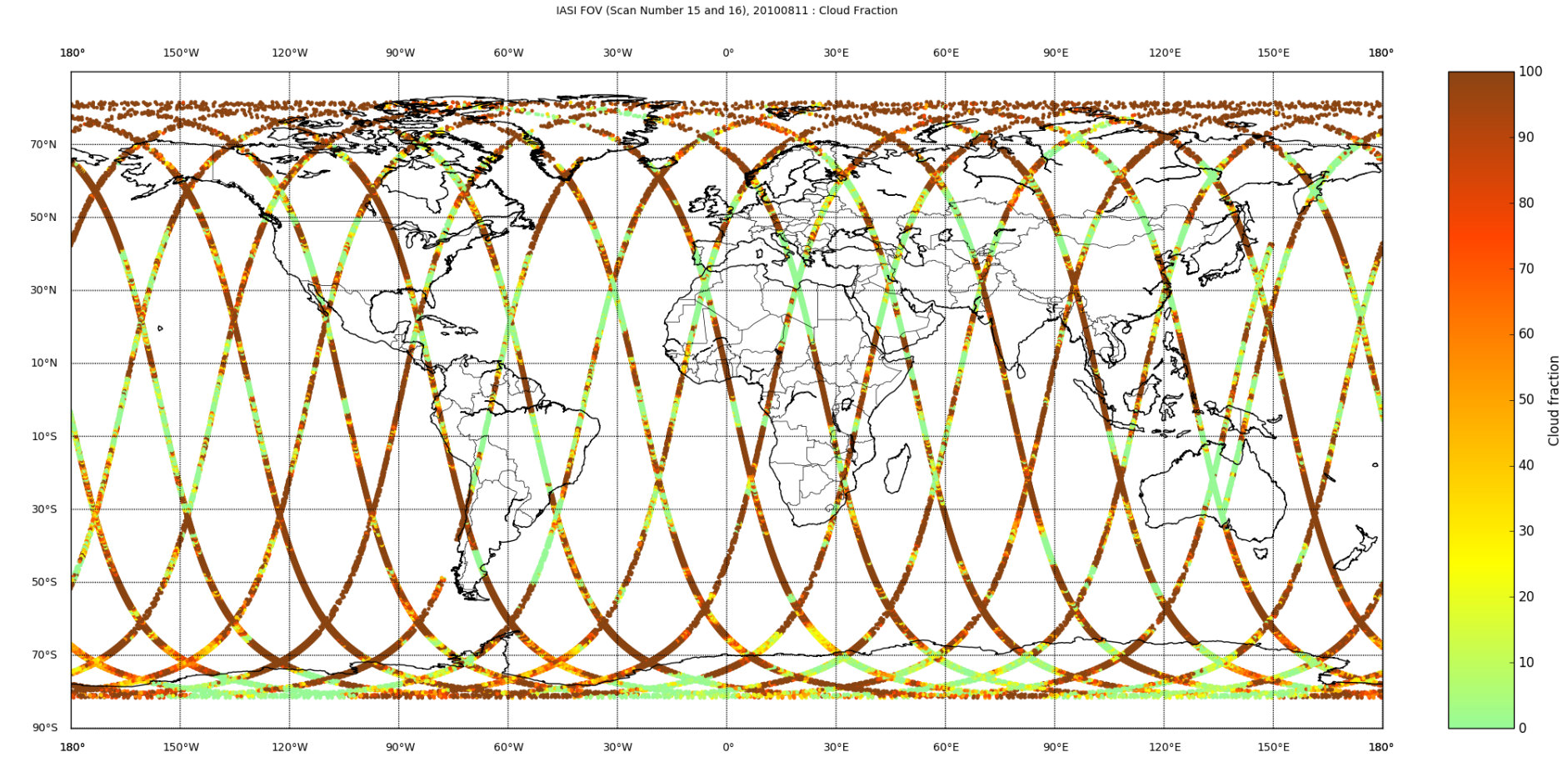


Courtesy: Pascal Prunet, SpasciA

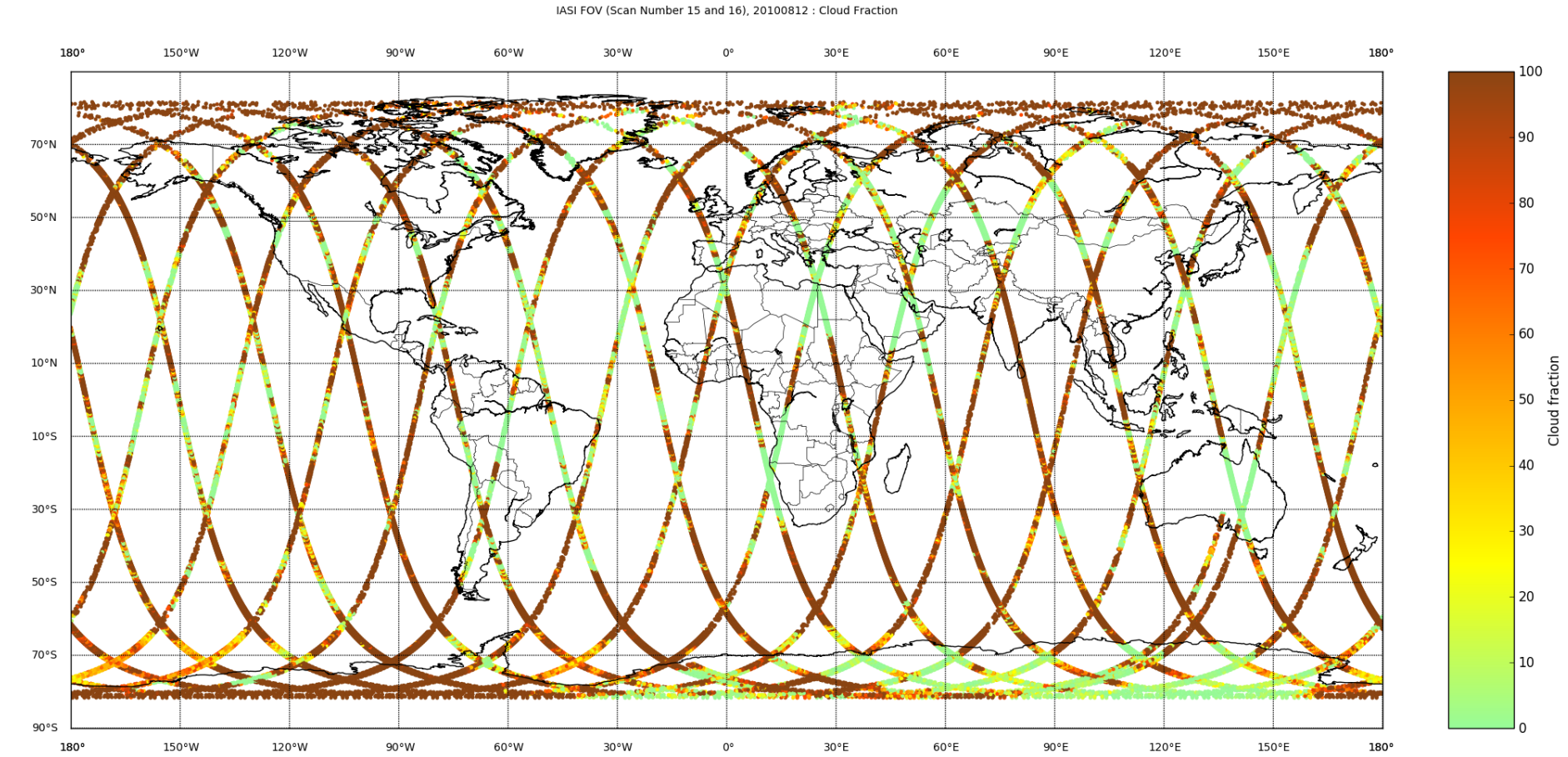
Cloud fraction within the IFOVs of IASI-A for nadir SP=[15,16], PN=[1,2,3,4], yyyymmdd=20100810



Cloud fraction within the IFOVs of IASI-A for nadir SP=[15,16], PN=[1,2,3,4], yyyymmdd=20100811



Cloud fraction within the IFOVs of IASI-A for nadir SP=[15,16], PN=[1,2,3,4], yyyymmdd=20100812



Statistics of cloud fraction within the IFOVs of IASI at nadir for assessing the FORUM case

AVHRR derived cloud fractions within the IASI IFOVs (12 km diameter at nadir) are given as an integer between 0 and 100 in the L1C IASI product (here IASI-A)

Two cases are considered here for yyyymmdd=20100809, total_nb(IFOV)=967064
nadir FORs i.e. SP=[15,16], 4 PN and all FORs i.e. SP=[1;30], 4 PN

	nadir FORs		all FORs	
cld_frc	nb(cld_frc)	%(cld_frc)	nb(cld_frc)	%(cld_frc)
clear	12949	**20.0%**	175626	18.2%
mixed	26221	40.6%	404600	41.8%
overcast	25456	**39.4%**	386838	40.0%
total	64626	100.0%	967064	100.0%

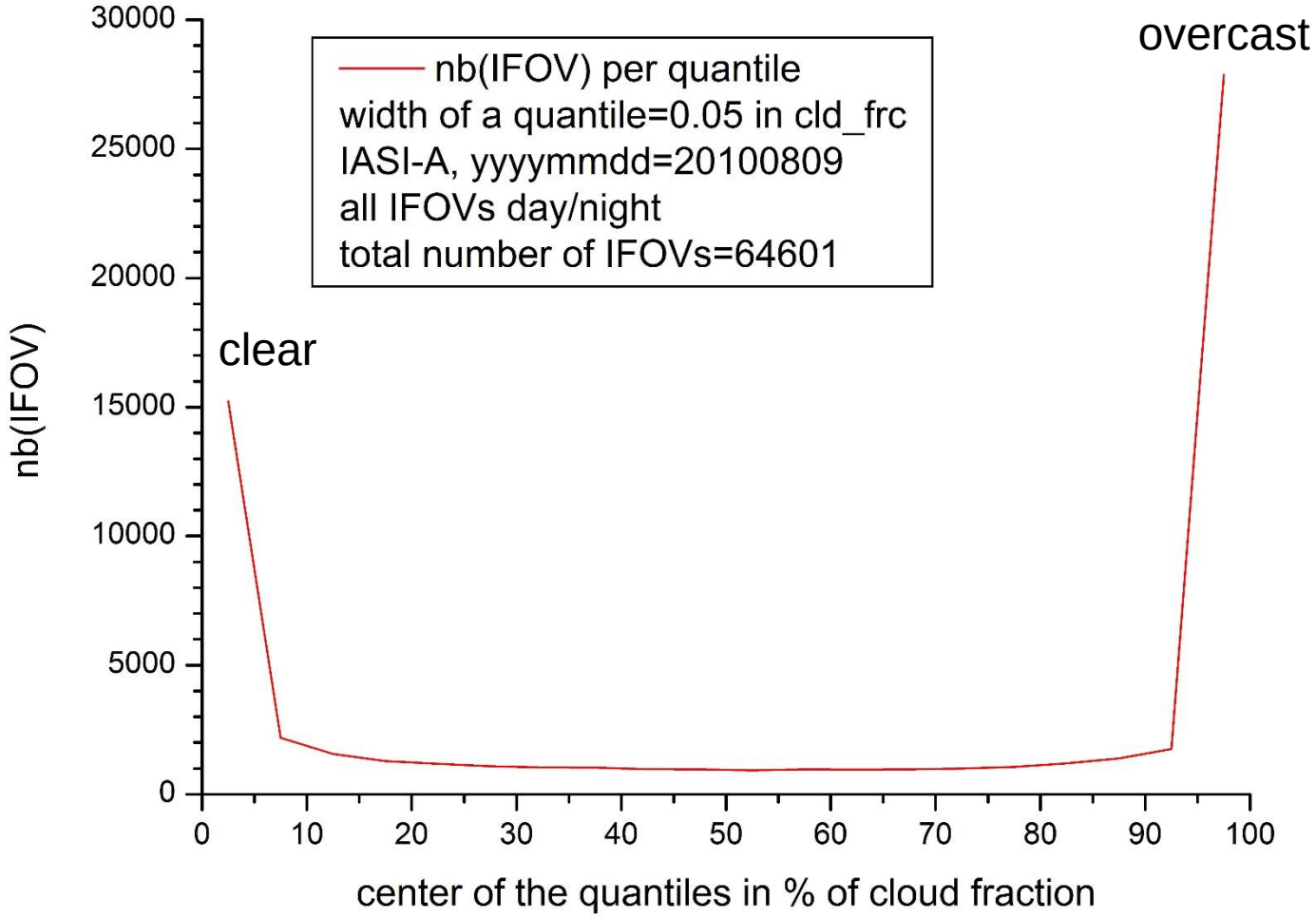
clear cld_frc ≤ 1
overcast cld_frc ≥ 99
mixed 2 ≤ cld_frc ≤ 98

	nadir FORs		all FORs	
cld_frc	nb(cld_frc)	%(cld_frc)	nb(cld_frc)	%(cld_frc)
clear	11517	**17.8%**	155154	16.0%
mixed	28875	44.7%	365739	37.8%
overcast	24234	**37.5%**	446171	46.2%
total	64626	100.0%	967064	100.0%

clear cld_frc = 0
overcast cld_frc = 100
mixed 1 ≤ cld_frc ≤ 99

This statistics is relatively stable in time → **use homogeneous either « clear » or « overcast » IFOVs for reliable retrievals, mixed ones are more complicated**

Statistics of the IASI cloud fraction



IFOVs of IASI-NG and FORUM

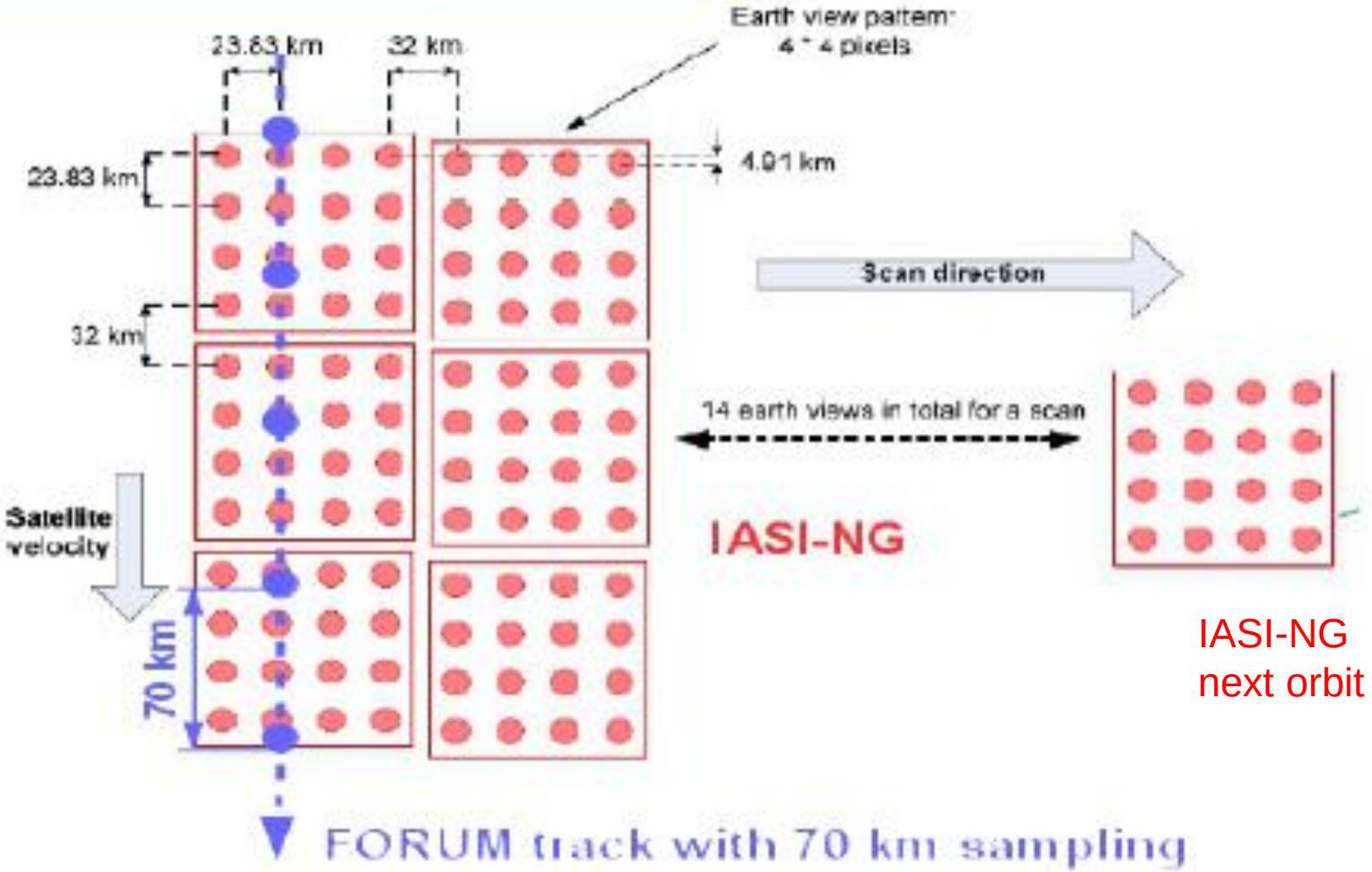


Figure 3.1: IASI-NG anticipated ground footprint and FORUM track

Link with FORUM (1/2)

- The requirement of the proposal is to have a FORUM Embedded Imager (FEI), operating in the thermal infrared (TIR), providing square images sharing the same bore-sight as the FORUM FTS instrument (FFTS) , for scene/cloud identification
- This information would be enough for performing the equivalent of what AVHRR is providing to IASI and/or METimage to IASI-NG
- If downlink of all interferograms is limited, one could perform an on-board analysis of the cloudiness within the FFTS footprint (or footprints if there are several of them)
- One could then select the “clear” and/or fully “overcast” footprints for which the interferograms would be downlinked
- Mixed cloudiness footprints are more difficult to process at L2
- A real-time algorithm for scene characterization has been proposed to ESA in the EE7 framework for TRAQ in the ON TRAQ study

Link with FORUM (2/2)

Quote from the proposal:

- The tandem with Metop-SG mission, necessary for exploiting a synergic use with IASI-NG, requires same polar SSO orbit at 817 km and same Local Solar Time (LST). The FFTS ground footprint must be as close as possible to the IASI-NG footprint. Since IASI-NG is anticipated to cover a very large area at the nadir with almost continuous acquisitions, Figure 3.1, the spatial coincidence is not a stringent requirement provided that the knowledge of the position, within the scene characterised by the imager, is well known.
- The simultaneous analysis using the full spectral coverage provided by the FORUM and IASI-NG missions is planned to be performed only for homogeneous scenes, which are expected to be about 90 % of the cases (as shown by the analysis reported in Section A.7 of Annex A). Therefore a sufficient number of cases is expected to be available without requiring any stringent pointing accuracy. A value of 3 mrad for the pointing accuracy is considered to be sufficient. However a more in-depth study should be preformed during Phase-A to quantify the expected scenes to be used in synergy with IASI-NG given the defined pointing requirements.

Spectroscopy of atmospheric species with FORUM in synergy with IASI

- The main objective of FORUM is quantifying the contribution of the FIR in the Earth radiative balance and H_2O and CO_2 are the driving contributors from 100 cm^{-1} to 1600 cm^{-1} (as covered by FORUM)
- Other species will just be mentioned for their spectroscopic importance: N_2O, HNO_3,

→ See the presentation by Agnès Perrin on HNO_3 and other minor species

- The following slides will briefly cover these two species with some examples from IASI for climate studies

CO_2

- The main contribution of FORUM is to provide a full coverage of the ν_2 band of CO_2 including the P and R branches on both sides of the main Q branch at 667 cm^{-1}
- Several hot bands on the lower wavenumber side have never been covered at high spectral resolution
- The consistency of the T(p) retrievals using only the upper part of this spectral region (IASI and IASI-NG) and retrievals using the full coverage (FORUM) will be a stringent test
- Decoupling T(p) and $x_{CO2}(p)$ would benefit from this
- Line mixing effects in CO_2 begin to be well understood, but FORUM will test an unchartered region
- Non-LTE effects could be detected and quantified during the day

→ See more in the presentation by Carmine Serio on Wednesday

H_2O

- The main contribution of FORUM is to provide a full coverage of the pure rotation band of H_2O
- Line position are known sufficiently well at the resolution of FORUM
- Line broadening parameters (both foreign and self) are calculated and not always measured experimentally
- Their temperature exponent is not well measured nor constrained by the standard line broadening theory
- And we know that water vapour lines are not always following Voigt
- The far wings of the strong lines do contribute significantly
- The MT_CKD continuum is defining a rule to separate the ± 25 cm^{-1} core of the line (described by the usual line-by-line parameters) from the far wings
- A new line shape model (Hartmann and Tran) has been proposed but is not yet coupled to a consistent continuum
- FORUM will be an extremely good instrument to test spectroscopic models of H_2O line shape and continnum

→ See more in the presentation by Elie Mlawer and Ralf Sussmann on Wednesday

→ See more in the presentation by Carmine Serio on Wednesday

Monthly mean spectra
IASI as a possible model for FORUM

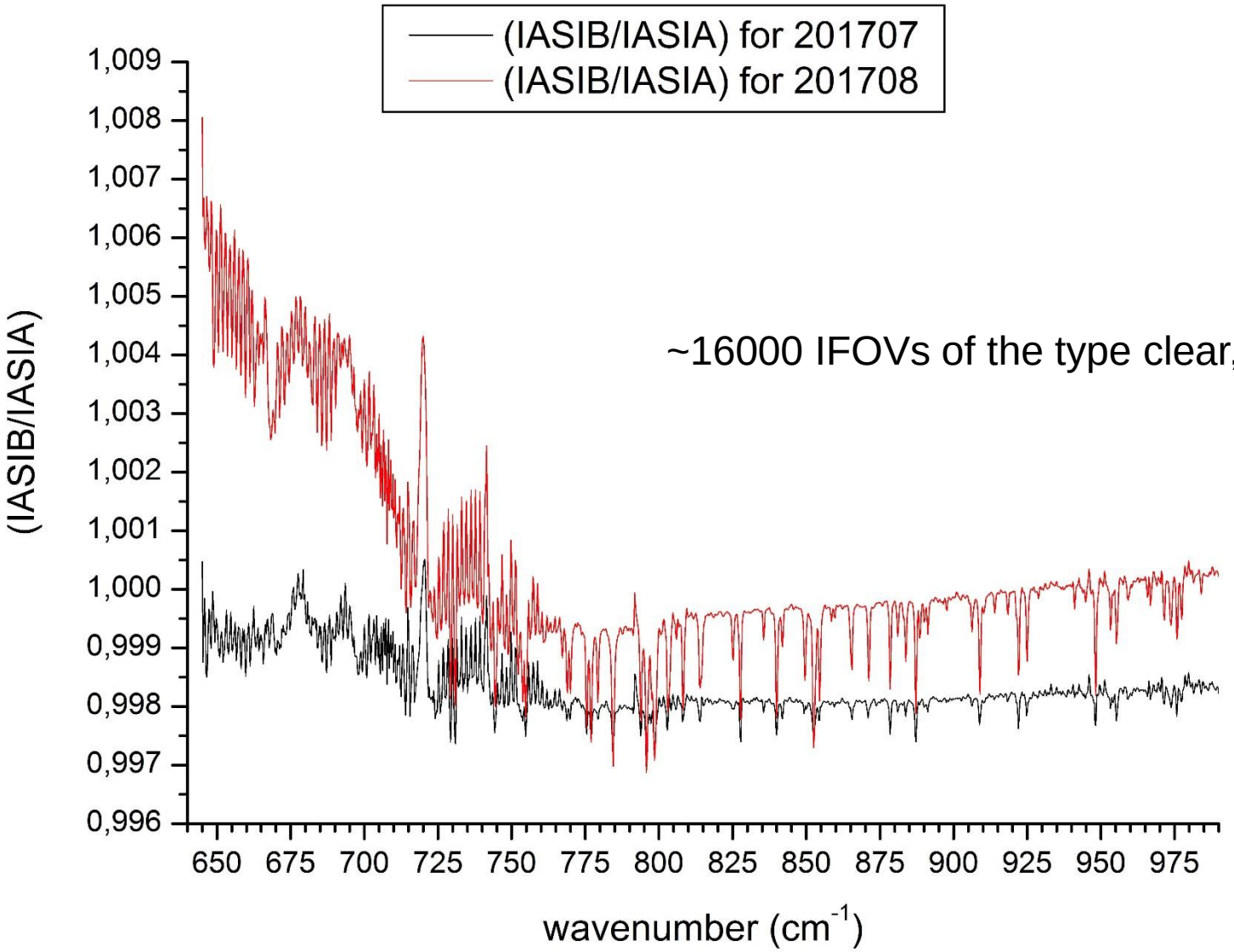
Generating grand average spectra for climate studies with IASI (1/2)

- Categories (or boxes) are used to divide the huge ensemble of available spectra into homogeneous subsets from which a random sampling (or draw) for generating averages can be considered as statistically representative. A category is defined according to the following criterions:
- latitude (subscript `il`)
- scan position or nadir angle (SP, subscript `ia`)
- pixel number (PN, subscript `ip`)
- ground or surface type (subscript `ig`)
- solar zenith angle (subscript `is`)
- nebulosity or cloud coverage (subscript `ic`)
- scan direction (subscript `id`)

Generating grand average spectra for climate studies with IASI (1/2)

- The additional subscript within a given category is the channel number (index ix).
- The corresponding average spectral radiance arrays are then of type `rad(il,ia,ip,ig,is,ic,ix,id)`
- Similar arrays are generated for the standard deviation `stdv` (rms around the mean), for the skewness and for the kurtosis (`skew` or `kurt` i.e. 3rd and 4th order moments) as well as for the extreme values (`rmin`,`rmax`)
- The number of subscripts and the range of possible values for the indices is an indication of the scale (memory and storage resources) of the exercise.
- `il=[1,2,3,4,5]` → [SH-polar, SH-mid, tropical, NH-mid, NH-polar]
- `ia=[1;30]` → all scan mirror positions → will be different for FORUM
- `ip=[1,2,3,4]` → 4 pixels or IFOVs within a given FOR → will be different for FORUM
- `ig=[1,2]` → land or water
- `is=[1,2]` → day or night
- `ic=[1,2]` → clear or overcast
- `id=[0,1,2]` → ccd0 or ccd1 (corner cube direction, `id`=2 both combined) → FORUM?
- `ix=[1;8461]` → nominal IASI L1C channels → less channels for FORUM

Comparing IASI-A and IASI-B

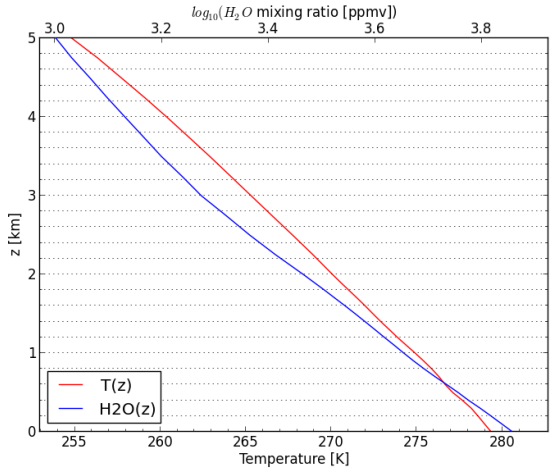


~16000 IFOVs of the type clear, sea, night

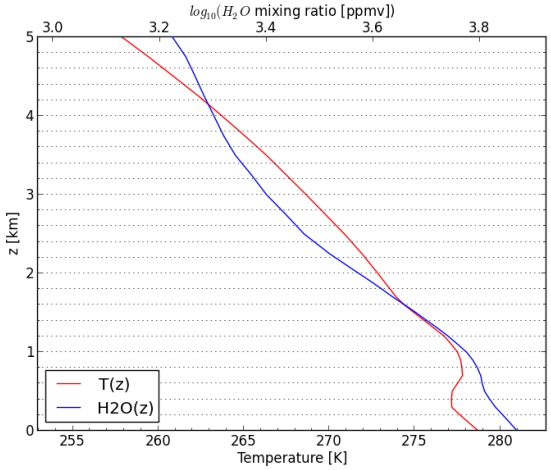
Window fitted and state vector

- Window: 940 - 980 cm^{-1}, "CO_2 laser band" or "hot band" region
- State vector: x=(T_{surf}, XCO_2, coeff_H_2O, coeff_O_3)
- For IASIA and IASIB Carmine Serio full instrument covariance matrix S_y → needed because IASI L1C spectra are "Gaussian" apodised
- For GOSAT diagonal covariance matrix S_y (L1B unapodised spectra)
- No *a priori* for T_{surf} and XCO_2 → constant $xCO_2(z)$ mixing ratio profile
- T(z) extracted from ECMWF ERA-Interim analyses (z=0 is sea surface)
- $H_2O(z)$ profile scaled from ECMWF ERA-I
- SF_6 fixed (including trend between 2010 and 2015)
- The retrieval sensitivity to the shape of the actual T(z) profile has been checked and used for pre-selecting the footprints (or IFOVs)
- Pre-selection of IASI footprints: cloud fraction index = 0 in the L1C product, homogeneity test using AVHRR radiance analysis within the IASI footprints, additional internal test for “cloud free” spectra using both sides of the 9.7 µm ozone band (similar to split window method)

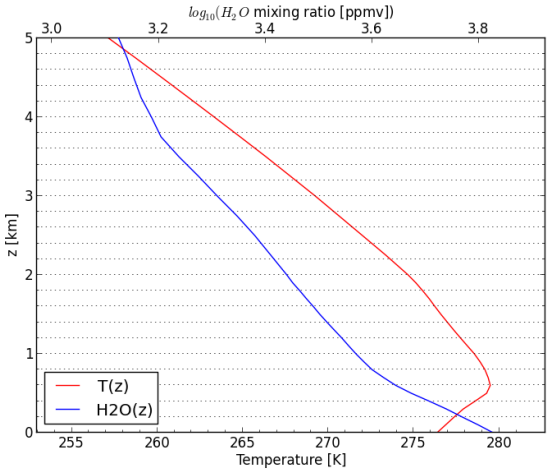
Temperature profile



normal lapse rate

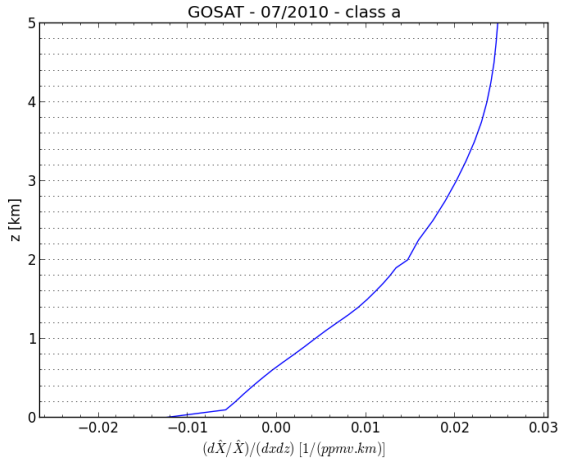


isothermal

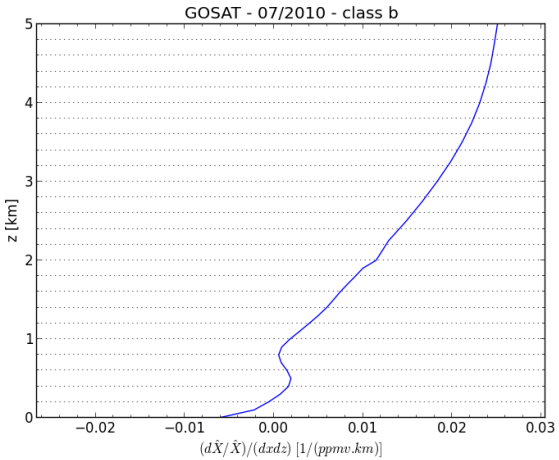


T(z) inversion

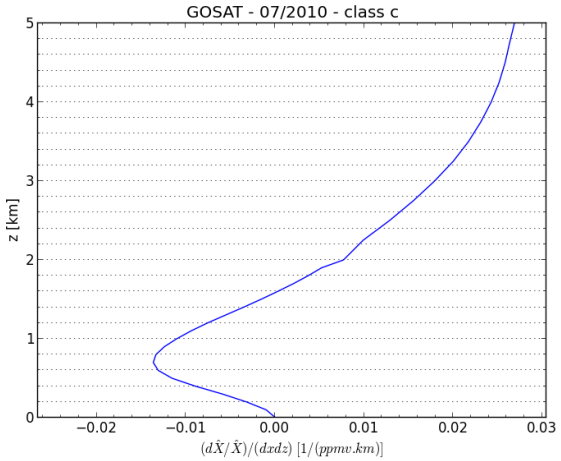
Sensitivity curves



normal lapse rate



isothermal



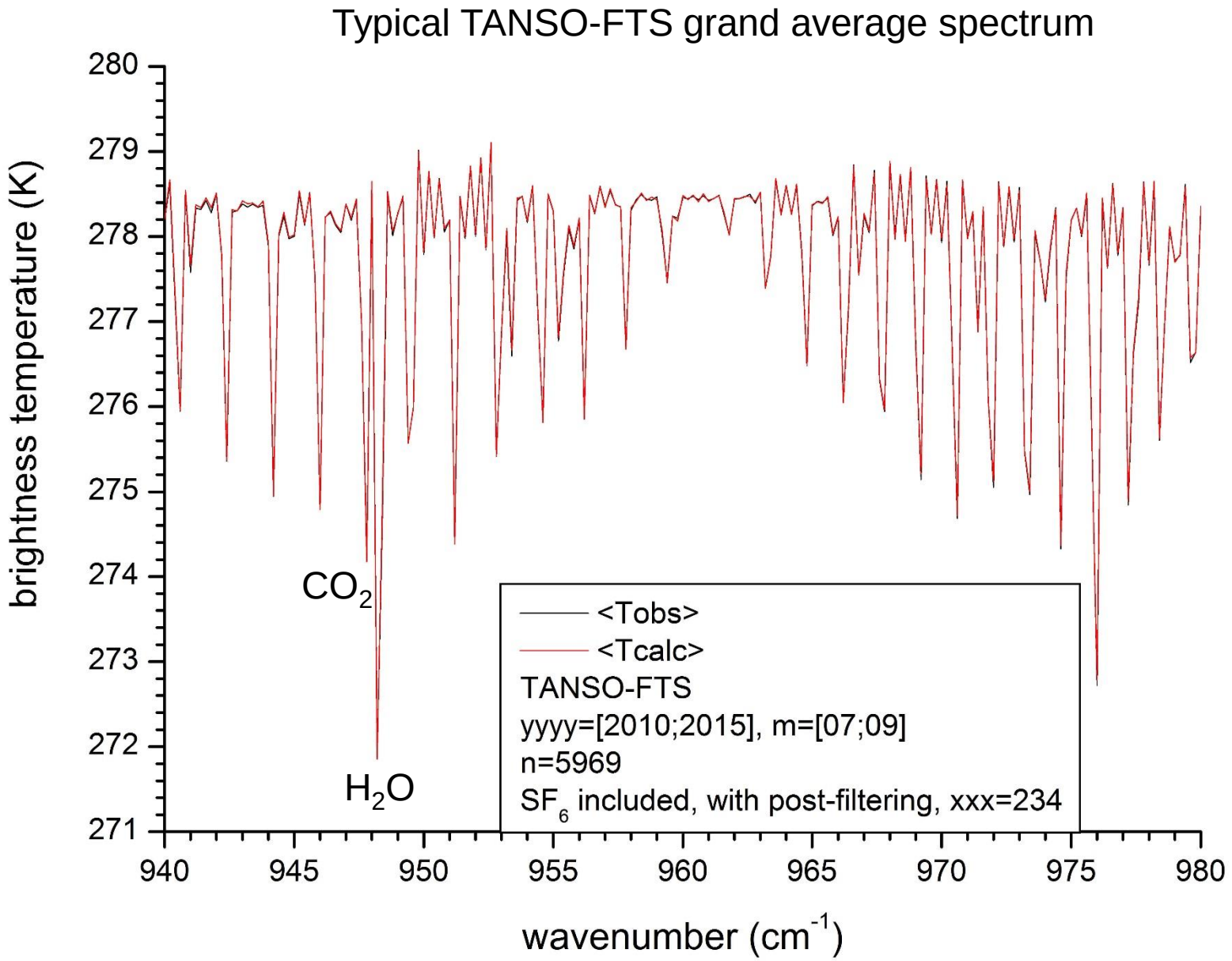
T(z) inversion

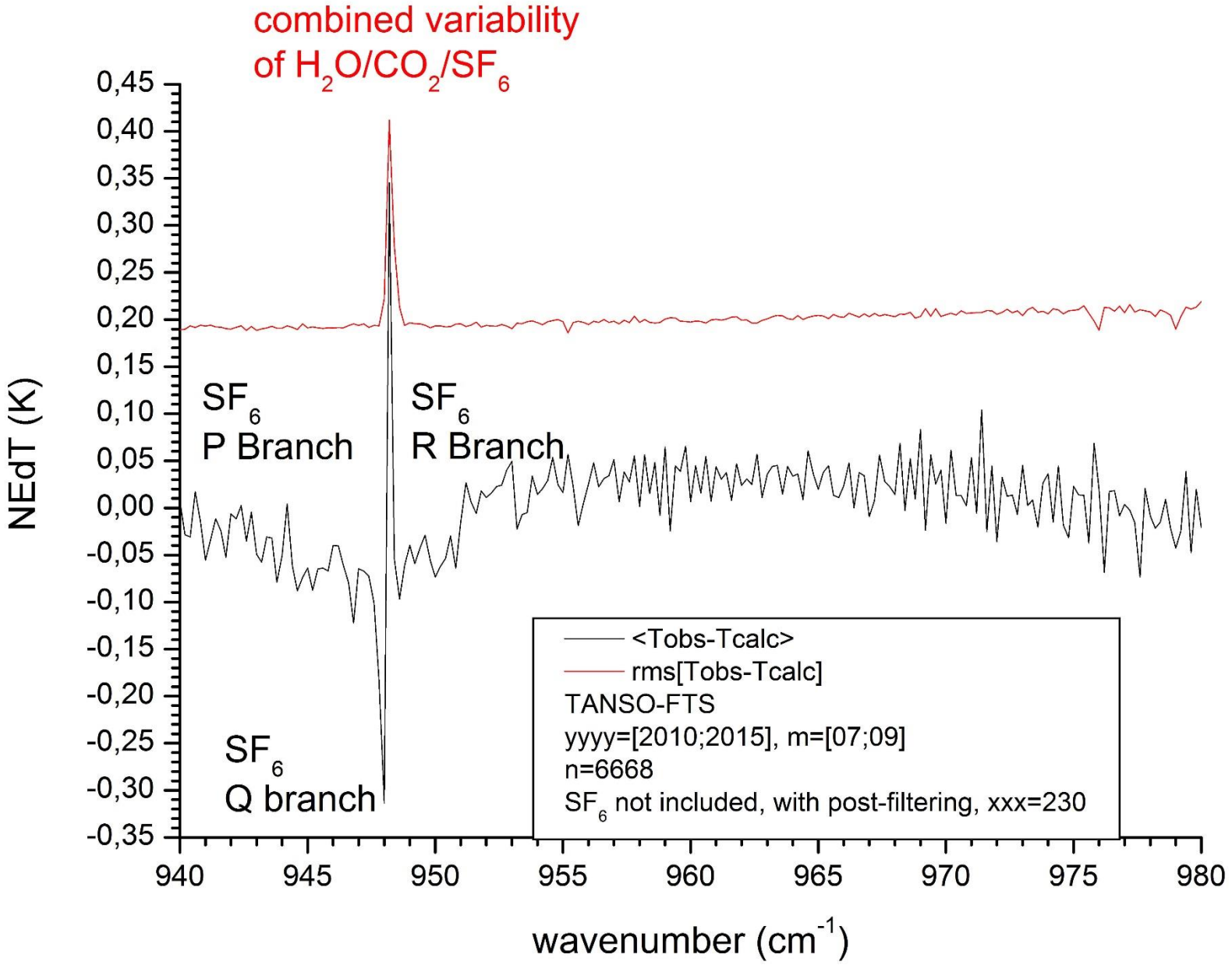
Pre-selection (or pre-filtering)
→ keep only IFOVs
with normal (negative) lapse rate T(z) profiles

Comparison of IASI and GOSAT spectra and residuals

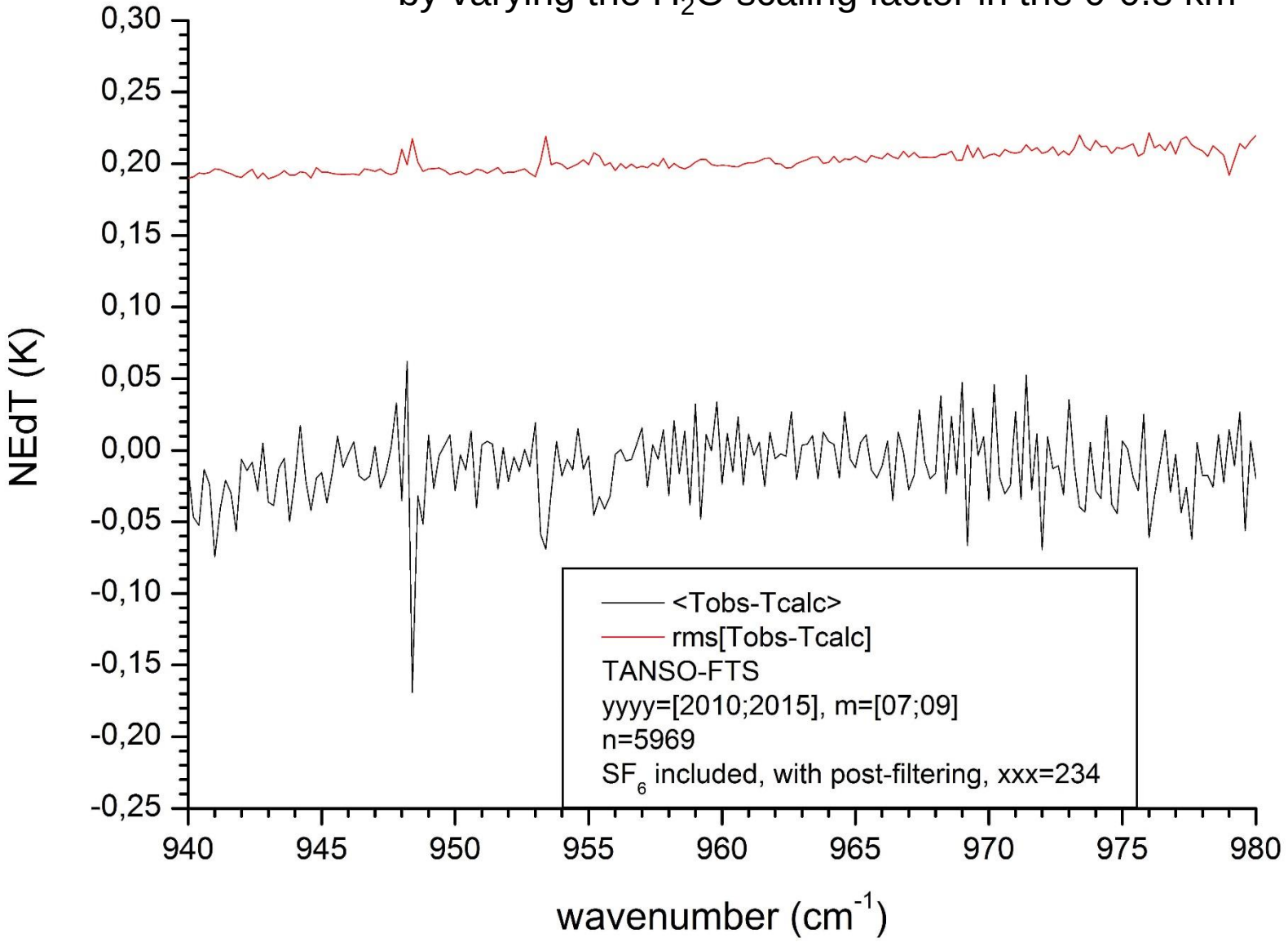
In the next figures you will see:

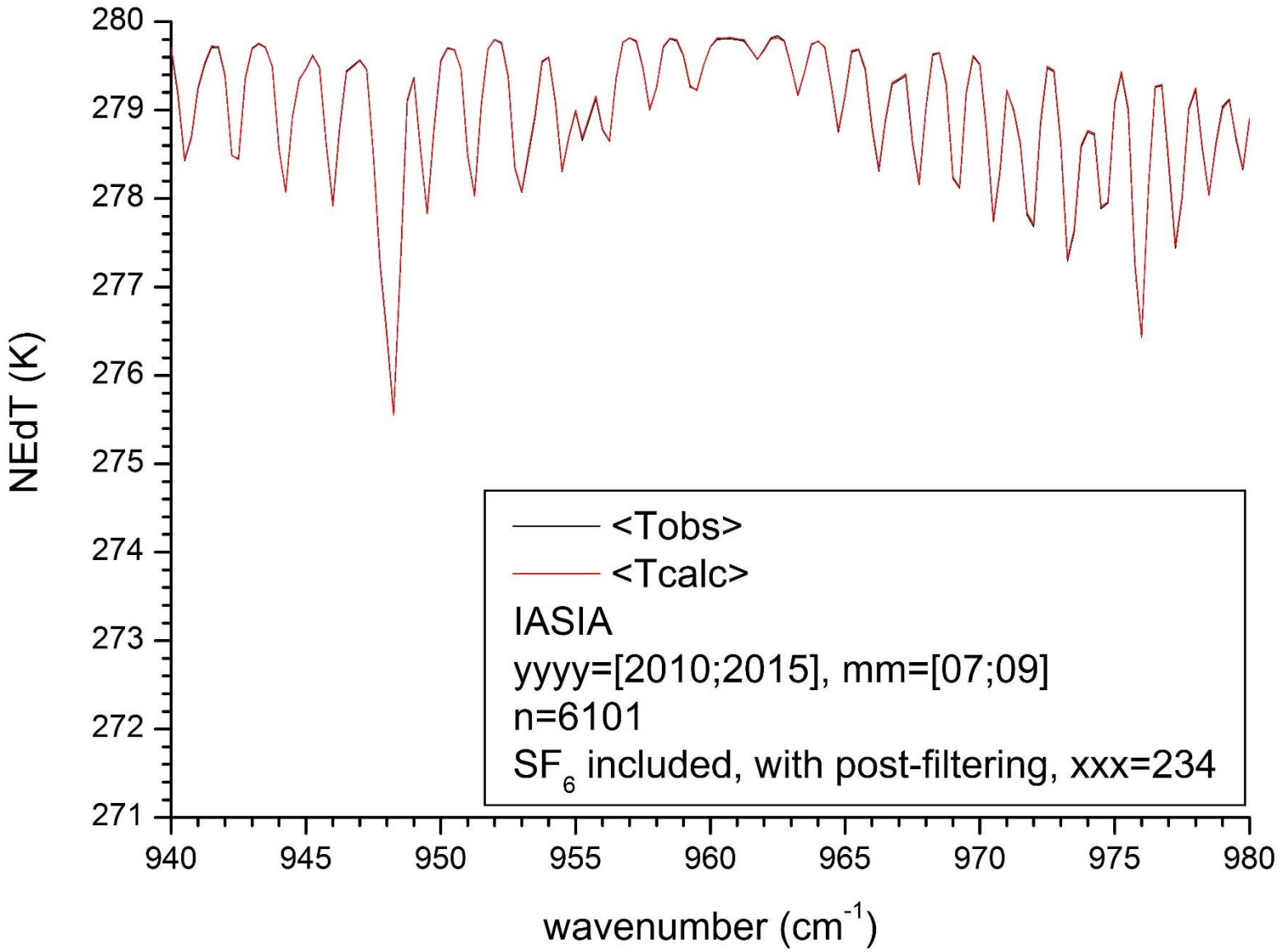
- TANSO-FTS spectra <Tobs> and <Tcalc>
- TANSO-FTS residuals <Tobs-Tcalc> and rms[Tobs-Tcalc] without SF_6
- TANSO-FTS residuals <Tobs-Tcalc> and rms[Tobs-Tcalc] with SF_6
- IASIA spectra <Tobs> and <Tcalc>
- IASIA residuals <Tobs-Tcalc> and rms[Tobs-Tcalc] with SF_6

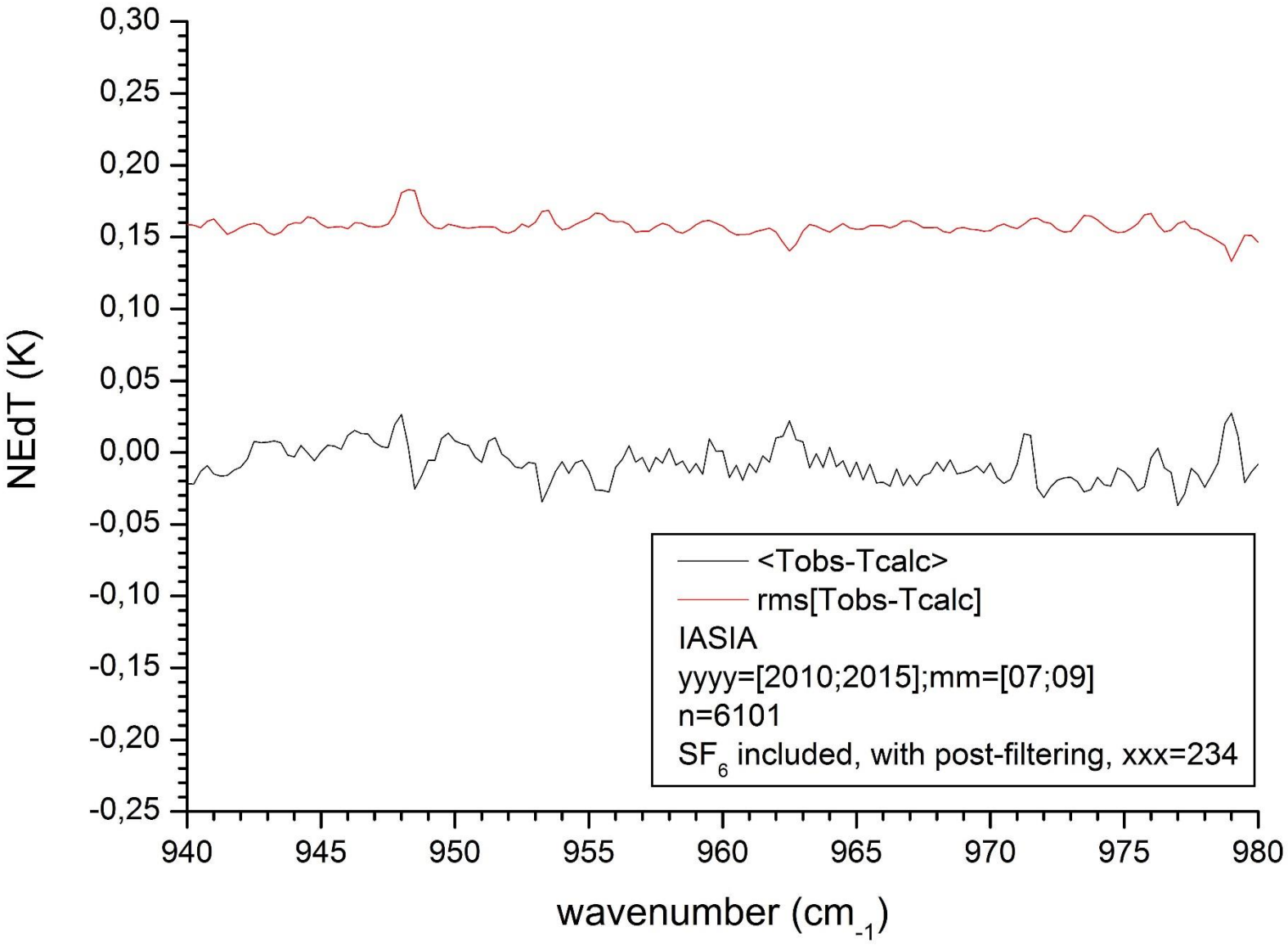

Typical TANSO-FTS grand average spectrum
brightness temperature (K)
wavenumber (cm-1)
280
279
278
277
276
275
274
273
272
271
940
945
950
955
960
965
970
975
980
CO2
H2O
<Tobs>
<Tcalc>
TANSO-FTS
yyyy=[2010;2015], m=[07;09]
n=5969
SF6 included, with post-filtering, xxx=234


combined variability
of H2O/CO2/SF6
NEdT (K)
0,45
0,40
0,35
0,30
0,25
0,20
0,15
0,10
0,05
0,00
-0,05
-0,10
-0,15
-0,20
-0,25
-0,30
-0,35
940
945
950
955
960
965
970
975
980
wavenumber (cm-1)
SF6
P Branch
SF6
R Branch
SF6
Q branch
<Tobs-Tcalc>
rms[Tobs-Tcalc]
TANSO-FTS
yyyy=[2010;2015], m=[07;09]
n=6668
SF6 not included, with post-filtering, xxx=230

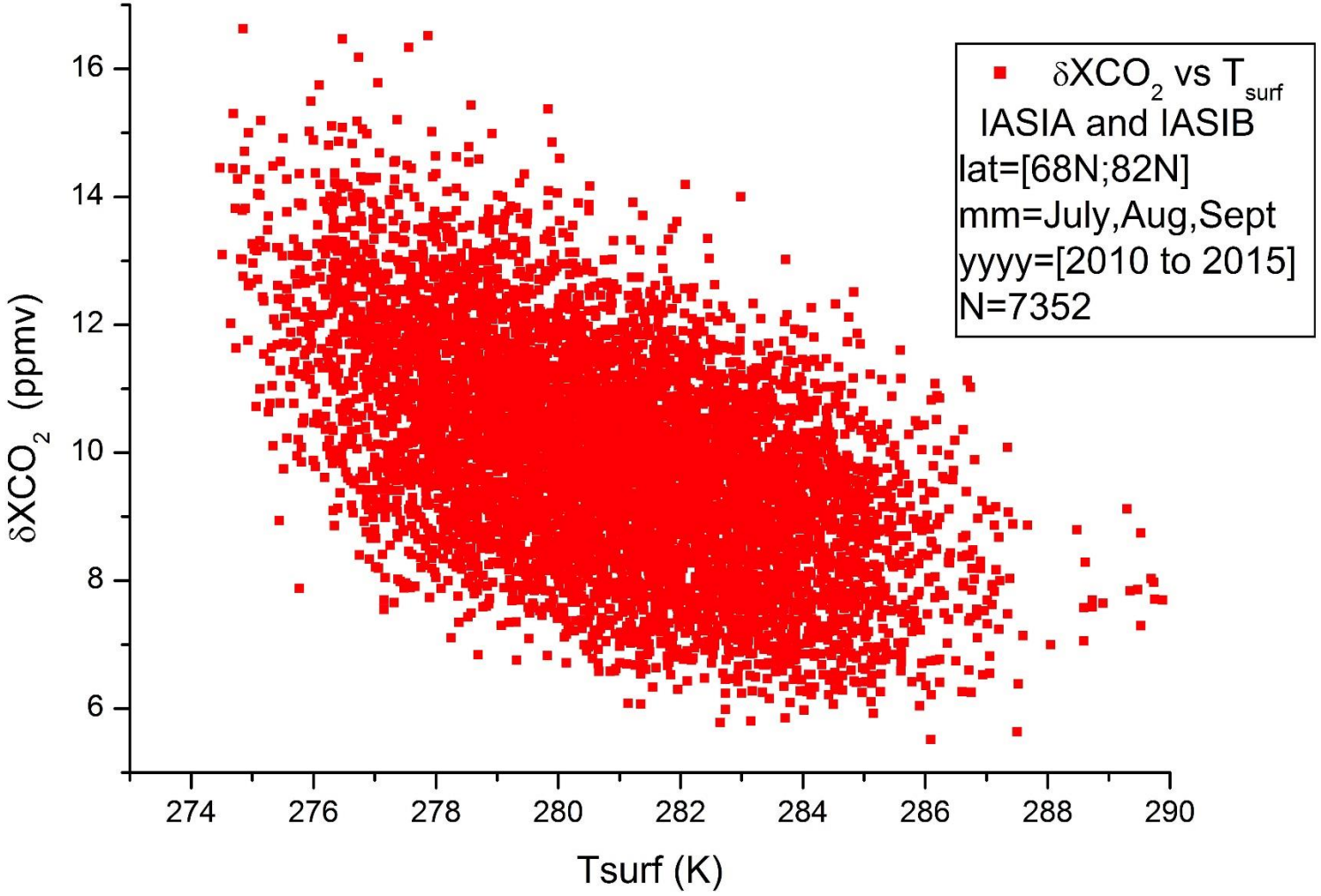
Residual variability is reduced in rms[Tobs-Tcalc]
by varying the H_2O scaling factor in the 0-0.8 km




NEdT (K)
280
279
278
277
276
275
274
273
272
271
940
945
950
955
960
965
970
975
980
wavenumber (cm-1)
<Tobs>
<Tcalc>
IASIA
yyyy=[2010;2015], mm=[07;09]
n=6101
SF6 included, with post-filtering, xxx=234


0,30
0,25
0,20
0,15
0,10
0,05
0,00
-0,05
-0,10
-0,15
-0,20
-0,25
NEdT (K)
940
945
950
955
960
965
970
975
980
wavenumber (cm-1)
<Tobs-Tcalc>
rms[Tobs-Tcalc]
IASIA
yyyy=[2010;2015];mm=[07;09]
n=6101
SF6 included, with post-filtering, xxx=234

δXCO_2 is decreasing as T_{surf} is increasing

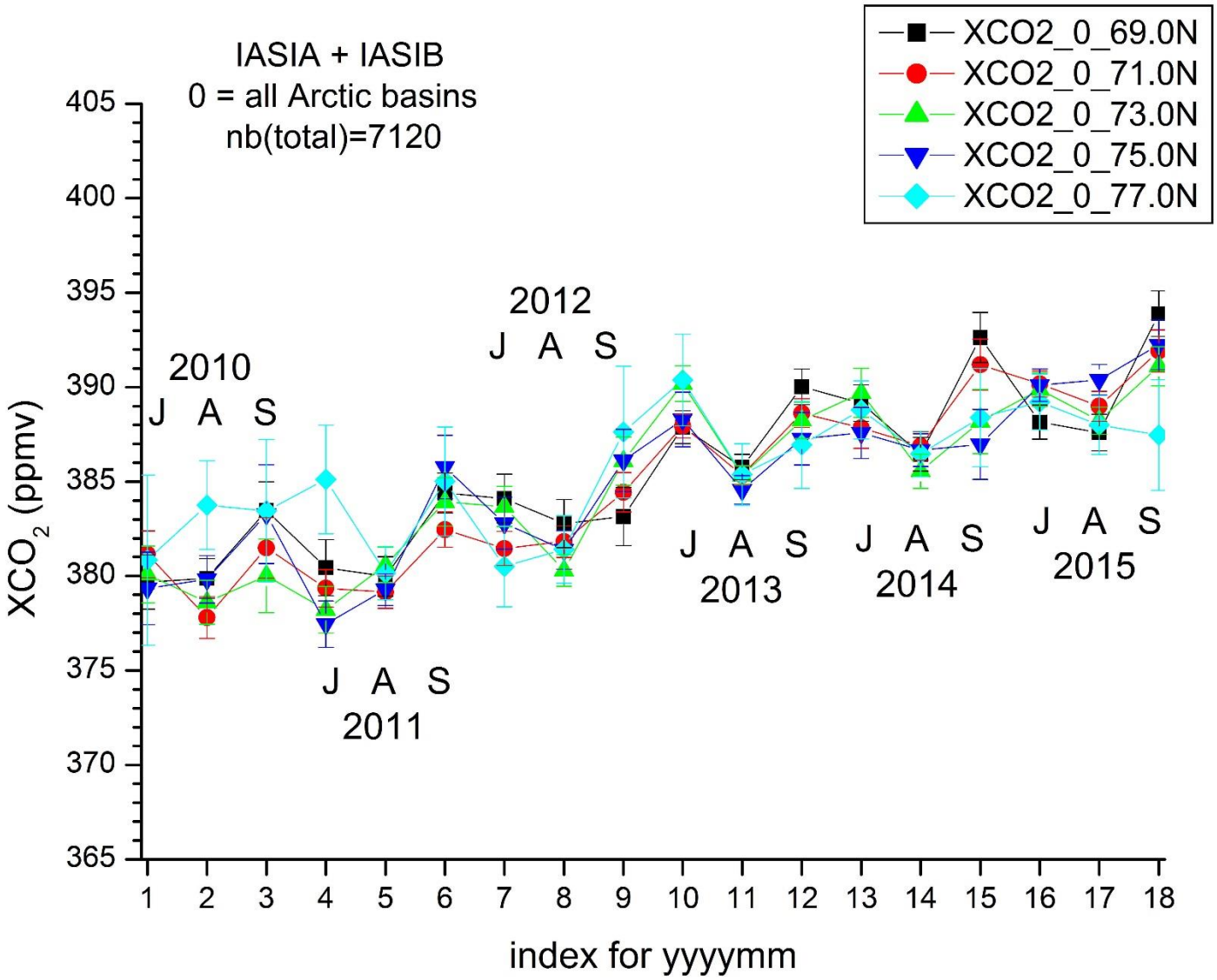


Monthly climatology of XCO_2 from the two IASI sounders

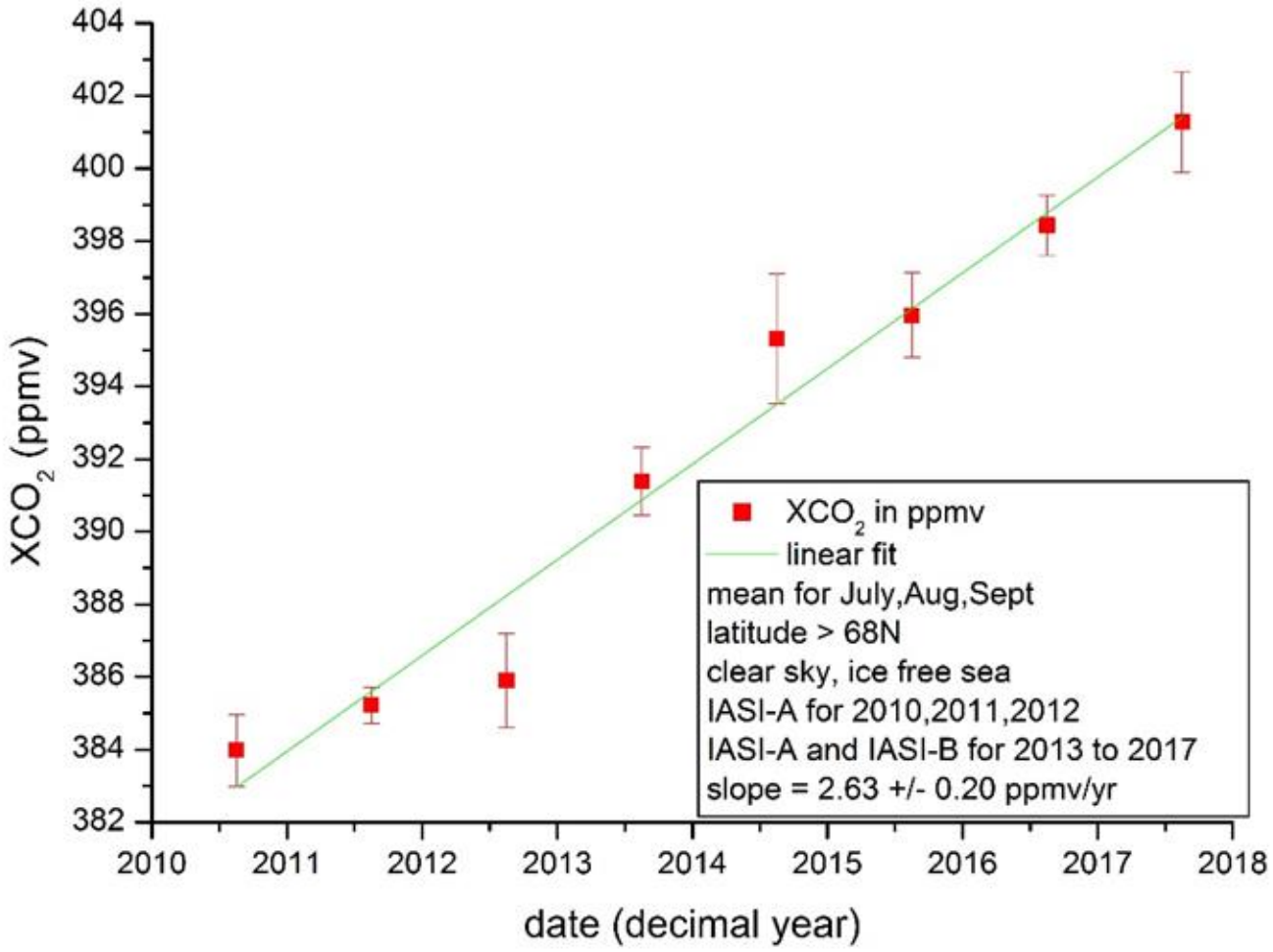
In the next slides you will see:

- The mean retrieved XCO_2 for the mean IFOVs for the 3 basins and for the full Arctic Ocean as a function of year and month (notation yyyymm)
- The values are given per 2° bands of latitude centered at 69N, 71N, 73N, 75N and 77N

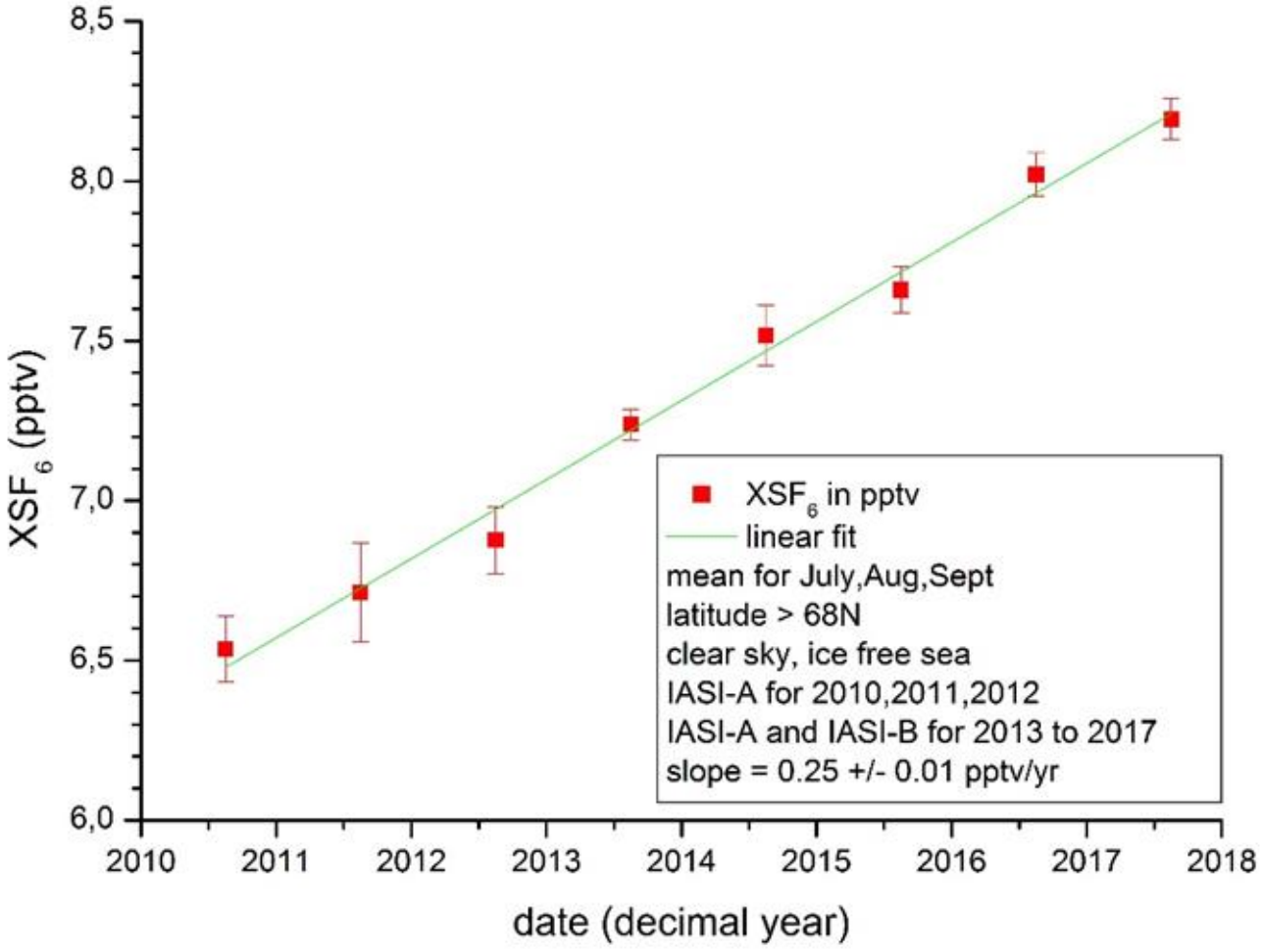
All arctic basins



CO_2 trends with IASI over the summer Arctic Ocean (ice free IFOVs)



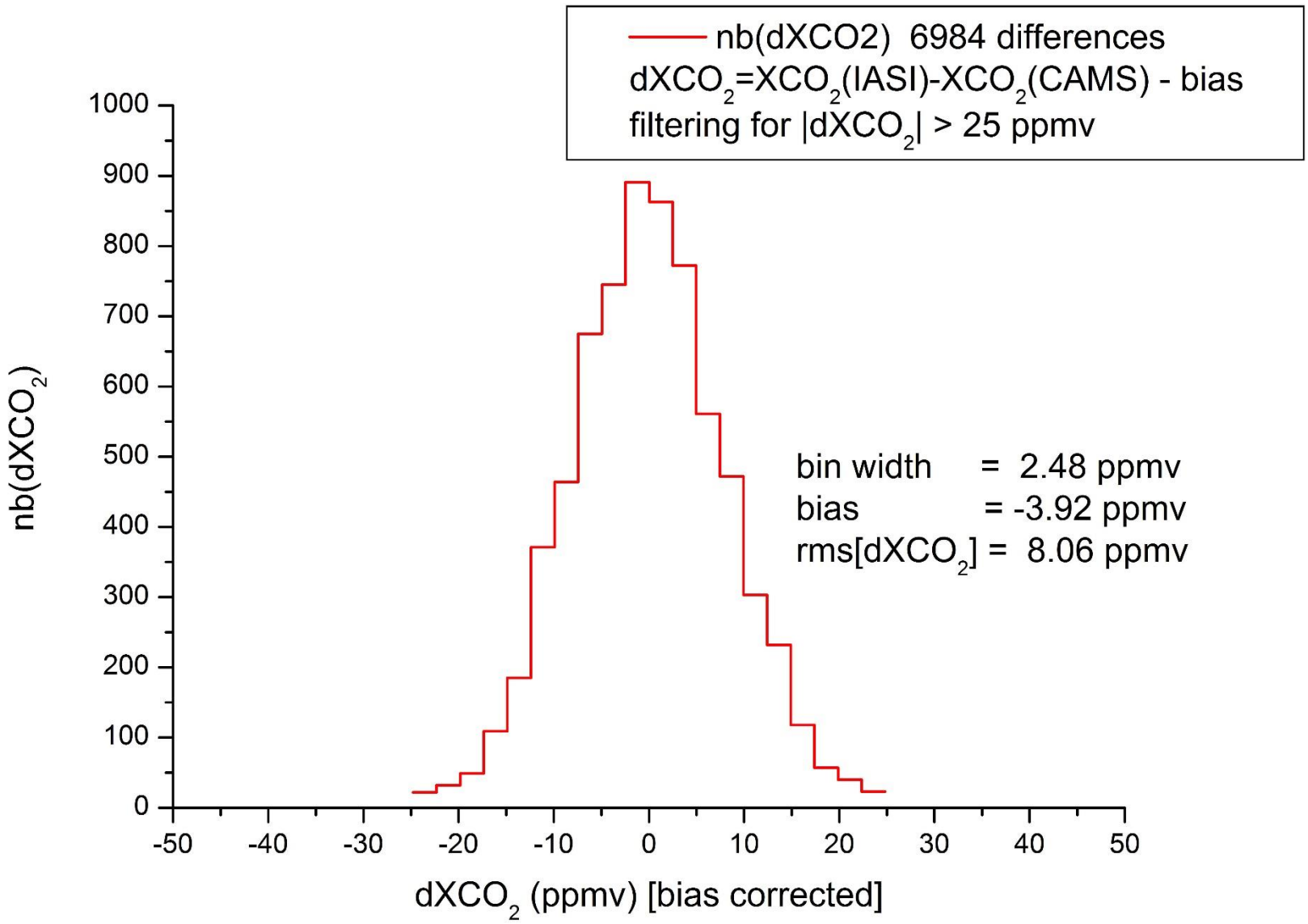
SF_6 trends with IASI over the summer Arctic Ocean (ice free IFOVs)



Comparison with the CAMS CO_2 inversion model
Frédéric Chevallier (LSCE using ECMWF IFS and *in situ* measurements)

- Boxes in longitude: 3.75°
- Boxes in latitude: 1.89°
- Time step: 3 hr for the 3 months and the 6 years
- IASIA and IASIB XCO_2 values for the mean IFOVs i.e. XCO_2(IASI) have been compared to the quasi-coincident (in time and space) XCO_2 value from the CAMS model i.e. XCO_2(CAMS) at the centre of the model boxes
- The overall statistics and results for Aug. 2013 will be presented as an exemple

Histograms of the differences $dXCO_2=XCO_2(IASI)-XCO_2(CAMS)$ - bias



Outlook

- FORUM will be invaluable in testing the spectroscopy of water vapour for line shape and continuum → a consistent model for H_2O is still needed and should be the basis for an extension to the TIR and SWIR
- Retrievals of $x_{H2O}(p)$ in the lower stratosphere using FIR channels (not covered by IASI/IASI-NG) will bring an important new information not le from other instruments. Synergy between FORUM and IASI-NG has a real potential
- Testing the spectroscopy of CO_2 is also very important for retrieving simultaneoulsly T(p) and $x_{CO2}(p)$
- Comparison of the retrieved L2 products of FORUM with those of IASI will ensure the “explorer” role of FORUM
- Spectral radiances and irradiances (converted to TOA fluxes) should be considered carefully and IASI results will be a good guidance
- The "surface window" i.e. 940-960 cm^{-1} (~10.4 µm) is quite useful for obtaining "climate quality records" at a regional scale
- And this window will be an anchor for the absolute radiometric calibration of FORUM
- Further studies need to be initiated for the best usage of the FEI (FORUM Embedded Imager) information to diagnose footprint homogeneity