Evolution of SST and XCO_2 in the summer ice free Arctic Ocean: is IASI able to contribute to climate change studies?

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

4th IASI Conference, 11-15 April 2016, Antibes/Juan-les-Pins, France

Outline

- Using the thermal infrared region (TIR) and IASI (MetOp) for ice free Arctic Ocean studies
- Retrieval scheme
- Sensitivity study as a function of T(z)
- Comparison between IASI-A and IASI-B, and with correlative measurements
- Monthly climatology of T_{surf} and XCO_2 for the period 2010 to 2015 in the 3 summer months
- Impact of IASI for climate studies

Why using IASI for Arctic Ocean studies?

- The Arctic Ocean is a key region where the effect of climate change can be detected over short time periods → the IASI series will emcompass more than 15 years (3 very stable and very similar instruments covering the full thermal infrared region TIR)
- 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 ≤ 70° usually, meaning poor coverage of the sub-polar regions)
- TIR sounders (IASI, AIRS, CrIS and GOSAT TANSO-FTS in B4) are achieving an all day global coverage (usually one daytime and one night time overpass)
- 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 IASI-A and IASI-B?

- It is interesting to compare spectra and retrieved geophysical parameters from the two 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
- 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

Retrieval scheme

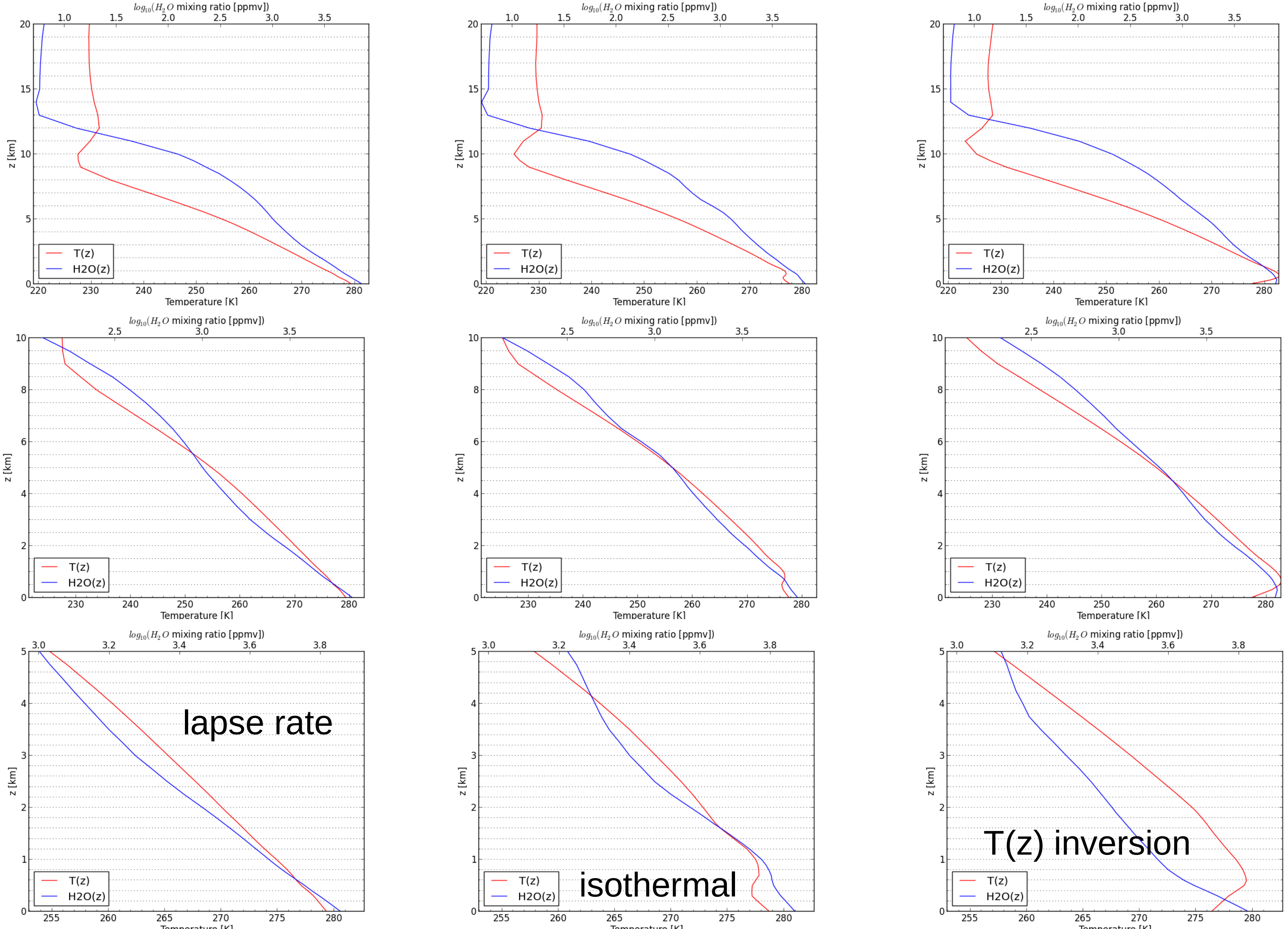
- The line-by-line LARA radiative transfer model (RTM) and its associated retrieval model (package, developed by J. Bureau and S. Payan) has been used
- Even though LARA can be configured for OEM, in the present study spectra where “least squares fitted” with a state vector containing T_{surf} and XCO_2 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

Window fitted and state vector

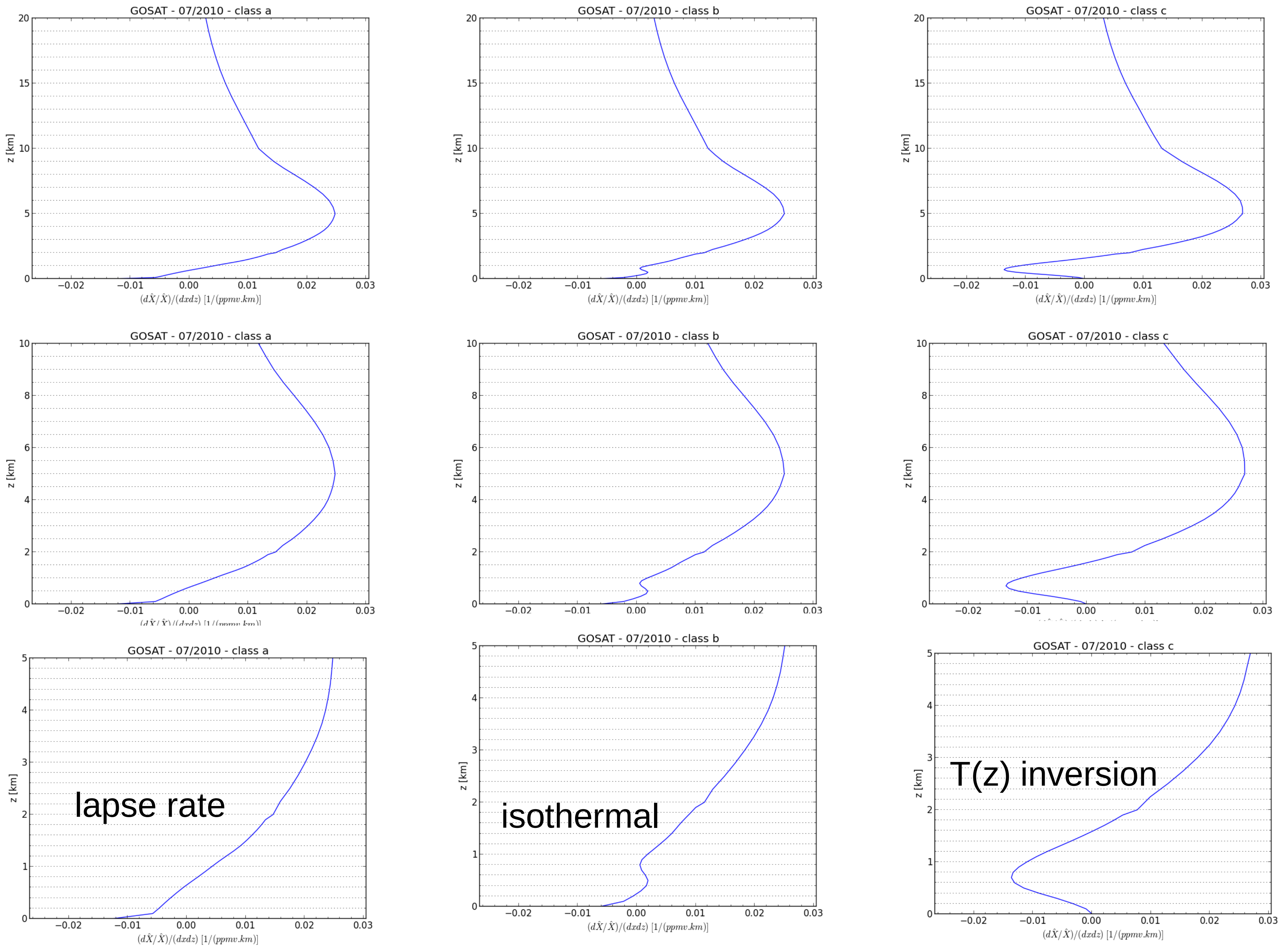
- Window: 940 - 980 cm^{-1}, "CO_2 laser band region"
- State vector: $x=(T_{surf}, XCO_2, coeff\_H_2O, coeff\_O_3)$
- Carmine Serio instrument full covariance matrix
- No *a priori* for T_{surf} and XCO_2, constant mixing ratio profile
- T(z) extracted from ECMWF ERA-Interim analyses
- H_2O(z) profile scaled from ECMWF ERA-I
- SF_6 fixed (including trend between 2010 and 2015)

For checking the retrieval sensitivity to the shape of the actual T(z) profile, results are analysed according 3 classes of profiles: normal lapse rate, isothermal, temperature inversion

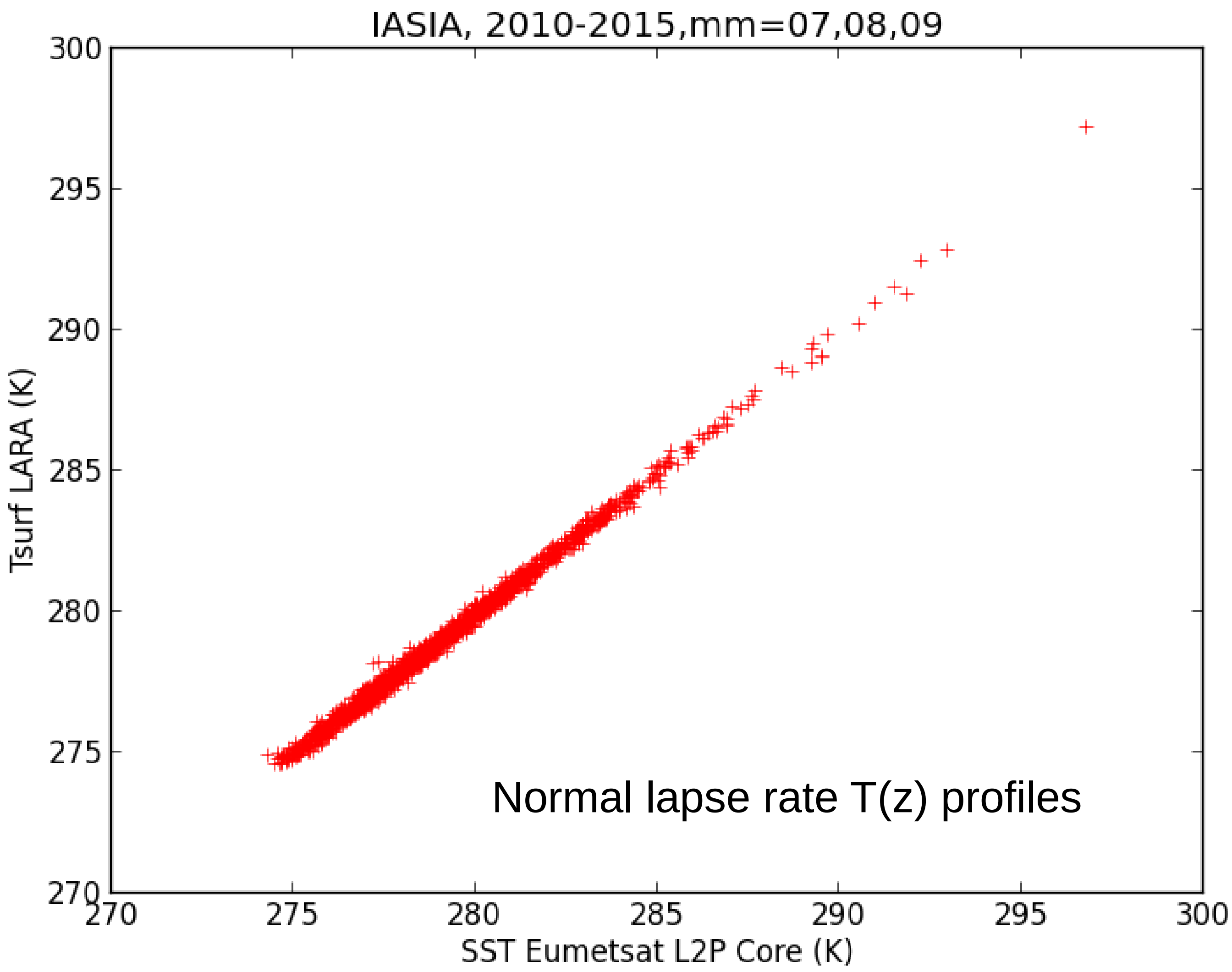
Temperature profile



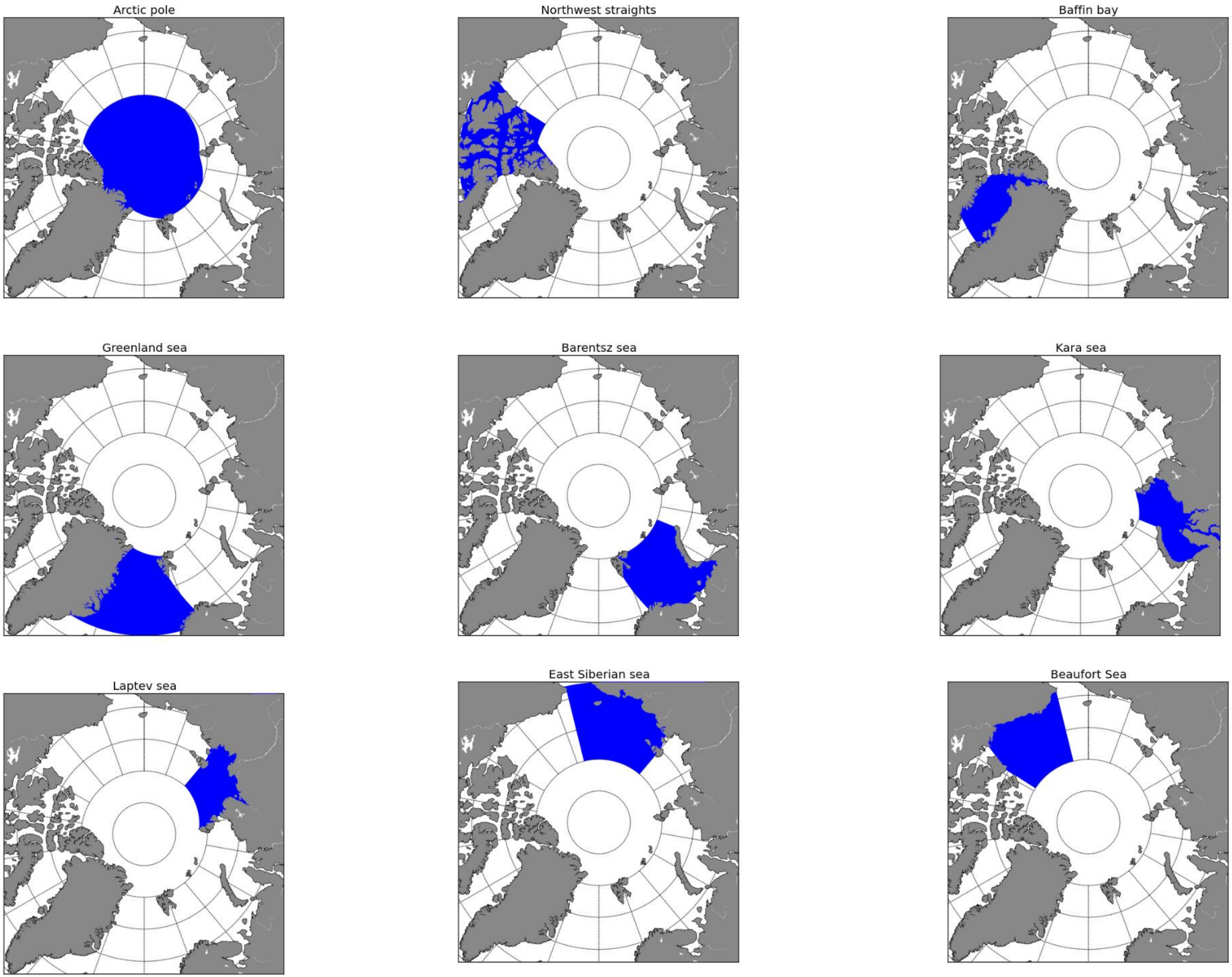
Sensitivity curves



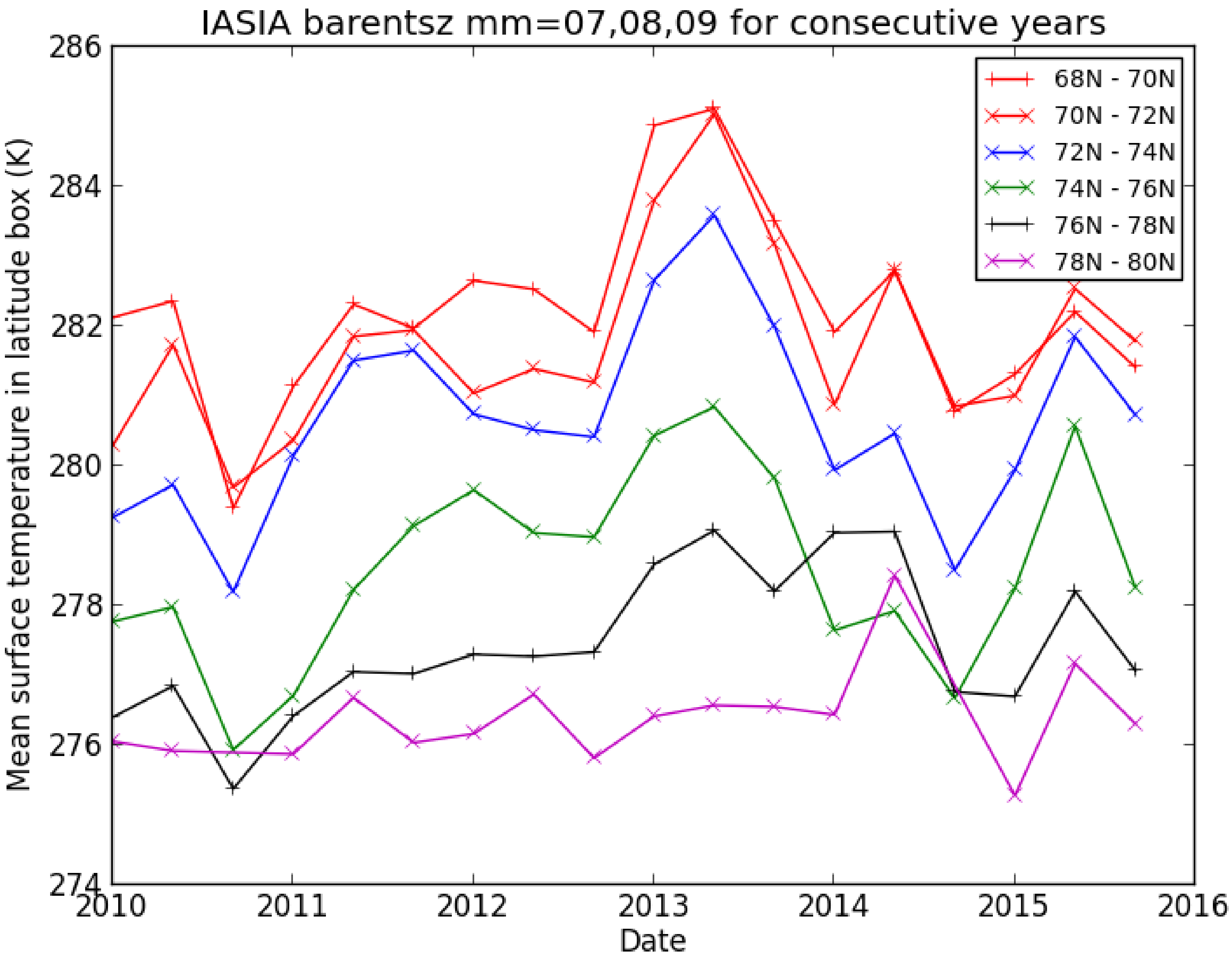
Comparisons of T_{surf} between IASI-A and L2P SST



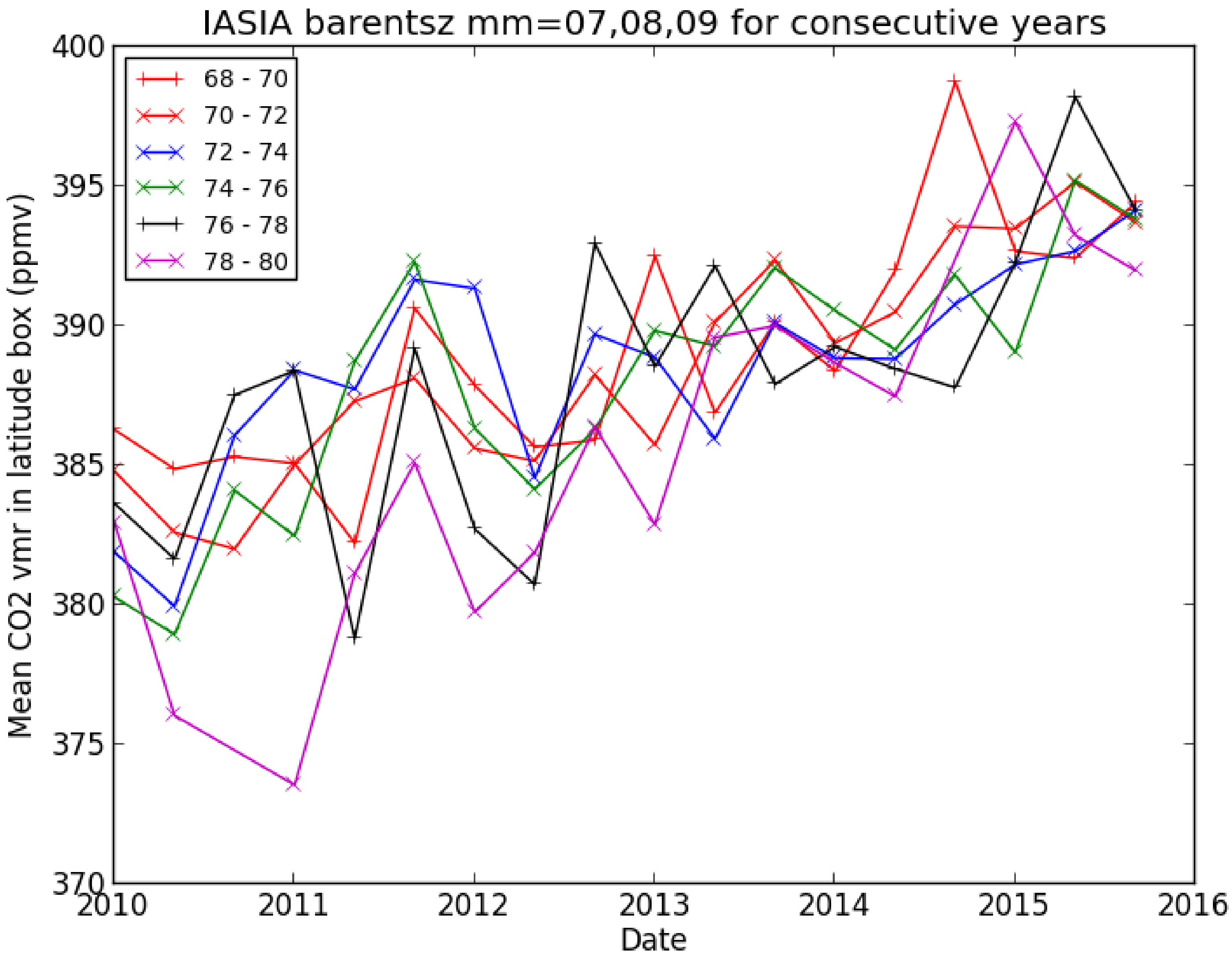
Basins considered for the Arctic Ocean



T_{surf} variation in the Barentsz basin of the Arctic Ocean



XCO_2 variation in the Barentsz basin of the Arctic Ocean



Time series for the variability/trend of T_{surf}

		IASI-A			IASI-B	
yyyymm	nb	<Tsurf>	month order	nb	<Tsurf>	month order
201007	250	279.32	09 < 07 < 08			
201008	392	279.68				
201009	587	277.60				
201107	364	279.70	09 < 07 < 08			
201108	420	279.90				
201109	565	278.45				
201207	305	279.56	09 < 07 < 08			
201208	526	279.90				
201209	595	278.69				
201307	276	279.62	09 < 07 < 08	299	280.07	09 < 07 < 08
201308	480	279.93		505	280.09	
201309	476	279.21		458	279.46	
201407	325	279.19	09 < 07 < 08	375	279.66	09 < 08 < 07
201408	525	278.96		560	279.21	
201409	611	277.98		579	278.37	
201507	355	280.07	09 < 08 < 07	342	280.86	09 < 08 < 07
201508	482	279.64		467	280.19	
201509	646	278.11		591	278.58	

Clear
homogeneous IFOVs
day, ice free
Arctic Ocean [68N ; 80N]

Only lapse rate cases

Average uncertainty
on the mean ~ 0.5 K

nb = number of IFOVs
for the average

Pluriannual variability of T_{surf} for summer months and IASI-A

yyyymm	nb	<Tsurf>	yearly order
201007	250	279.32	2014 < 2010 < 2012 < 2013 < 2011 < 2015
201107	364	279.70	
201207	305	279.56	
201307	276	279.62	
201407	325	279.19	
201507	355	280.07	--> variation over 6 years +0.15 K
201008	392	279.68	2015 ~ 2010 < 2011 = 2012 < 2013 ~ 2014
201108	420	279.90	
201208	526	279.90	
201308	480	279.93	
201408	525	278.96	
201508	482	279.64	--> variation over 6 years -0.04 K
201009	587	277.60	2010 < 2014 < 2015 < 2011 < 2012 < 2013
201109	565	278.45	
201209	595	278.69	
201309	476	279.21	
201409	611	277.98	
201509	646	278.11	--> variation over 6 ans +0.51 K

Clear
homogeneous IFOVs
day, ice free
Arctic Ocean [68N ; 80N]

Only lapse rate cases

Average uncertainty
on the mean ~ 0.5 K

nb = number of IFOVs
for the average

No significant trend
at this regional scale

Pluriannual variability of T_{surf} for summer months IASI-A/IASI-B

yyyymm	IASI-Anb	IASI-A <Tsurf>	IASI-B nb	IASI-B <Tsurf>	<ΔTsurf>[A-B]
201307	276	279.62	299	280.07	-0.55
201407	325	279.19	505	279.66	-0.47
201507	355	280.07	458	280.86	-0.79
201308	480	279.93	375	280.09	-0.16
201408	525	278.96	560	279.21	-0.25
201508	482	279.64	579	280.19	-0.55
201309	476	279.21	342	279.46	-0.25
201409	611	277.98	467	278.37	-0.39
201509	646	278.11	591	278.58	-0.47

Clear
homogeneous IFOVs
day, ice free
Arctic Ocean [68N ; 80N]

Only lapse rate cases

Average uncertainty
on the mean ~ 0.5 K

nb = number of IFOVs
for the average

Overall consistency
of the monthly trend
for the 3 years

Possible small biais
between the retrieved
T_{surf} using
the two sounders

Time series for the variability/trend of CO_2

		IASI-A			IASI-B	
yyyymm	nb	<Tsurf>	month order	nb	<Tsurf>	month order
201007	250	386.26	07 > 09 > 08			
201008	392	383.02				
201009	587	384.42				
201107	364	383.58	09 > 07 > 08			
201108	420	383.36				
201109	565	385.24				
201207	305	385.93	09 > 07 > 08			
201208	526	384.28				
201209	595	387.16				
201307	276	391.10	07 > 09 > 08	299	390.07	07 > 09 > 08
201308	480	387.84		505	387.52	
201309	476	390.36		458	389.01	
201407	325	390.98	09 > 07 > 08	375	390.12	07 > 09 > 08
201408	525	389.72		560	389.16	
201409	611	392.33		579	390.01	
201507	355	392.62	09 > 07 > 08	342	392.09	09 > 07 > 08
201508	482	391.26		467	390.74	
201509	646	393.92		591	393.56	

Clear
homogeneous IFOVs
day, ice free
Arctic Ocean [68N ; 80N]

Only lapse rate cases

Average uncertainty
on the mean ~ 0.5 ppmv

nb = number of IFOVs
for the average

mm=08 i.e. August
has the smallest XCO_2
in all years and
for both sounders

Pluriannual variability of CO_2 for summer months and IASI-A

yyyymm	nb	<CO_2>	yearly order
201007	250	386.26	2011 < 2012 < 2010 < 2014 < 2014 < 2015
201107	364	383.58	-2.68
201207	305	385.93	+2.35
201307	276	391.10	+5.17
201407	325	390.98	-0.12
201507	355	392.62	+1.64 --> over 5 years +1.27 ppmv/yr
201008	392	383.02	2011 < 2010 < 2012 < 2013 < 2014 < 2015
201108	420	383.36	+0.34
201208	526	384.28	+0.92
201308	480	387.84	+3.56
201408	525	389.72	+1.88
201508	482	391.26	+1.54 --> over 5 years +1.65 ppmv/yr
201009	587	384.42	2010 < 2011 < 2012 < 2013 < 2014 < 2015
201109	565	385.24	+0.82
201209	595	387.16	+1.92
201309	476	390.36	+3.20
201409	611	392.33	+1.97
201509	646	393.92	+1.59 --> over 5 years +1.90 ppmv/yr

Clear
homogeneous IFOVs
day, ice free
Arctic Ocean [68N ; 80N]

Only lapse rate cases

Average uncertainty
on the mean ~ 0.5 ppmv

nb = number of IFOVs
for the average

Trend slightly less than
the “standard” ~2 ppmv/yr

Arctic Ocean is a sink
in summer?

Pluriannual variability of CO_2 for summer months IASI-A/IASI-B

yyyymm	IASI-Anb	IASI-A $<CO_2>$	IASI-B nb	IASI-B $<CO_2>$	$<\Delta CO_2>$[A-B]
201307	276	391.10	299	390.07	+1.03
201407	325	390.98	505	390.12	+0.86
201507	355	392.62	458	392.09	+0.53
201308	480	387.84	375	387.52	+0.32
201408	525	389.72	560	389.16	+0.56
201508	482	391.26	579	390.74	+0.52
201309	476	390.36	342	389.01	+1.35
201409	611	392.33	467	390.01	+2.32
201509	646	393.92	591	393.56	+0.36

Clear IFOVs
Homogeneous
day, ice free
Arctic Ocean [68N ; 80N]

Only lapse rate cases

Average uncertainty
on the mean ~ 0.5 ppmv

nb = number of IFOVs
for the average

Overall consistency
of the monthly trend

Possible small biais
between the retrieved
XCO_2 using the
two sounders

Summary (1/2)

- This exercise was done to compare the capabilities of retrievals of T_{surf} and CO_2 from 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 of 6 years for IASI-A (2010 to 2015) and 3 years for IASI-B (2013 to 2015) with a global, a basin scale and 2° latitude band disaggregation in the latitude region [68N ; 80N]
- The individual T_{surf} uncertainty of IASI is ~ 0.05 K 1σ for clear IFOVs, homogeneous, over sea and with a normal atmospheric lapse rate T(z) profile (from ECMWF)
- The individual XCO_2 uncertainty 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 IASI-A and 3 years period for IASI-B

Summary (2/2)

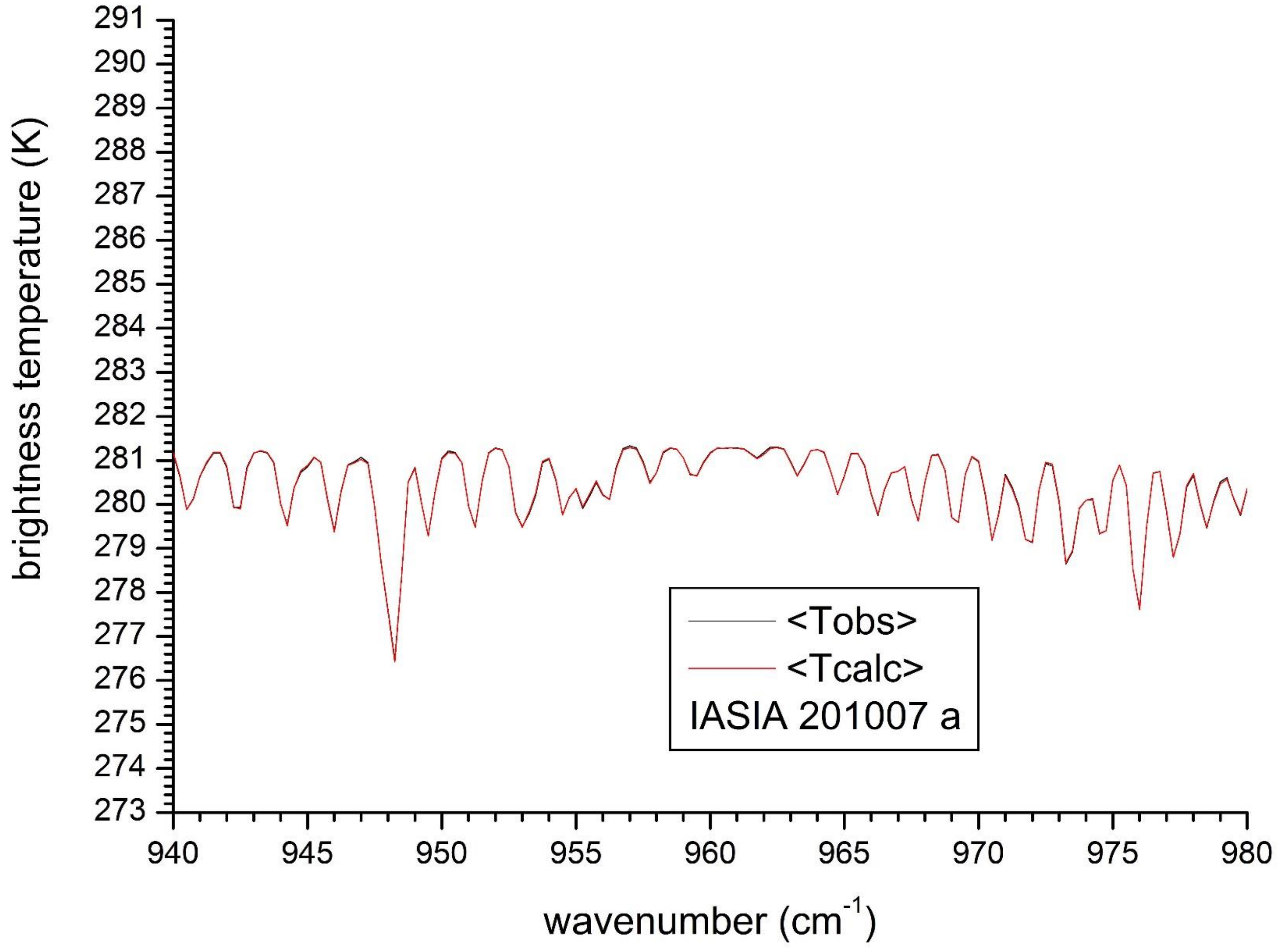
- There is a significant interannual variability in XCO_2 over the ice free Arctic Ocean, to be correlated to large anomalies as the year 2012 when an absolute minimum in the ice pack area was observed (by other instruments)
- More work is needed to refine the analysis and get a better statistics on 2° regional zones of identified Artctic Oceans basins using more IFOVs (a "thinning" of IFOVs was performed in the present work)
- The zonal average of XCO_2 over ice free Arctic waters by latitude bands 2° wide 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 IASI mission is indeed providing series of "climate quality variables" for T_{surf} and CO_2 in the not so well documented Arctic region
- Small remaining inter-instrument differences still need to be carefully examined

Acknowledgements

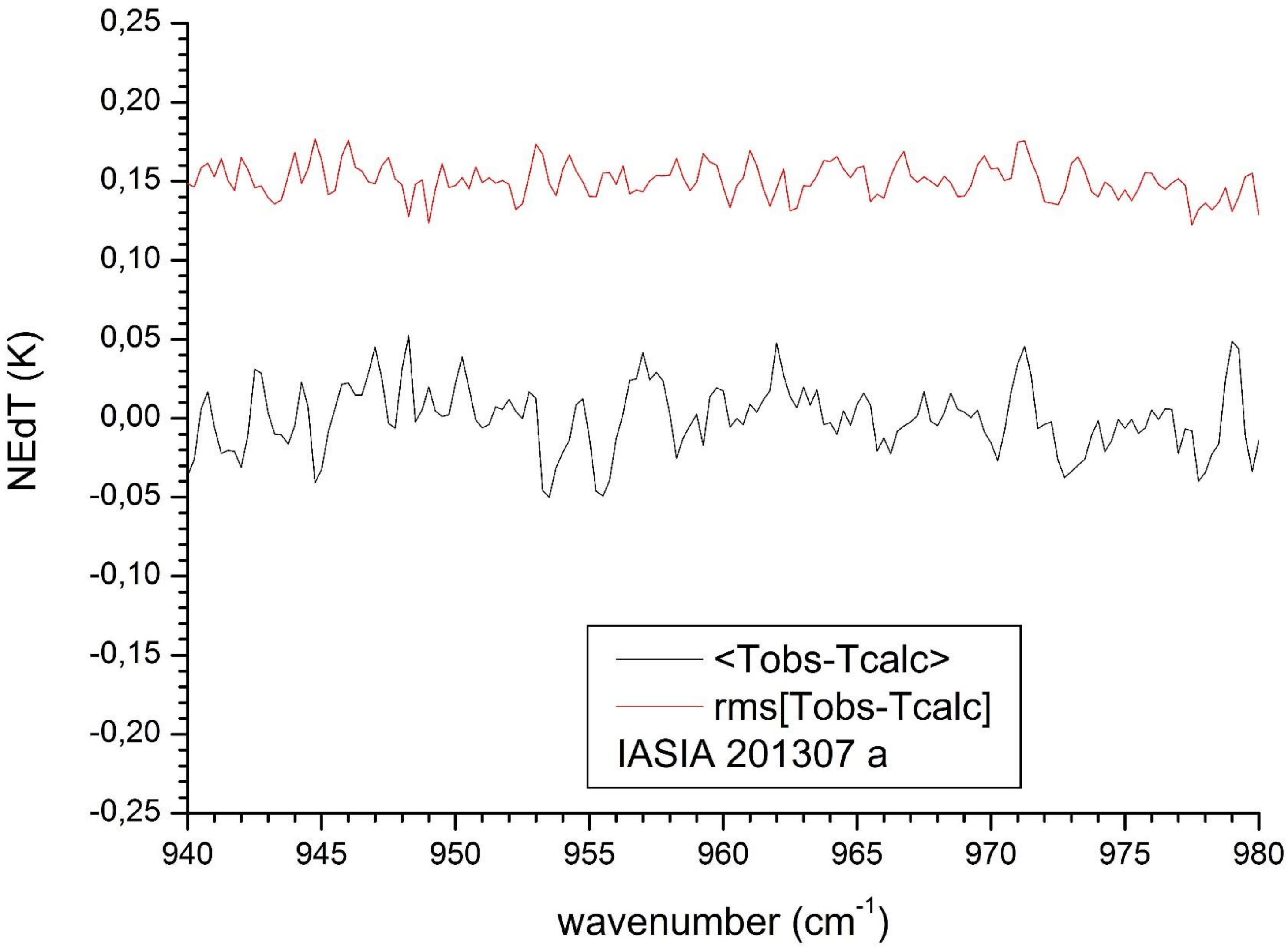
- Support from cnes to LATMOS and IPSL
- Access to IASI L1 and L2 products of EUMETSAT
- Mesocentre IPSL and French atmospheric data base Ether
- Special thanks to D. Coppens and B. Théodore from EUMETSAT

Backup slides

Fitted spectra with T_{obs} and T_{calc}



Fitted spectra with <obs-calc> and <rms>



Forward model uncertainties in the RTM 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} (2 spectral samples for IASI) is a proper way to handle this problem