Are thermal infrared measurements of CO_2 from GOSAT and IASI over the Arctic Ocean in summer able to detect climatic change?

Claude Camy-Peyret[(1)], Jérôme Bureau[(2)] and Sébastien Payan[(2)]

<claude.camy-peyret@upmc.fr>

[(1)] IPSL (UPMC/UVSQ) Paris, France

[(2)] LATMOS/IPSL, Paris, France

12th IWGGMS, 7-9 June 2016, Kyoto, Japan

Outline

- Using the thermal infrared region (TIR) covered by TANSO-FTS in B4 (GOSAT) and IASI (MetOp) for ice free Arctic Ocean studies in summer
- Retrieval scheme and sensitivity study as a function of T(z)
- Comparison for coincidences between GOSAT and IASI-A/IASI-B for T_{surf} and XCO_2
- Monthly climatology of T_{surf} and XCO_2 for the 3 summer months for GOSAT/IASI-A (2010 to 2015) and GOSAT/IASI-B/IASI-A (2013-2015) $\rightarrow$ only this 3 years period presented during this talk
- Impact of TIR sounders for climate studies

Why using TIR for Arctic Ocean studies?

- The Arctic Ocean is a key region where the effect of climate change can be detected
- Two similar instruments covering the thermal infrared region TIR can be used over an extended period: GOSAT (7 years) and IASI (10 years)
- Other sounders (for CO_2 or CH_4) are dwelling on the SWIR region (GOSAT and OCO-2 currently) using solar reflected/backscattered light
- Hence only daytime observations are possible with an additional constraint on the solar zenith angle (SZA $\leq$ 70° usually, meaning poor coverage of the sub-polar regions)
- TIR sounders (GOSAT TANSO-FTS in B4, IASI, AIRS and CrIS) are achieving a daily global coverage (usually one daytime and one night time overpass) $\rightarrow$ no night above the Arctic circle during July/Aug, however
- Their sensitivity to near surface concentrations is limited by the thermal contrast, but TIR sounders provide essential information in particular for the diurnal/nocturnal cycle and at high latitudes where models are poorly constrained by lack of observations

Why and how to compare GOSAT,IASI-A and IASI-B?

- It is important to compare spectra and retrieved geophysical parameters from three TIR sounders to check their consistency $\rightarrow$ IFOVs over ice free open water are most favourable for this comparison (retrievals over ice pack are more complicated)
- IASI-A and IASI-B on MetOp-A and MetOp-B can view the same IFOV in the same geometry within a time difference between 40 min and 50 min
- IASI-A and IASI-B can have quasi-coinciding IFOVs with GOSAT within the chosen criterion of 30 km and 1 hr
- Comparisons can be done for off-nadir observations and the choice of the polar summer period (July, August, September) lead mostly to daytime only observations in the latitude region [68N ; 80N]
- The retrieved products T_{surf} and CO_2 will be considered here

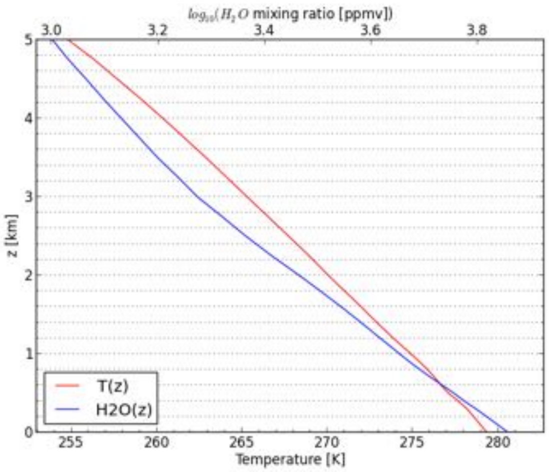
Window fitted and state vector

- Window: 940 - 980 cm^{-1}, "CO_2 laser band region"
- State vector: x=(T_{surf}, XCO_2, coeff_H_2O, coeff_O_3)
- For IASI-A and IASI-B Carmine Serio instrument full covariance matrix S_y → needed because IASI spectra are “Gaussian” apodised
- For GOSAT diagonal covariance matrix S_y (L1B unapodised spectra)
- No *a priori* for T_{surf} and XCO_2 → constant mixing ratio profile
- T(z) extracted from ECMWF ERA-Interim analyses
- 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 IFOVs

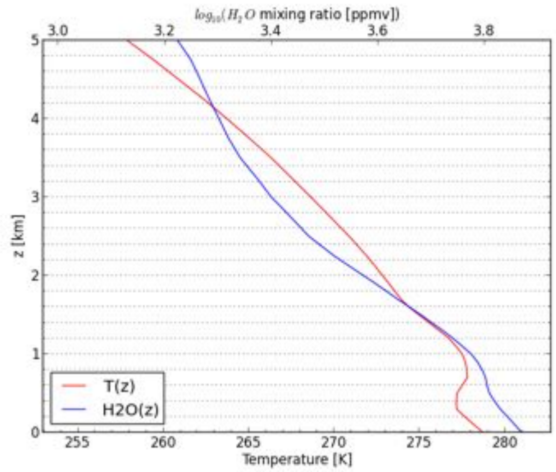
Retrieval scheme

- The line-by-line LARA radiative transfer model (RTM) and its associated retrieval model (package developed by J. Bureau and S. Payan) has been used
- Even though LARA can be configured for OEM, in the present study spectra where "least squares fitted" with a state vector containing T_{surf} and XCO_2 as well as multiplicative scaling factors for the vertical mixing ratio profiles of H_2O and O_3
- The temperature profile is taken from ECMWF product (and fixed)
- The emissivity of Masuda for sea water is used/fixed

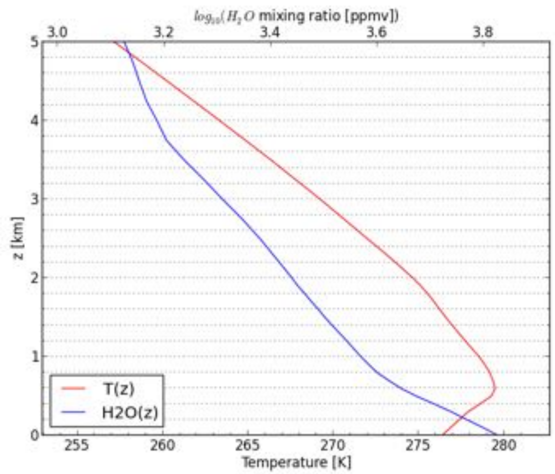
Temperature profile



lapse rate

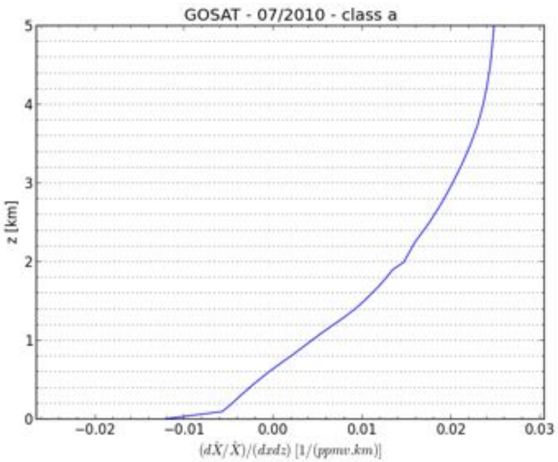


isothermal

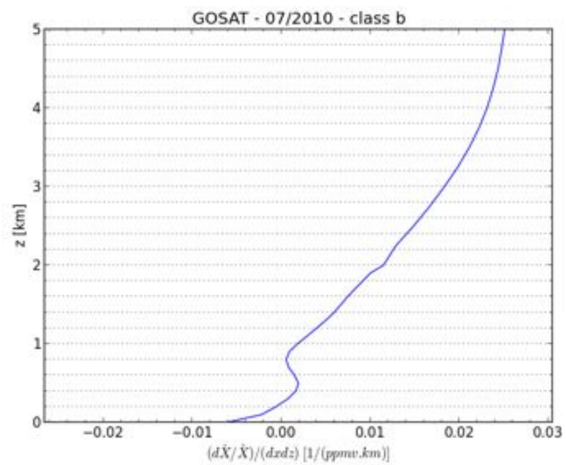


T(z) inversion

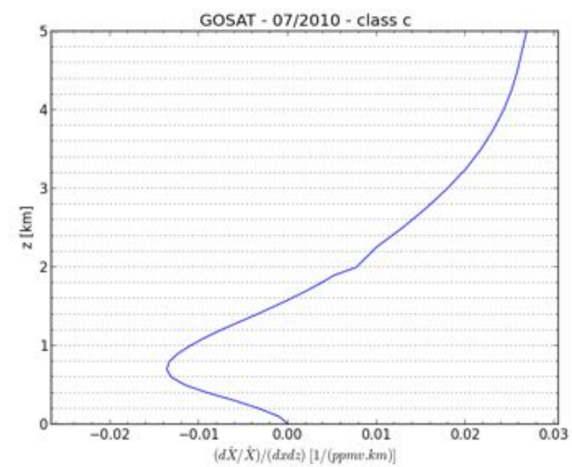
Sensitivity curves



lapse rate



isothermal



T(z) inversion

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

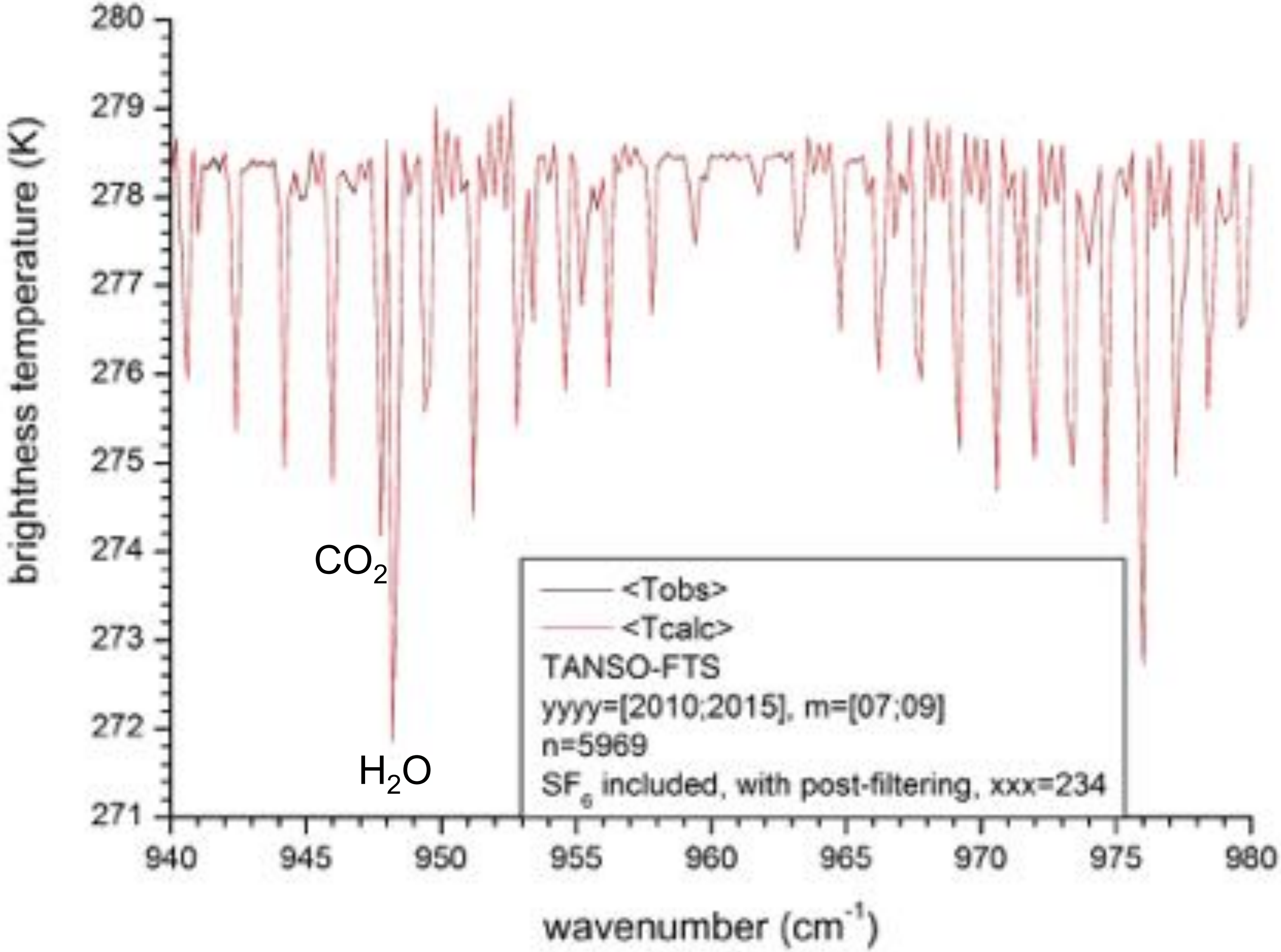
Inversion configuration

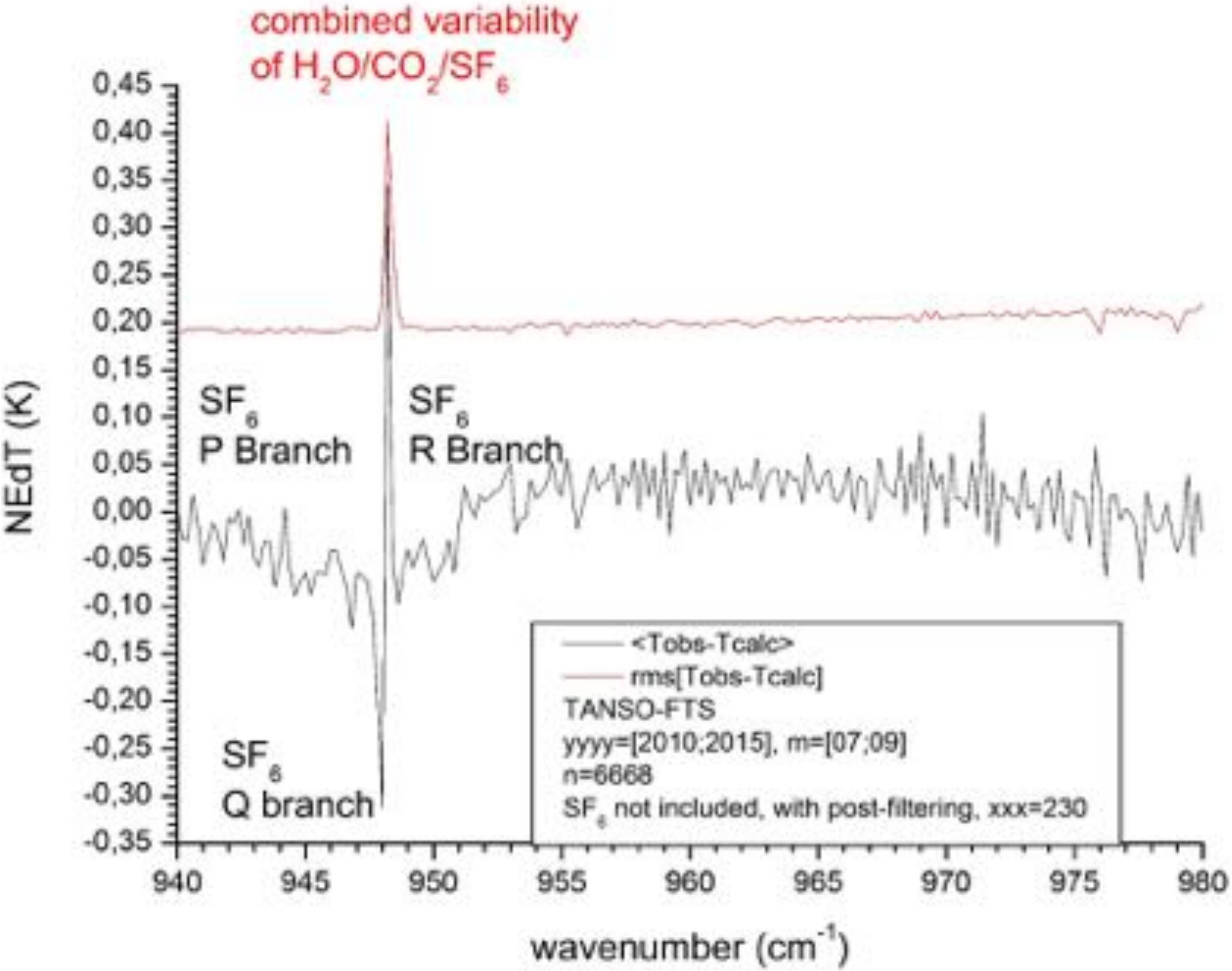
Config xxx	description
230	no SF_6, 1 scaling factor for $H_2O(z)$, inflate S_y around 948 cm^{-1}
231	with SF_6 values and trend fixed from GAW, idem for H_2O
232	idem for with SF_6, 2 scaling factors for $H_2O(z)$
233	variable SF_6, 2 scaling factors for $H_2O(z)$, nominal S_y
238	scaled SF_6 values, 2 scaling factors for $H_2O(z)$, nominal S_y

- TANSO-FTS: L1B v201.202, spectrally calibrated, 201 spectral samples
- IASI-A and IASI-B: standard L1C product (EPS or BUFR), 161 spectral samples
- years: yyyy=[2010, 2011, 2012, 2013, 2014, 2015]
- months: mm=[07, 08, 09]
- Uncorrelated L1B TANSO-FTS noise (diagonal S_y matrix)
- Ful covariance S_y matrix from C. Serio, App. Opt., 2015 for IASI-A and IASI-B
- T(z) and shape of $H_2O(z)$ from ECMWF ERA-Interim
- pre-selection before retrieval: standard lapse rate for T(z), sea, clear IFOV
- definition of "clear"

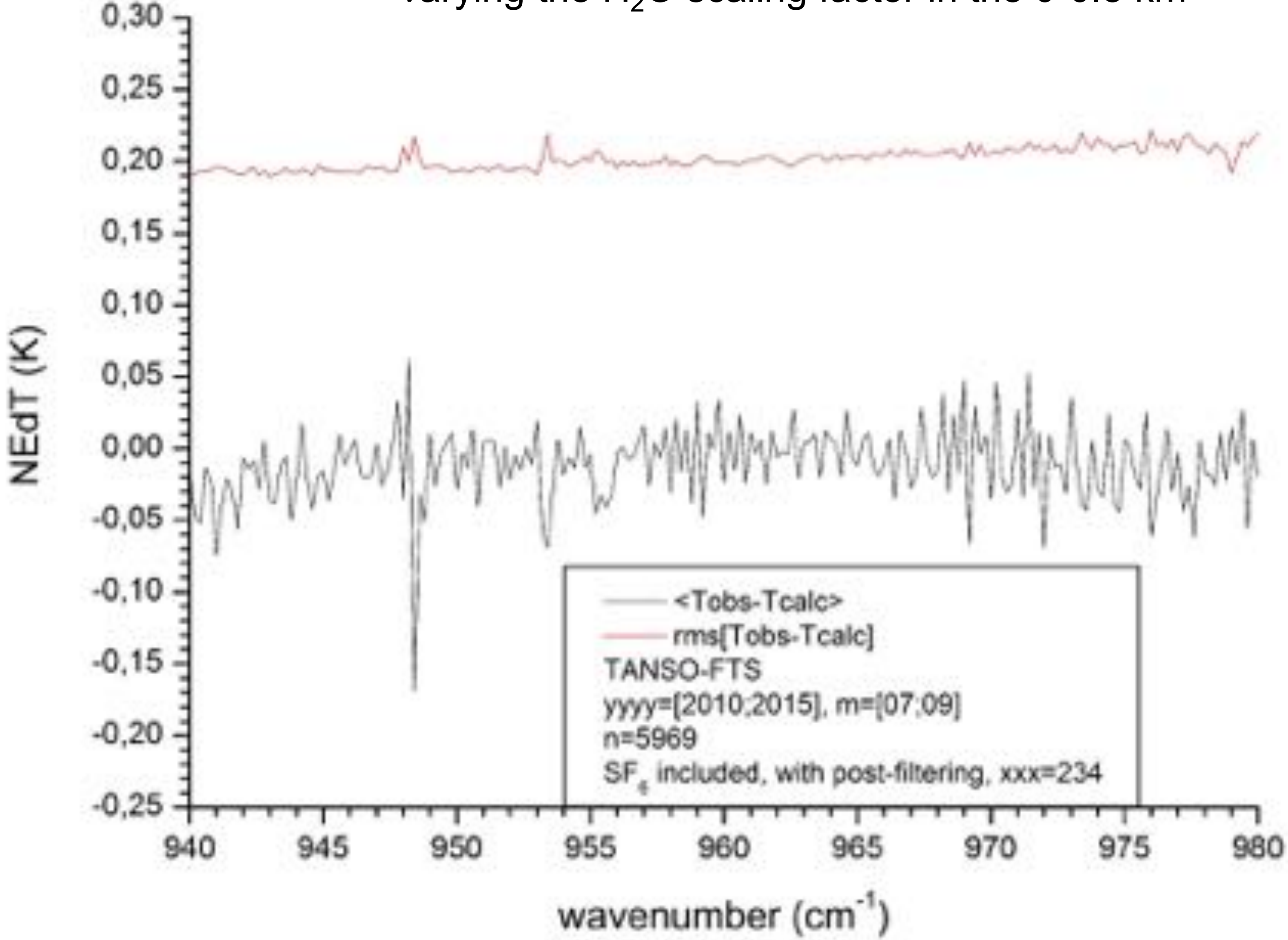
- controlled level and slope on both sides of the O_3 band
- apparent background brightness temperature BT > 272 K
- contrast of the CO_2 lines in the 940-980 cm^{-1} region > 4.2
- contrast of the H_2O lines in the 820-940 cm^{-1} region > 4.0
- contrast = rms{ΔBT(absorption lines)}/rms{ΔBT(emission lines)}

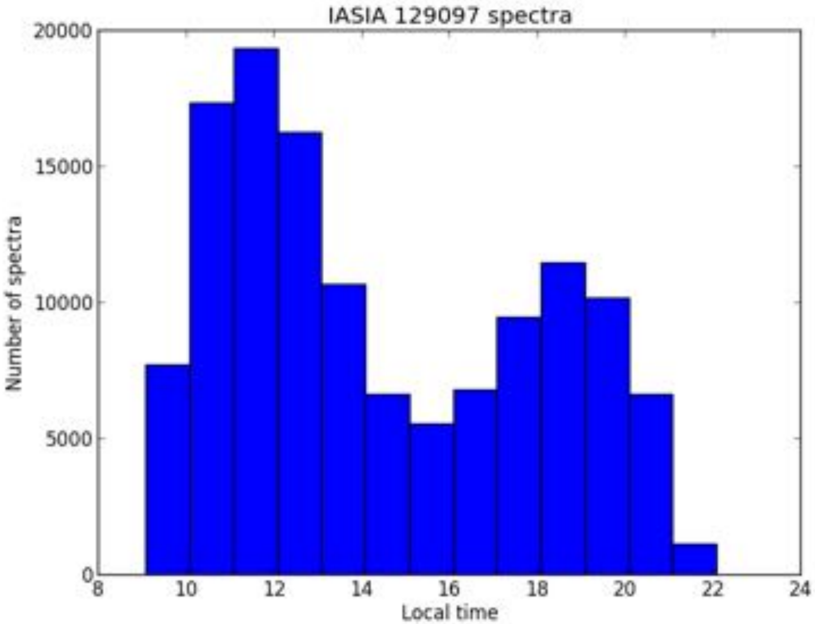
Typical TANSO-FTS grand average spectrum



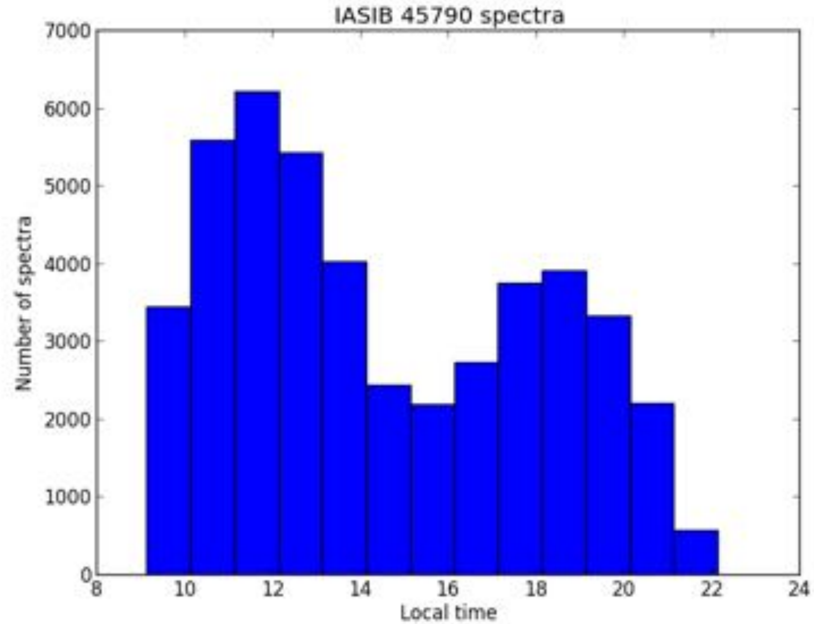

combined variability
of H2O/CO2/SF6
NEdT (K)
SF6
P Branch
SF6
R Branch
SF6
Q branch
<Tobs-Tcalc>
rms[Tobs-Tcalc]
TANSO-FTS
yyyy=[2010;2015], m=[07;09]
n=6668
SF6 not included, with post-filtering, xxx=230
wavenumber (cm-1)

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

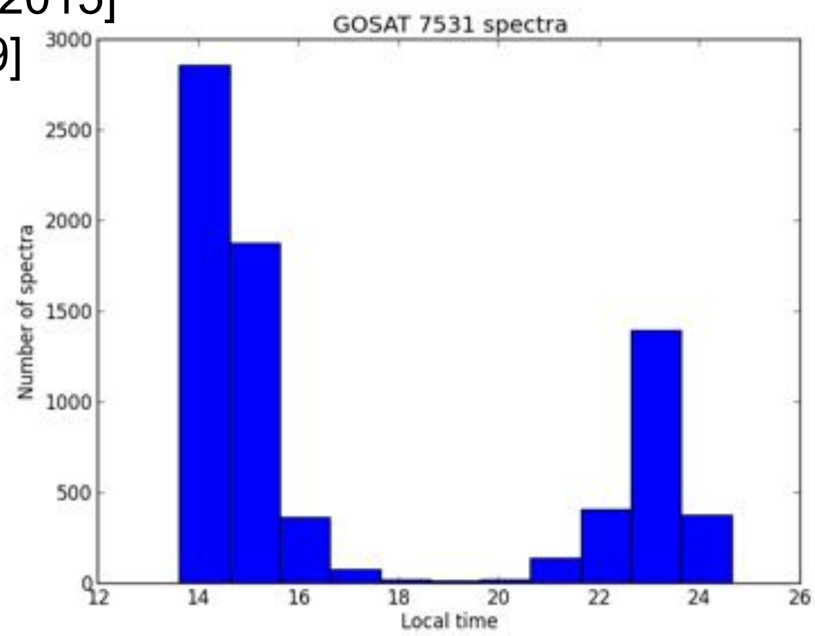




IASI-A [2010;2015]
mm=[07,08,09]

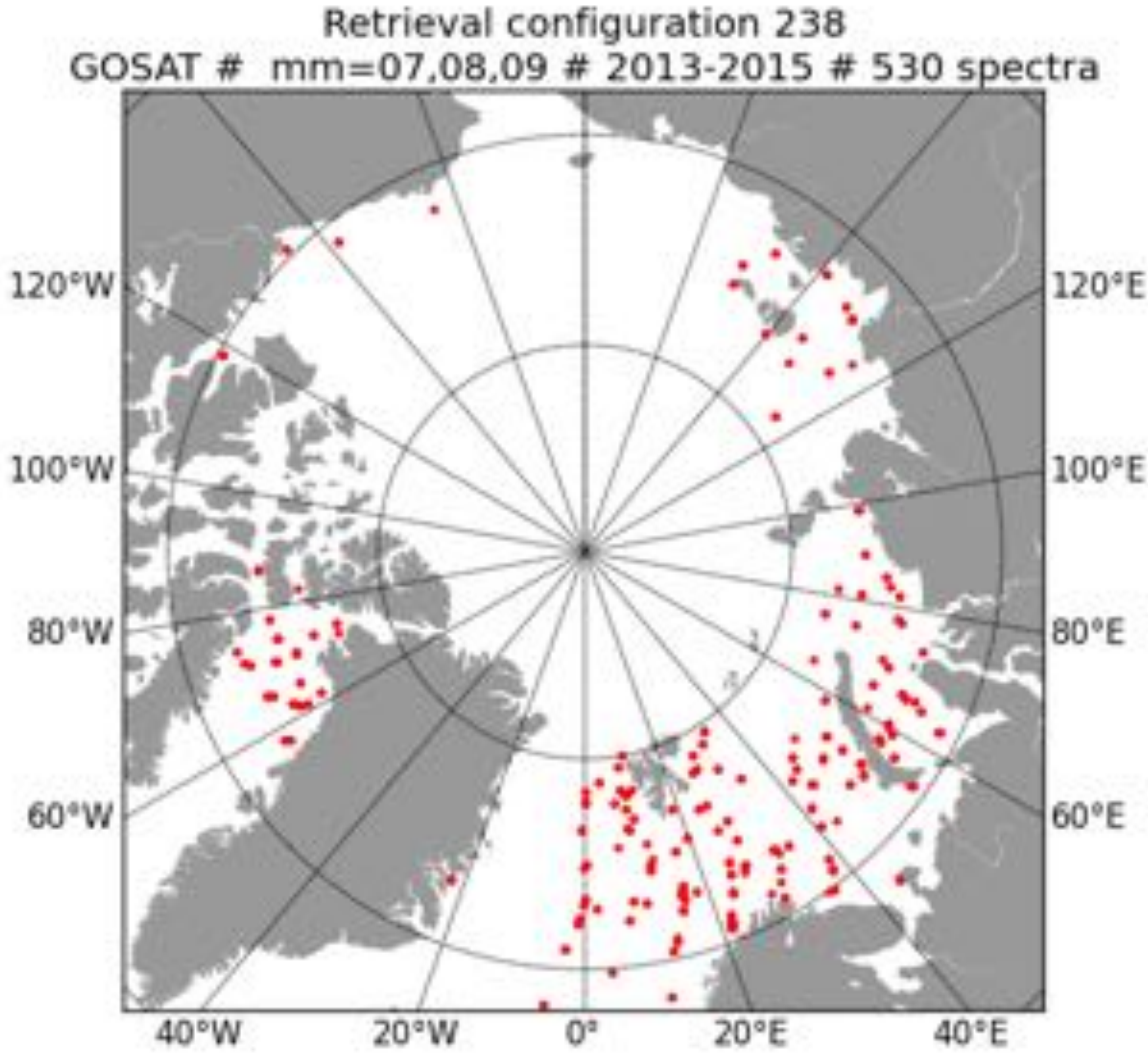


IASI-B [2010;2015]
mm=[07,08,09]

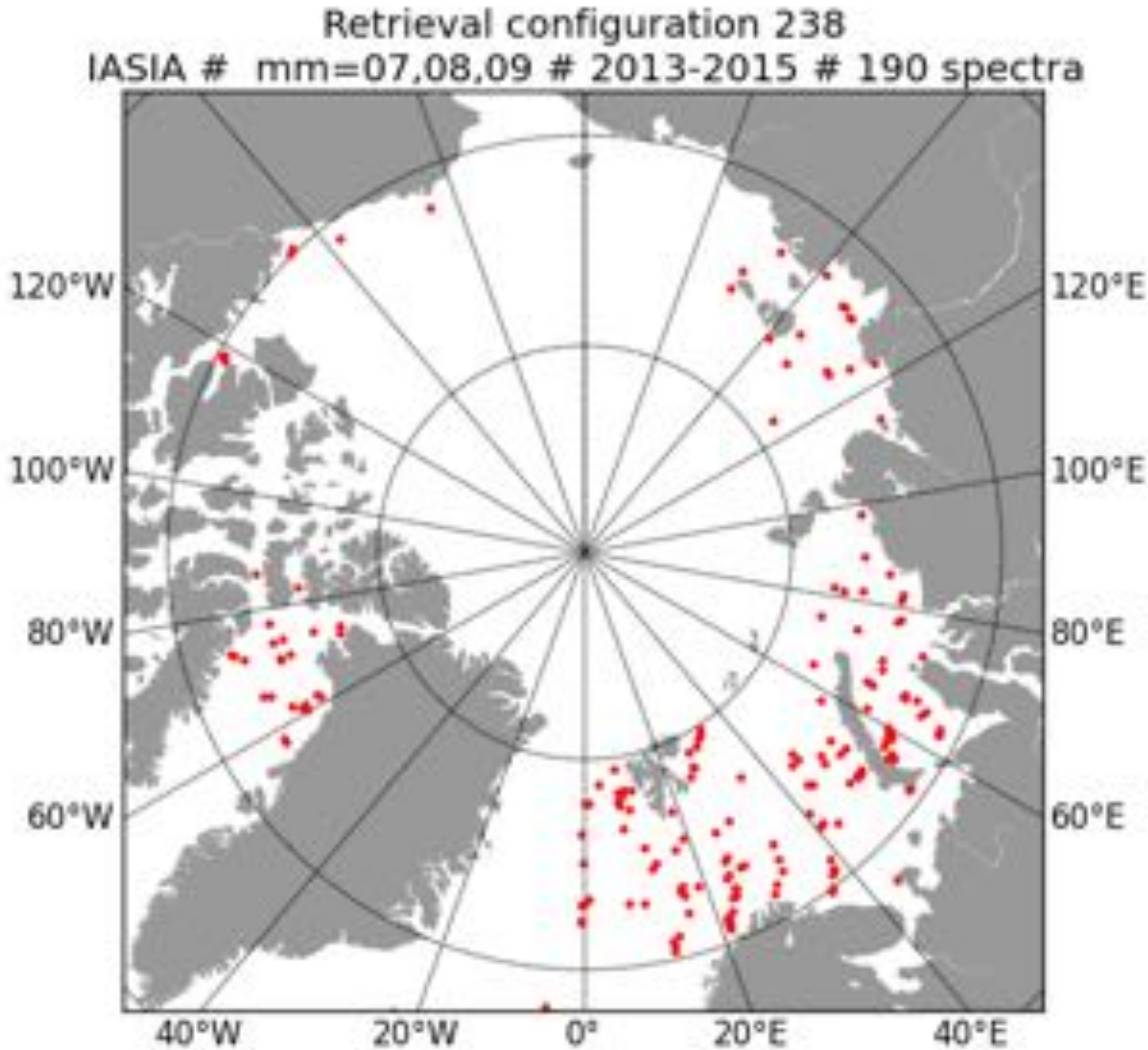


GOSAT [2010;2015]
mm=[07,08,09]

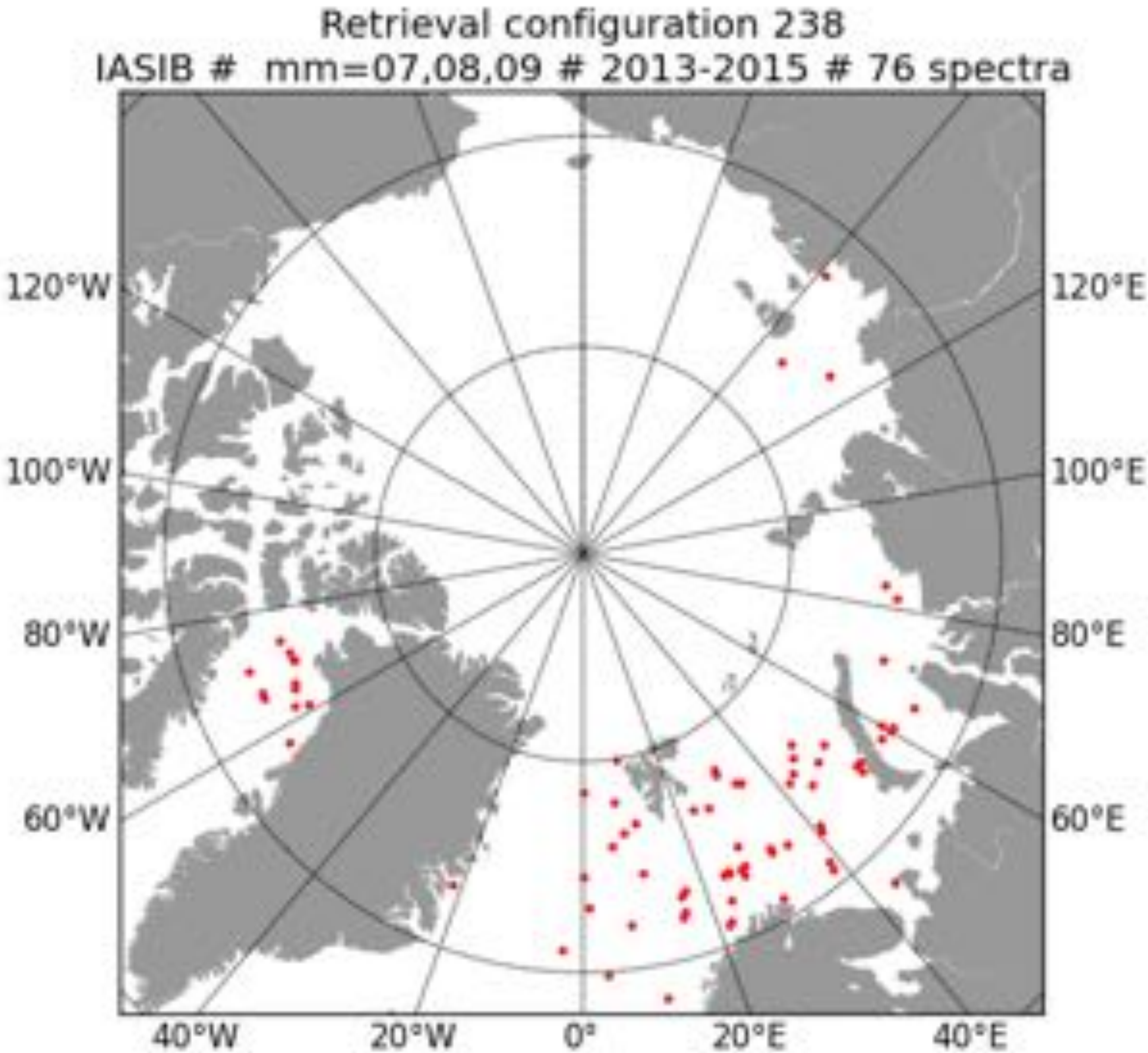
Distribution of the solar local time at the pre-selected IFOVs



Distribution of coincidences of GOSAT with IASIA or IASIB



Distribution of coincidences of IASIA with GOSAT



Distribution of coincidences of IASB with GOSAT

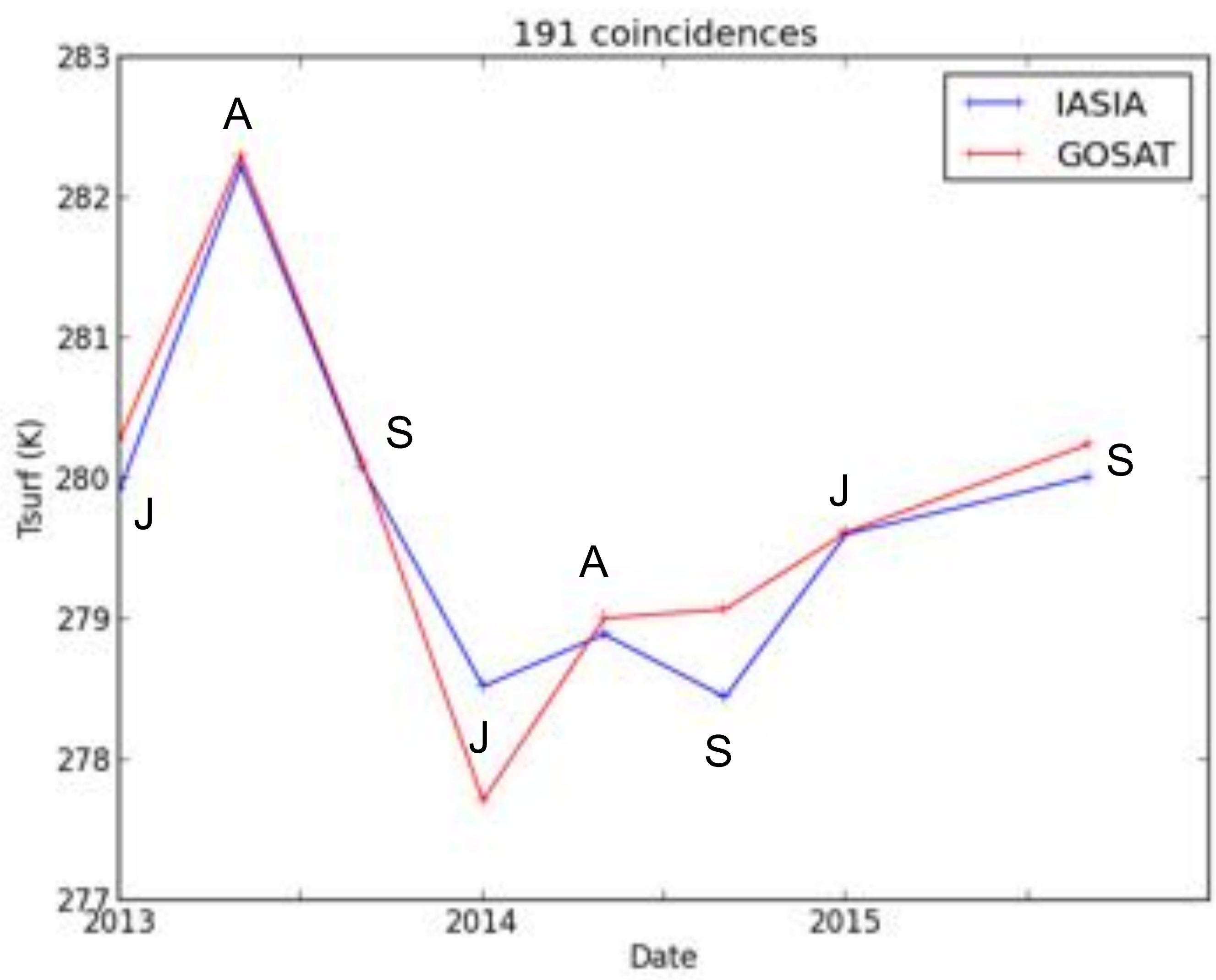
Comparison of T_{surf} for IASI/GOSAT coincidences, xxx=238
$\Delta L < 30$ km, $\Delta t < 1$ hr

Full Arctic ocean

1 slide for IASIA/GOSAT and 1 slide for IASIB/GOSAT

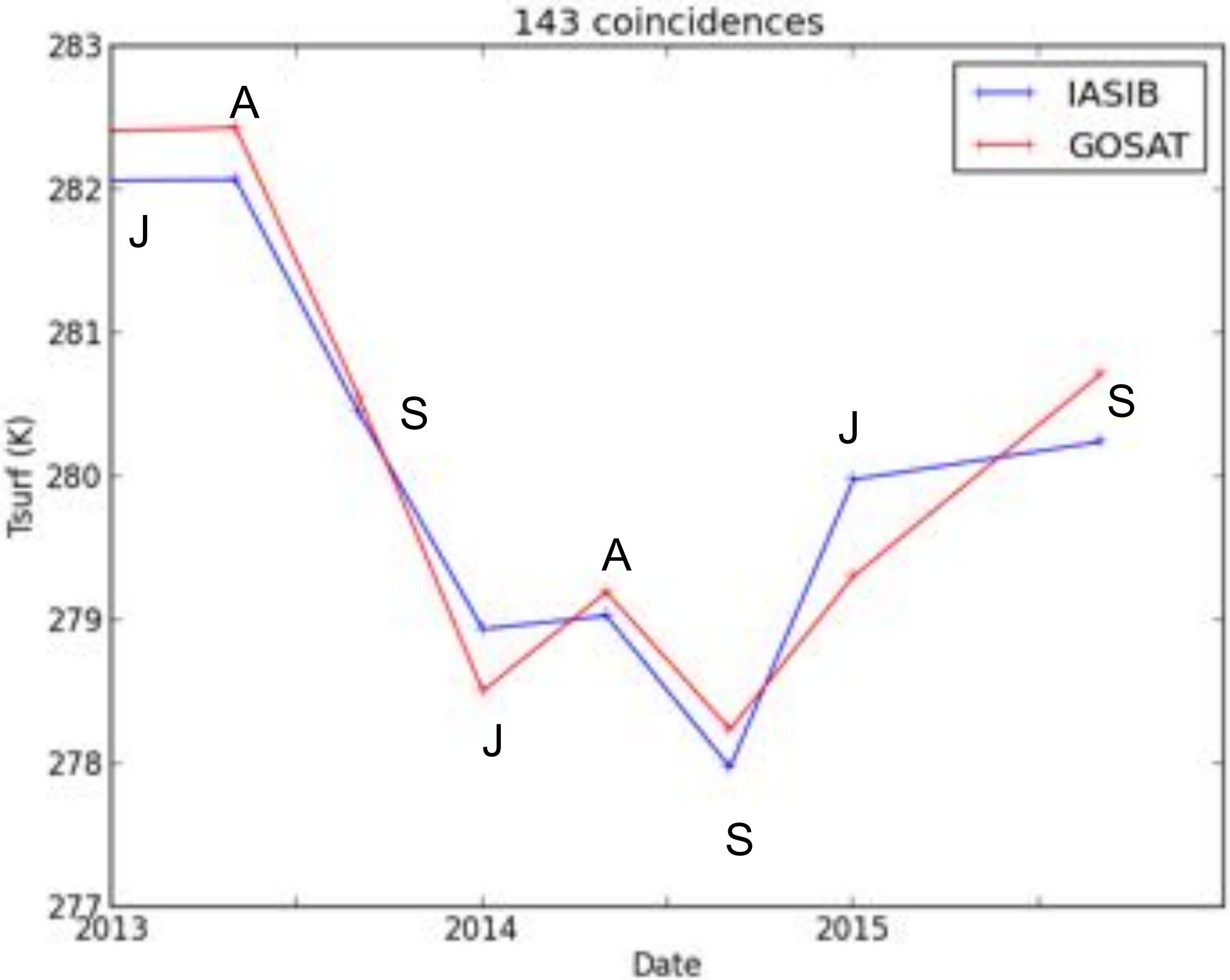
The number of pairs of spectra (one for each sounder) used in the covered period is given above each figure

For GOSAT several consecutive spectra (with dt ~ 4.6 s) pertain to almost the same location (3 IFOVs mode)



J=July, A=Aug, S=Sept

Aug 2015 missing
Because cryocooler
Problems in GOSAT



Aug 2015 missing
Because cryocooler
Problems in GOSAT

Comparison of T_{surf} for IASI/GOSAT coincidences in the period [2013;2015], mean differences, xxx=238

$< T_{surf}(GOSAT) - T_{surf}(IASIA) > \;=\; 0.105 \pm 0.012$ K n=191

$< T_{surf}(GOSAT) - T_{surf}(IASIB) > \;=\; 0.193 \pm 0.020$ K n=143

Conclusion: The absolute radiometric calibration in the [940;980] cm^{-1} region is critical. The statistics of the coincidences is not high enough to make a final statement on the difference between GOSAT and the two IASI.

Note that version v201.202 of TANSO-FTS L1B spectra have been used. The new non-linearity correction applied for version v203.203 will probably change the results. There is probably a small absolute radiometric calibration difference between IASI-A and IASI-B in this specific spectral region.

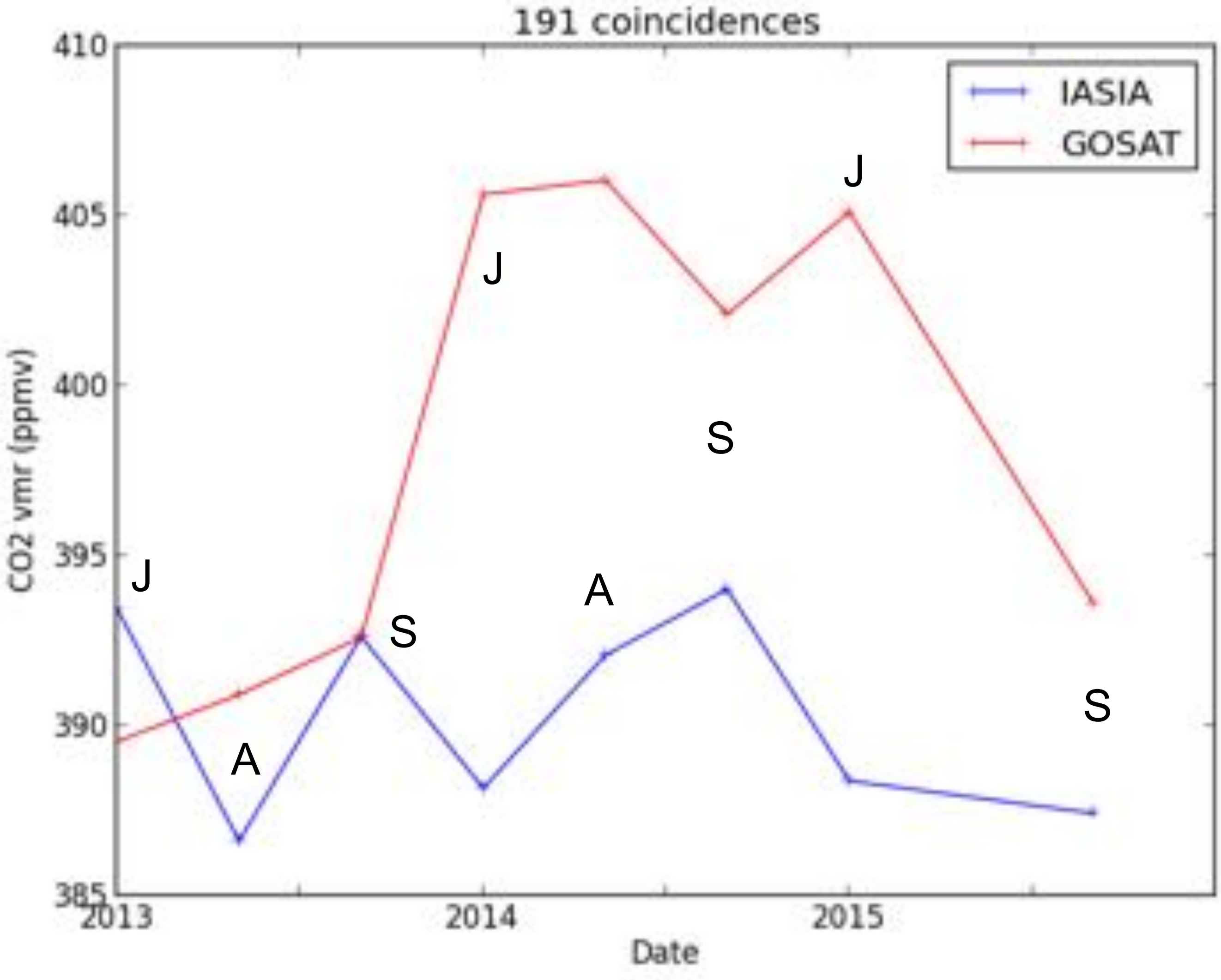
Comparison of XCO_2 for IASI/GOSAT coincidences, xxx=238
$\Delta L < 30$ km, $\Delta t < 1$ hr

Full Arctic ocean

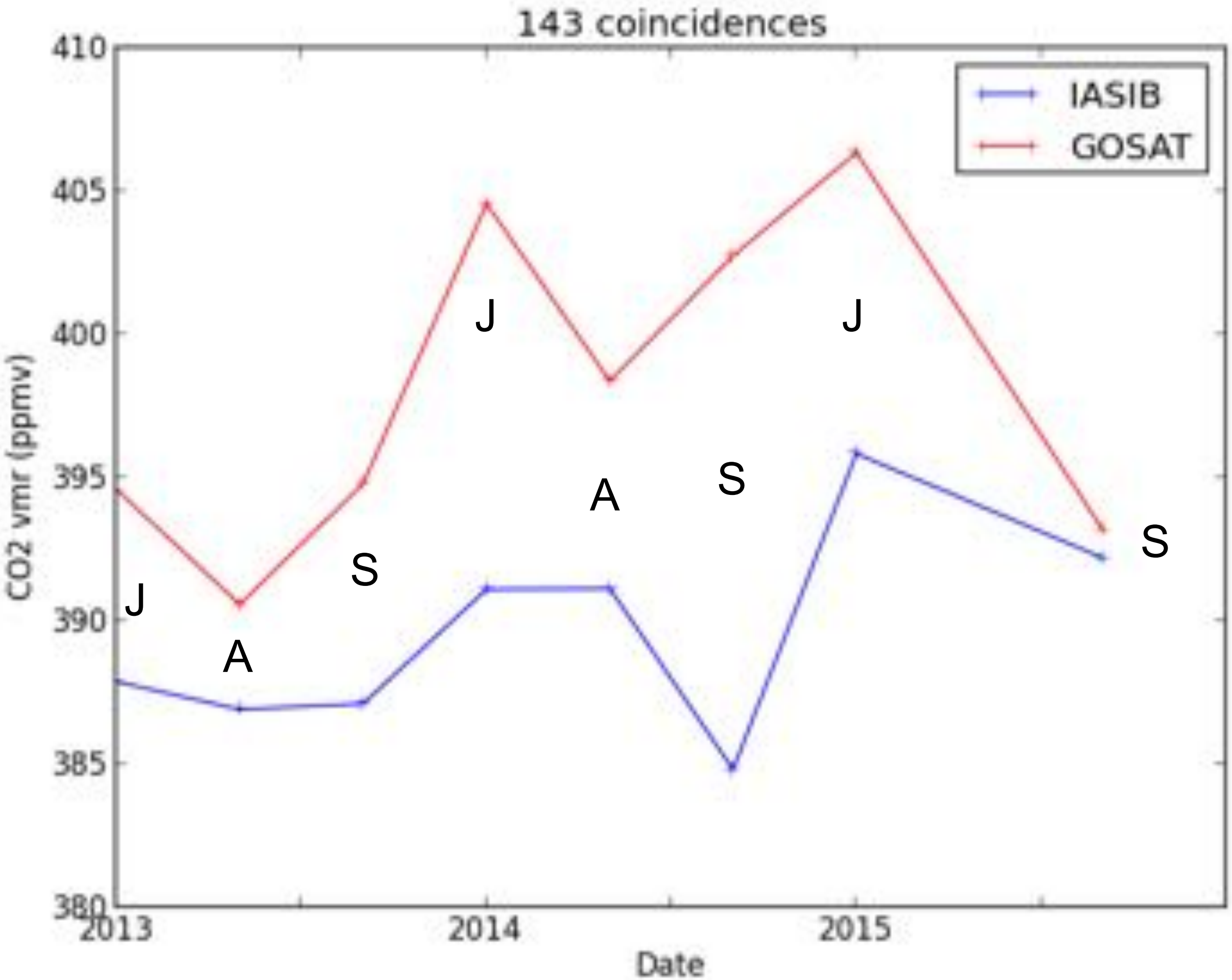
1 slide for IASIA/GOSAT and 1 slide for IASIB/GOSAT

The numbers for each sounder are the total numbers of IFOVs used in the covered period (not the monthly ones)

For GOSAT several consecutive spectra (with dt ~ 4.6 s) pertain to almost the same location (3 IFOVs mode)



Aug 2015 missing because cryocooler problems in GOSAT



Aug 2015 missing because cryocooler problems in GOSAT

Comparison of XCO_2 for IASI/GOSAT coincidences in the period [2013;2015], mean differences, xxx=238

$< XCO_2(GOSAT) - XCO_2(IASIA) > = 6.41 \pm 0.16$ ppmv n=191

$< XCO_2(GOSAT) - XCO_2(IASIB) > = 6.29 \pm 0.24$ ppmv n=143

Conclusion: the bias in XCO_2 (derived from TIR) between GOSAT and IASI is probably due to the difference between the absolute radiometric calibration of the Japanese and French/European instruments

The same type of absolute radiometric calibration differences in other spectral regions may explain some of the bias observed by other groups for XCH_4 retrieved from GOSAT and IASI in the 7.8 µm region

The exact impact of the ILS knowledge on the retrieved values has to be assessed

Summary (1/2)

- This exercise was done to compare the capabilities of retrievals of T_{surf} and CO_2 from GOSAT, IASI-A and IASI-B in one "surface window" i.e. 940-960 cm^{-1} (~10.4 µm) for obtaining "climate quality records" at a regional scale in the summer months of the Arctic Ocean for a period for 3 years common to GOSAT, IASI-A and IASI-B (2013 to 2015) in the latitude region [68N ; 80N]
- The individual T_{surf} precision of GOSAT is ~ 0.10 K 1σ and of IASI is ~ 0.16 K 1σ for clear IFOVs, homogeneous, over sea and with a normal atmospheric lapse rate T(z) profile (from ECMWF)
- The individual XCO_2 precision of GOSAT is ~ 6 ppmv 1σ and of IASI is ~ 10 ppmv 1σ for clear IFOVs, homogeneous, over sea and with a normal lapse rate
- There is no *a priori* constrain on the XCO_2 value except a constant mixing ratio profile $x_{CO2}(z)$. The exact shape of the profile in the oceanic boundary layer is not very well constrained by the models due to the complicated sea-air exchanges
- The variation of T_{surf} with latitude and between July/Aug/Sept is significant
- The interannual variability does not show a trend in T_{surf} at the regional scale
- The overall trend in the CO_2 column averaged VMR is well captured over the 6 years period for GOSAT and IASI-A and 3 years period for IASI-B

Summary (2/2)

- There is a significant interannual variability in XCO_2 over the ice free Arctic Ocean, to be correlated to large anomalies as the year 2012 when an absolute minimum in the ice pack area was observed (by other instruments)
- More work is needed to refine the analysis and get a better statistics on identified Arctic Ocean basins using more IFOVs (a “thinning” of IASI-A and IASI-B IFOVs was performed in the present work, all useful IFOVs have been used for GOSAT)
- The zonal average of XCO_2 over ice free Arctic waters between 68N and 80N for the 3 months of July, August and September and the 6 years between 2010 and 2015 show the expected overall geophysical behaviour, with significant zonal and interannual variations, however
- With these characteristics TIR measurements at high latitude can constrain CO_2 flux inversion models through the ocean-land contrast and latitudinal as well as monthly variations especially in summer
- A longer time frame analysis will consolidate these conclusions using IASI-A data before 2010, more data of IASI-A and IASI-B in 2016, 2017, 2018, and with the operational and backup IASI after the launch of IASI-C
- The GOSAT and IASI mission are not yet providing a fully consistent time series of “climate quality variables” for T_{surf} and CO_2 due to remaining inter-instrument absolute radiometric calibration differences which still need to be carefully examined
- Using the newly available TANSO-FTS version v203.203 including an improved non-linearity correction in B4 (TIR) will reduce the bias between GOSAT and IASI-A/IASI-B

Acknowledgements

- Support from cnes to LATMOS and IPSL
- Access to GOSAT L1b spectra of JAXA Japan Aerospace Exploration Agency and
- Mesocentre IPSL and
  French atmospheric data base Ether
- Acces EUMETSAT products of

Backup slides

Forward model uncertainties near 948 cm^{-1}

- SF_6 Q branch in the vicinity of one CO_2 line and one H_2O line → need better T/P dependence of the SF_6 cross-sections and better line parameters (temperature dependence for the foreign and self-broadening for this H_2O line)
- This leads to an additional spectral variability around 948 cm^{-1}
- Inflating the measurement error near 948 cm^{-1} (3 spectral samples for GOSAT, 2 samples for IASI) is a way to handle the problem
- A more effective solution has been to vary separately the $H_2O(z)$ scaling factor in the range 0.0-0.8 km and in the range 0.8-14.0 km (ensuring continuity). This is correcting for the error of ECMWF in the lowermost layers/levels.
- This is reducing the biais in <Tobs-Tcalc> and loweringing the rms[T_{obs}-T_{calc}], correcting for the impact of the knowledge of the shape of the H_2O profile on the retrieved values of T_{surf} and XCO_2