IASI / METOP retrievals within the project MUSICA

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1. Retrieval setup (target products: H2O, δD, and CH_4)
2. Theoretical error estimation
3. Empirical validation using ground-based FTIR
4. CH_4 product: error estimation, and empirical validation

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General retrieval characteristics

- Optimal estimation retrieval:

$$[y - F(x)]^T S_\epsilon [y - F(x)] + [x - x_a]^T S_a [x - x_a]$$

- Line-by-line forward model: PRFFWD

- Application of HITRAN 2008 spectroscopic parameters

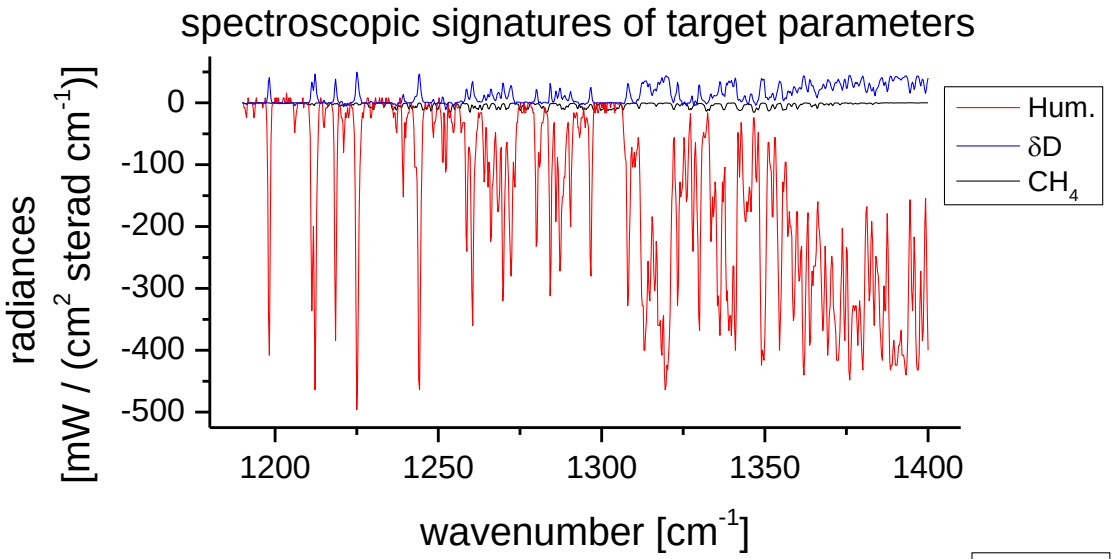
- Use broad spectral window (1190 – 1400 cm^{-1}) and simultaneous retrieval of $H_2{}^{16}O$, $HD^{16}O$ (+ δD), CH_4, and N_2O (+ CO_2, O_3, and HNO_3)

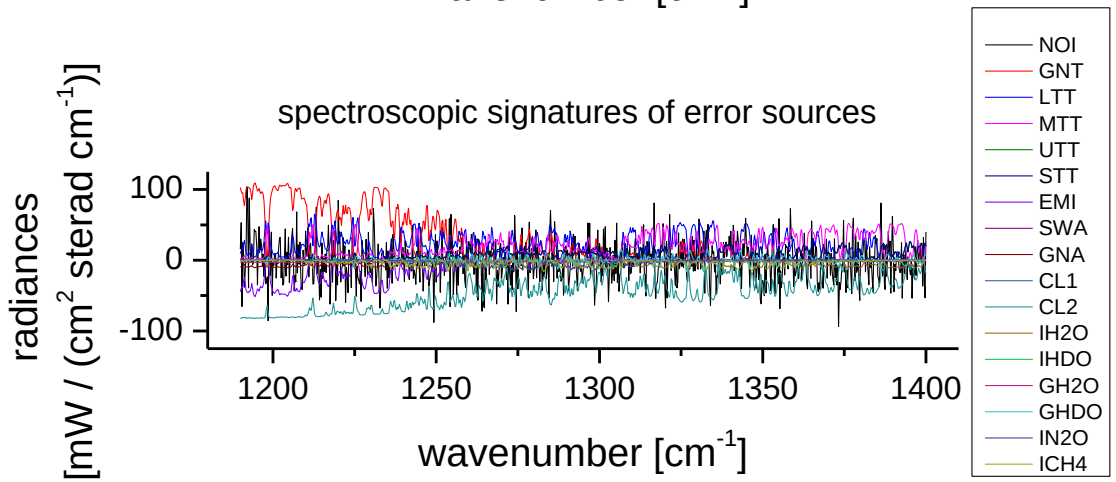
- The a priori is kept constant, i.e. all the retrieved variability is introduced by the IASI measurement !

- Retrieval of temperature profile (but constraint towards EUMETSAT L2 temperature)

- We only consider cloud free pixel (based on EUMETSAT level 2 cloud product)

1190-1400 cm^{-1}: target parameters and errors





Humidity has a strong variability:
very strong signature

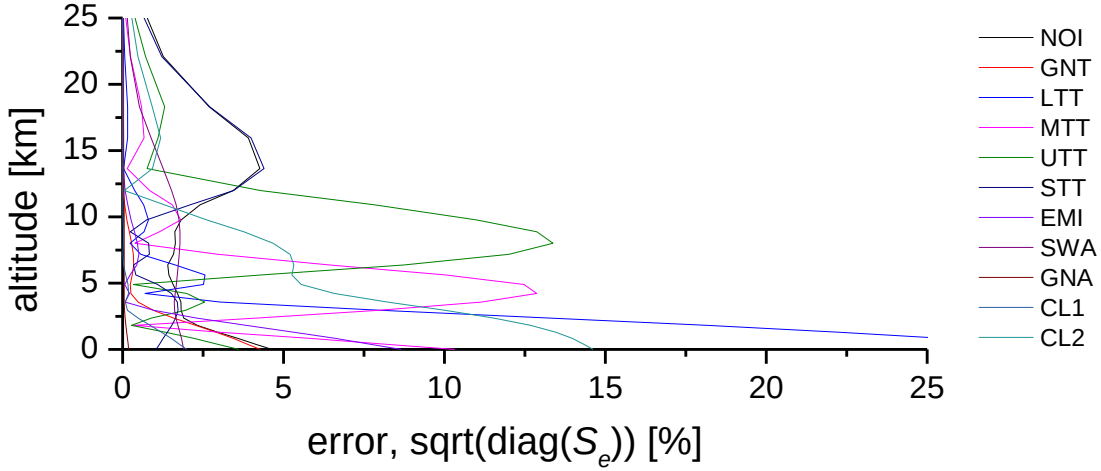
δD and CH4 variability is weak: weak signature!
→ retrieval will be difficult or very difficult!

Error signatures (ϵ):

<u>NOI:</u> meas. Noise
<u>GNT:</u> ground temperature
<u>LTT, MTT, UTT, STT:</u> atmos. temp.
<u>EMI:</u> emissivity
<u>SWA:</u> Swath angle
<u>CL1, CL2:</u> low and high cloud
<u>IH2O, IHDO, GH2O, GHDO, IN2O, ICH4:</u> Hitran parameter uncertainty

Typical errors for humidity and δD product

(1): Humidity error covariances: $S_e = G\epsilon\epsilon^T G^T$

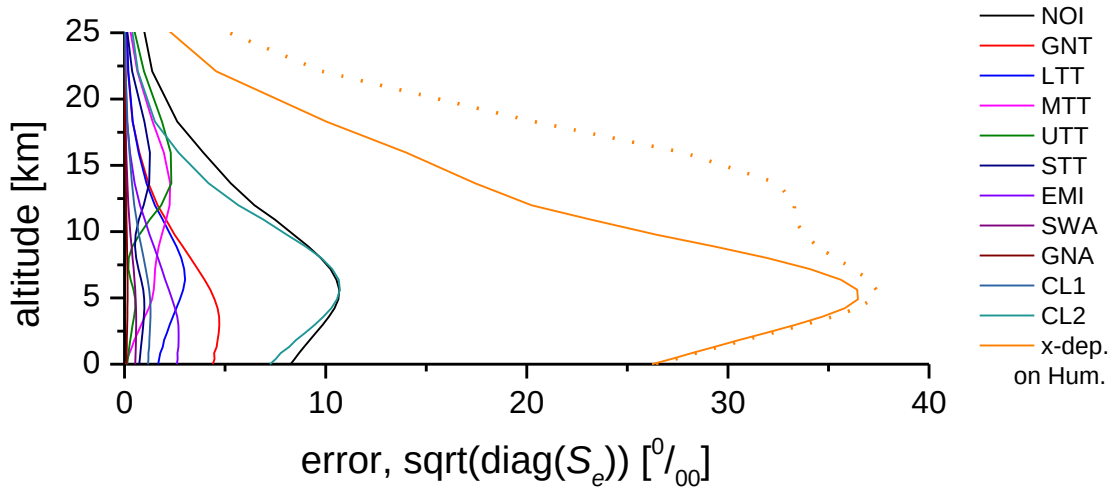


Leading error sources:

- Atmospheric temperture uncertainty (LTT - STT)
- High subvisible cloud (CL2)

(2): δD (or HDO/H2O) error covariances (Schneider et al., 2012): $S_e = PG\epsilon\epsilon^T G^T P^T$

Trafo P: { ln[H2O] , ln[HDO] } → { 1/2*ln[H2O]+ln[HDO] , ln[HDO]-ln[H2O] }



Leading error sources:

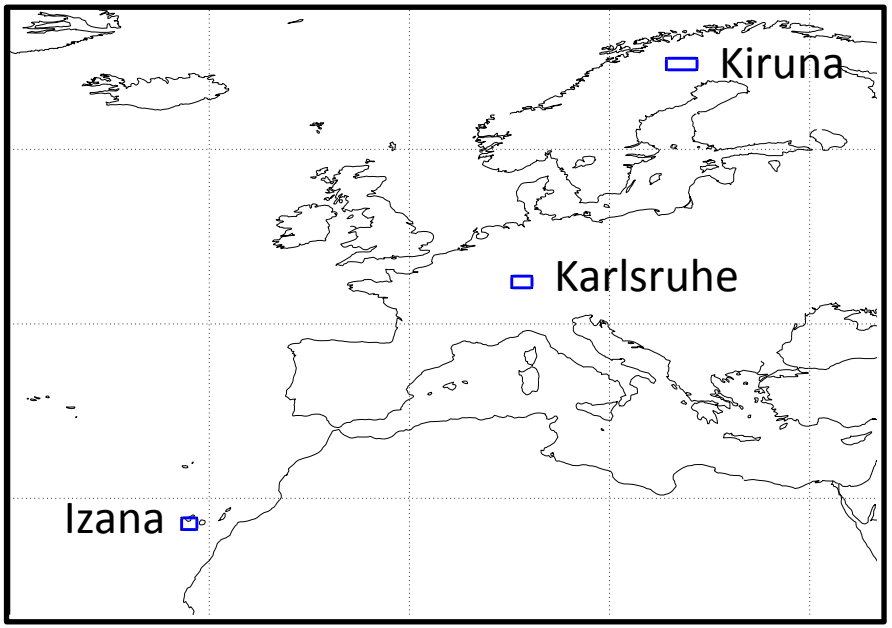
- Cross-dependence on humidity
- Measurement noise (NOI)
- High subvisible cloud (CL2)

Empirical validation of IASI products

Ideal situation: continuous, high-quality observations of atmospheric reference profiles within 2 hours of overpasses

Here we use reference data obtained from the ground-based FTIR experiments operated within the prestigious international network NDACC

Test retrievals for three sites where IASI observations are made in coincidence with gb FTIR NDACC reference observations (res.: 0.005cm^{-1} !):



Ground-based FTIR as validation reference

(1): Gb FTIR provide profile data with very high quality

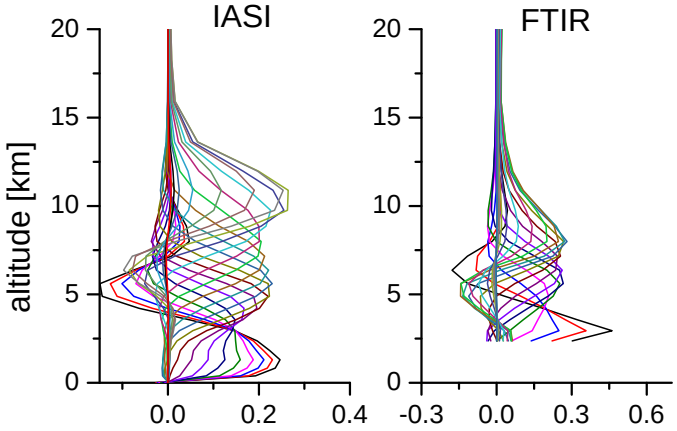
Humidity: Schneider et al. (2006; 2009); Sussmann et al. (2009); Palm et al. (2009)

δD: Schneider et al. (2006; 2012)

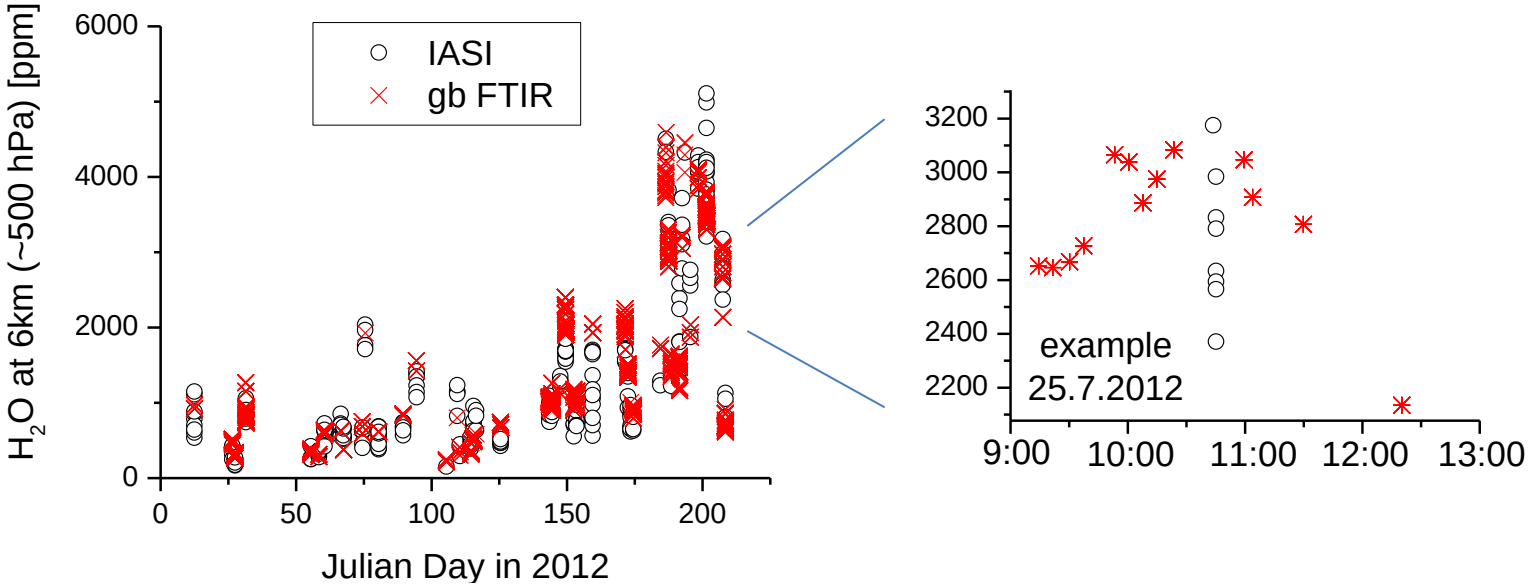
CH_4: Sepúlveda et al. (2012)

O_3: Barret et al. (2003); Schneider et al. (2008); García et al. (2012)

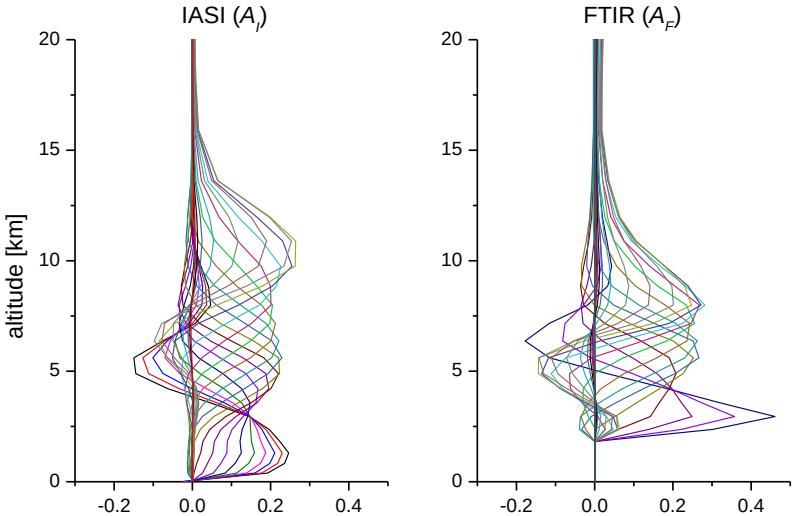
(2): Gb FTIR and IASI kernels overlap



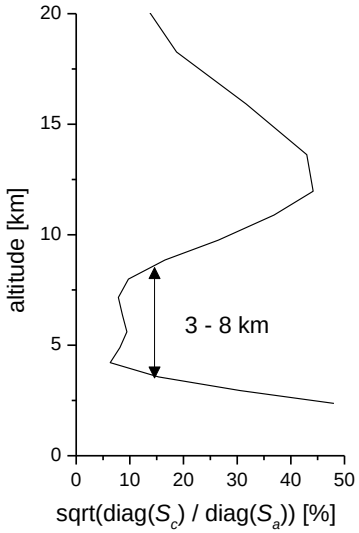
(3): Gb FTIR can measure quasi continuously (during daytime)

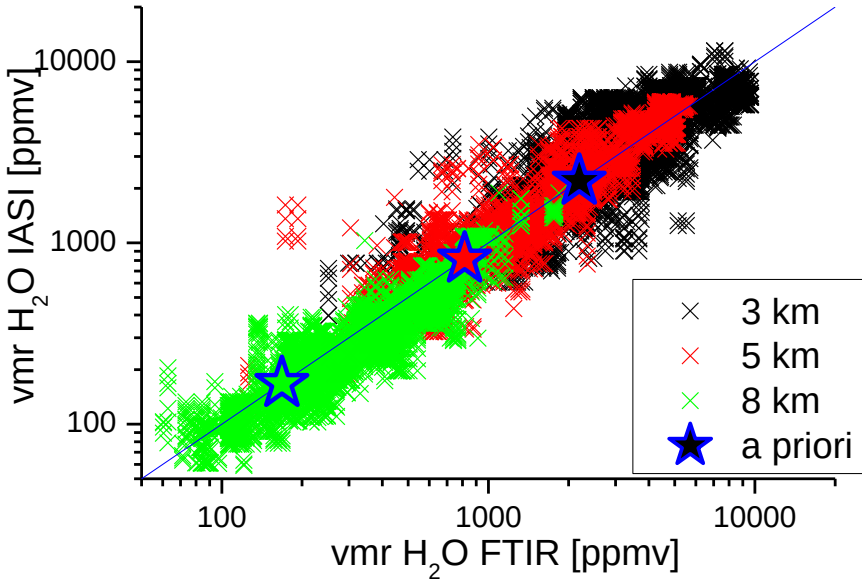


Validation of humidity, example Izana



$$S_c = (A_I - A_F)\, S_a\, (A_I - A_F)^T$$

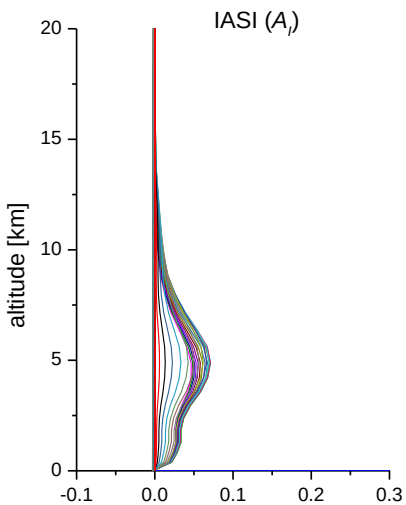


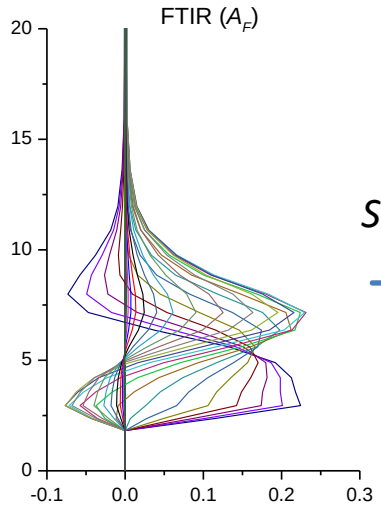


AVKs are similar: comparison is straightforward

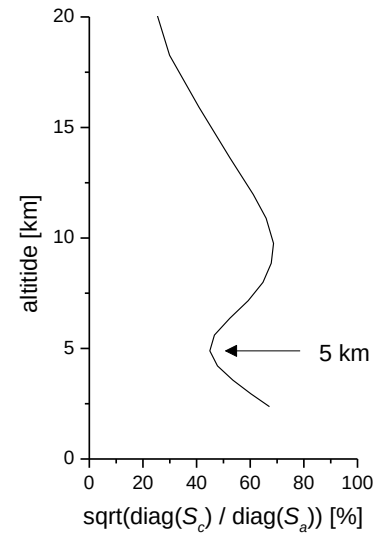
- Good agreement between IASI and FTIR
- No significant difference

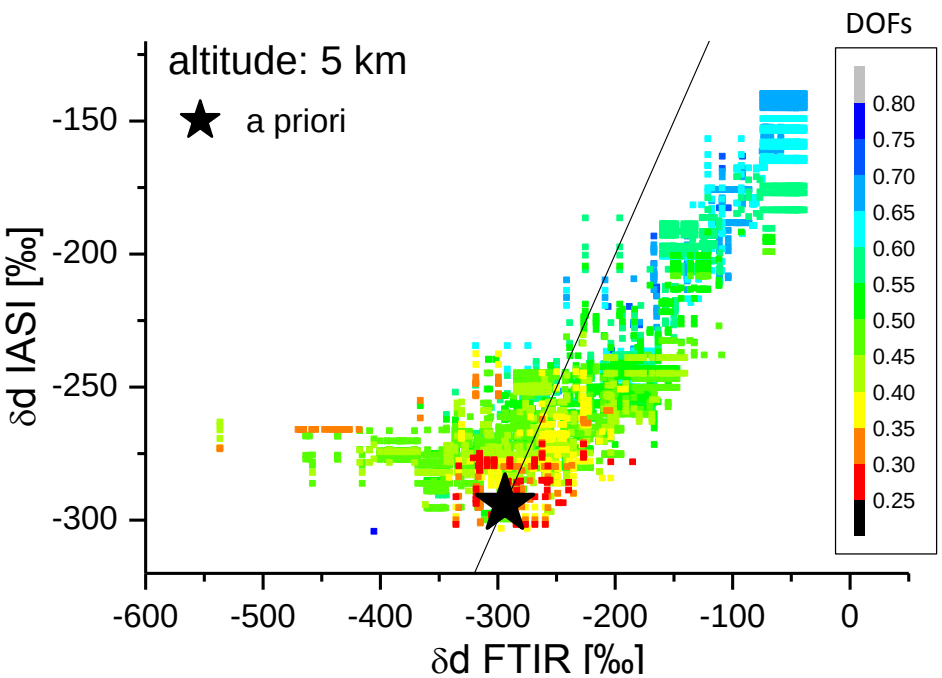
Validation of δD, example Izana





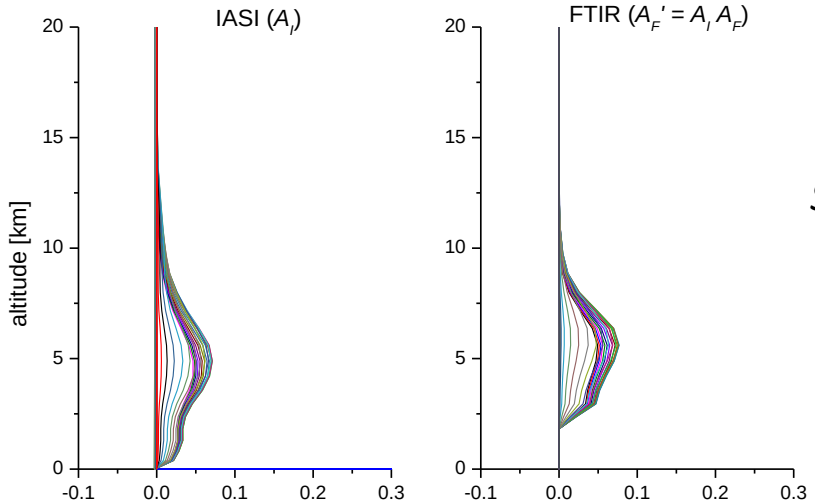
$$S_c = (A_I - A_F)\, S_a\, (A_I - A_F)^T$$



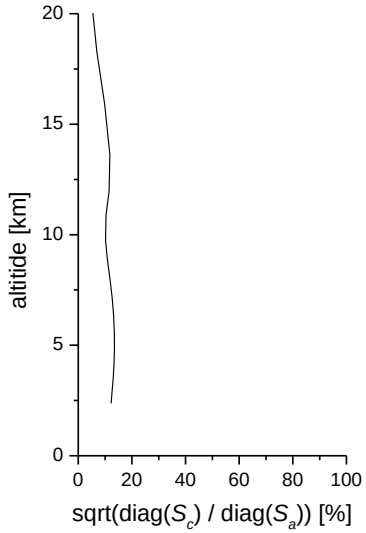


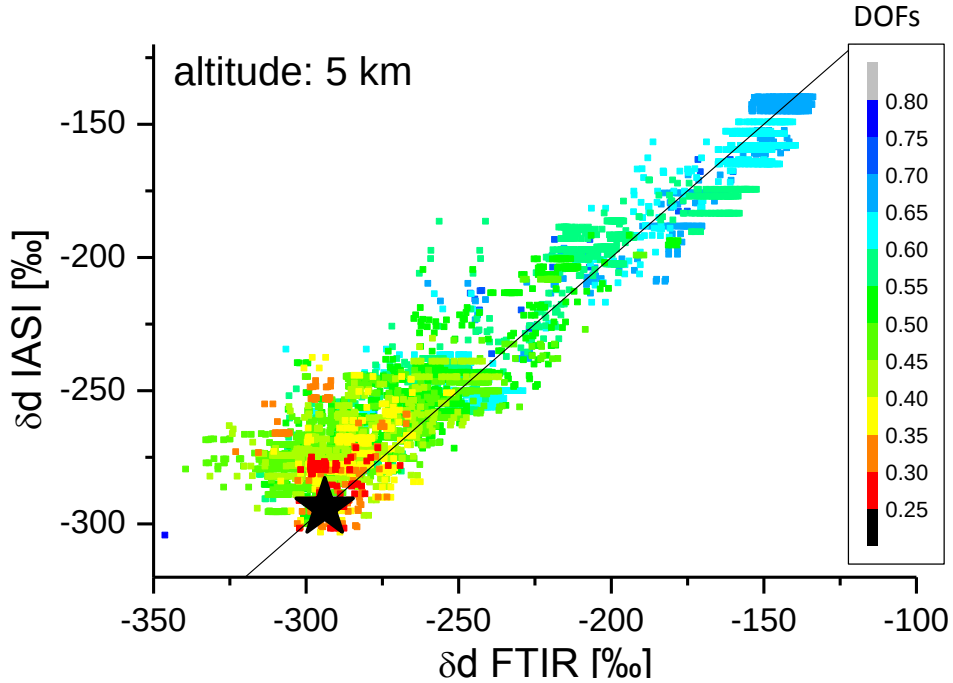
AVKs are significantly different: Interpretation of this inter-comparison is difficult!

Validation of δD (adjusting FTIR sensitivity: $A_F' = A_I A_F$)



$$S_c = (A_I - A_F)\, S_a\, (A_I - A_F)^T$$



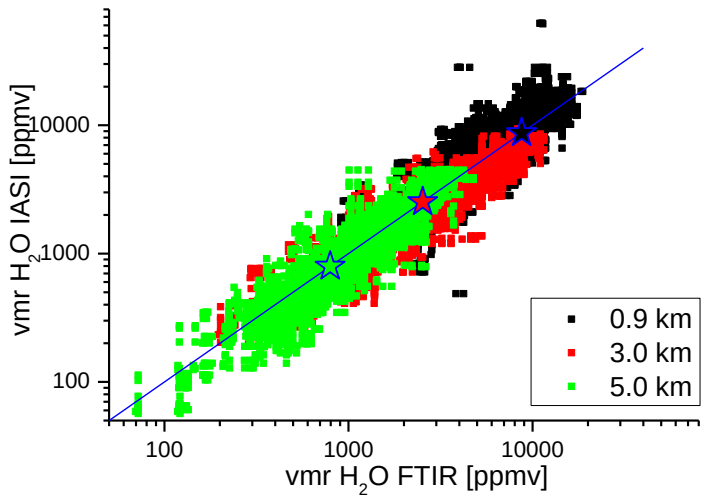


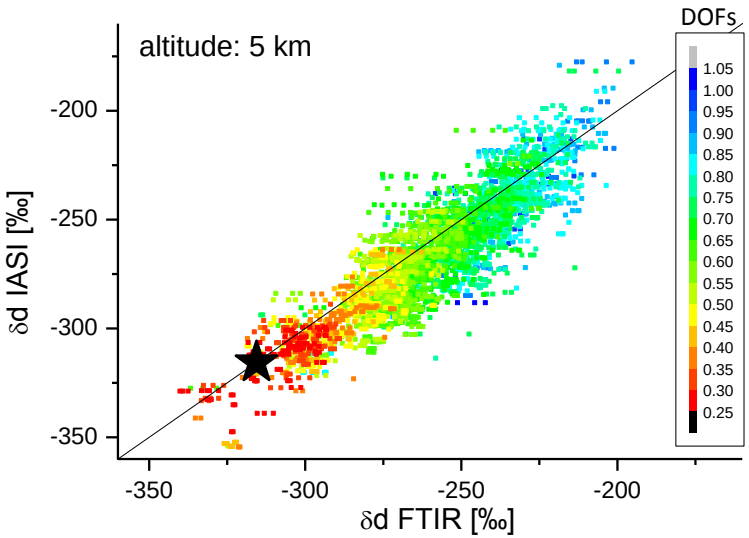
When adjusting AVKs:

- Good agreement between IASI and FTIR
- No significant difference

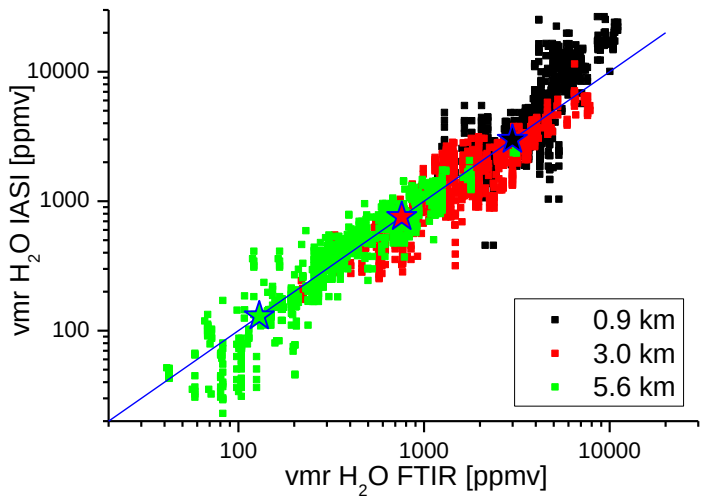
→ IASI can well measure middle tropospheric δD

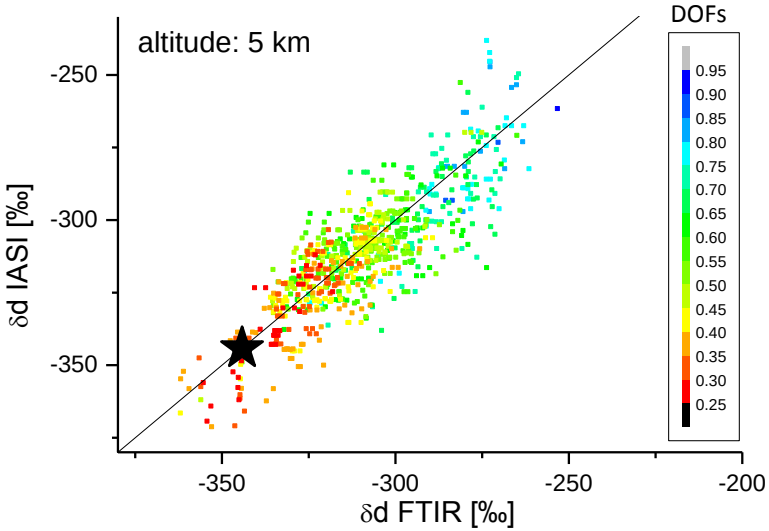
Validation of humidity and δD, Karlsruhe:



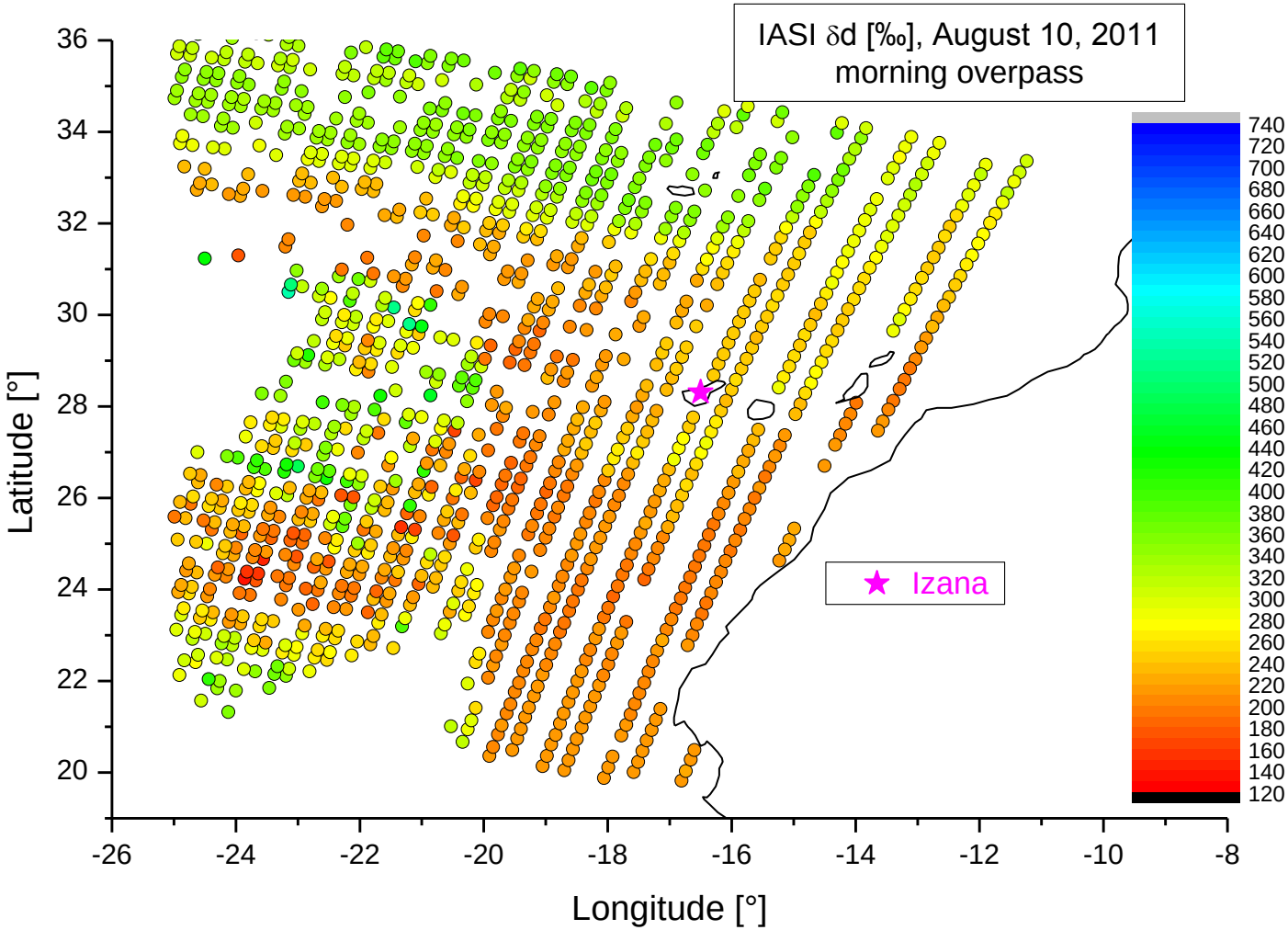


Validation of humidity and δD, Kiruna:

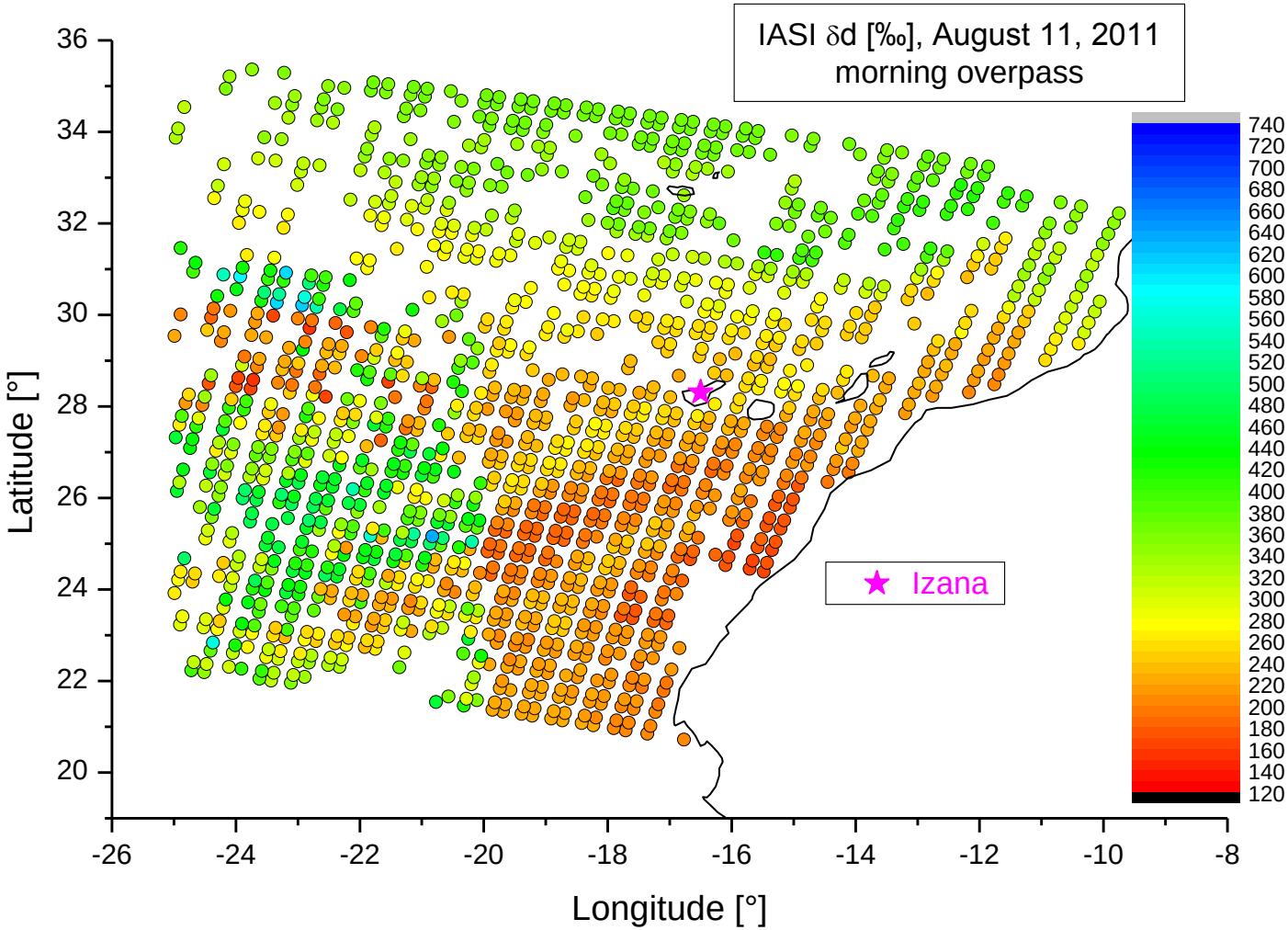




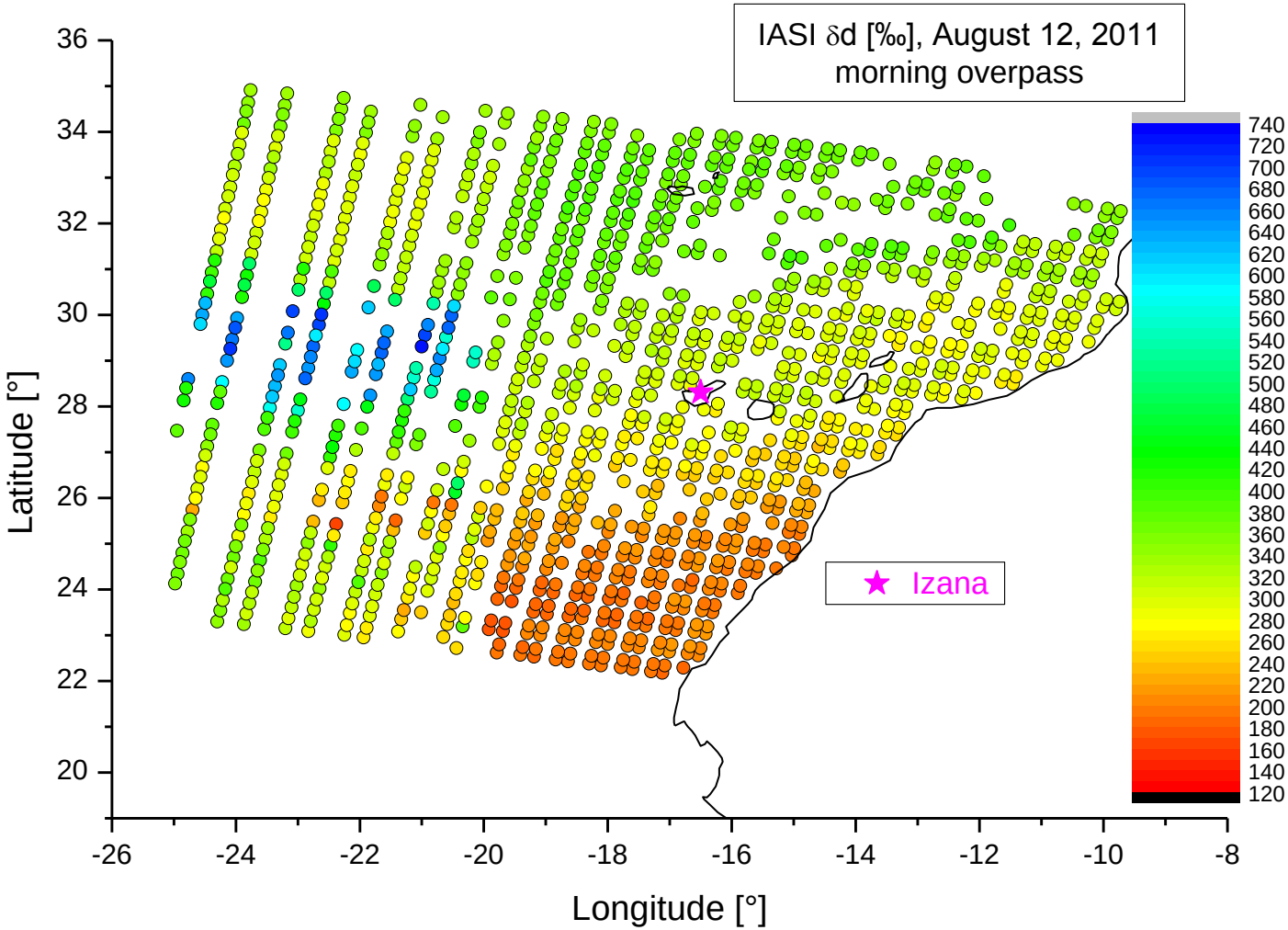
IASI's unique potential for continuous δD observations



IASI's unique potential for continuous δD observations

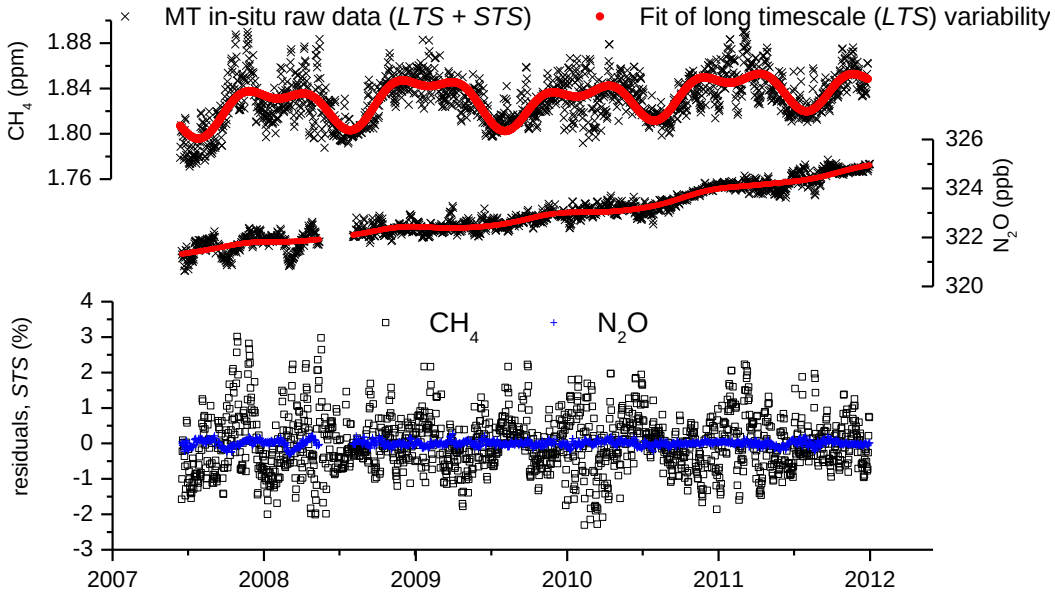


IASI's unique potential for continuous δD observations

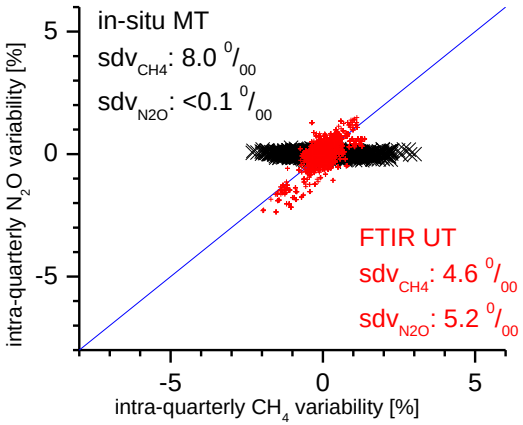


Middle/upper tropospheric CH_4

$CH_4 = LTS(CH_4) + STS(CH_4)$; whereby LTS is long timescale and STS short timescale variability



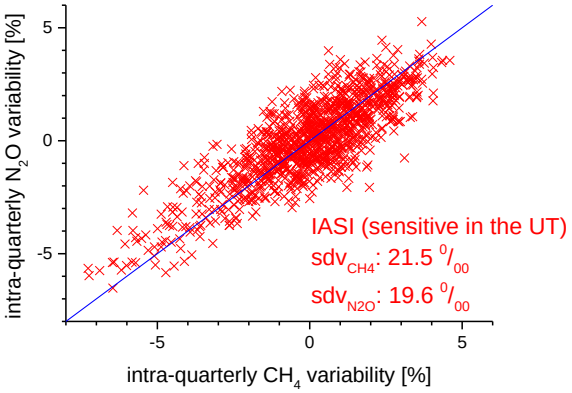
$STS(CH_4)$ and $STS(N_2O)$ as seen by in-situ and remote sensors



For intra-quarterly timescales (short timescales, STS) in-situ N_2O is very stable!

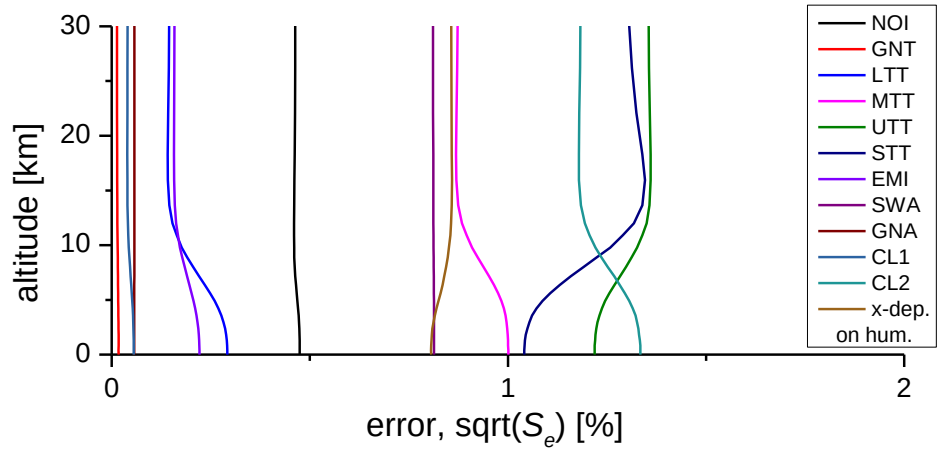
→ We use the N_2O STS variability as stability reference of the remote sensors and correct CH_4 accordingly:

$$CH_4' = LTS(CH_4) + \underbrace{\{ STS(CH_4) - STS(N_2O) \}}_{\text{corrected short timescale (STS) variability}}$$



CH_4 error estimation

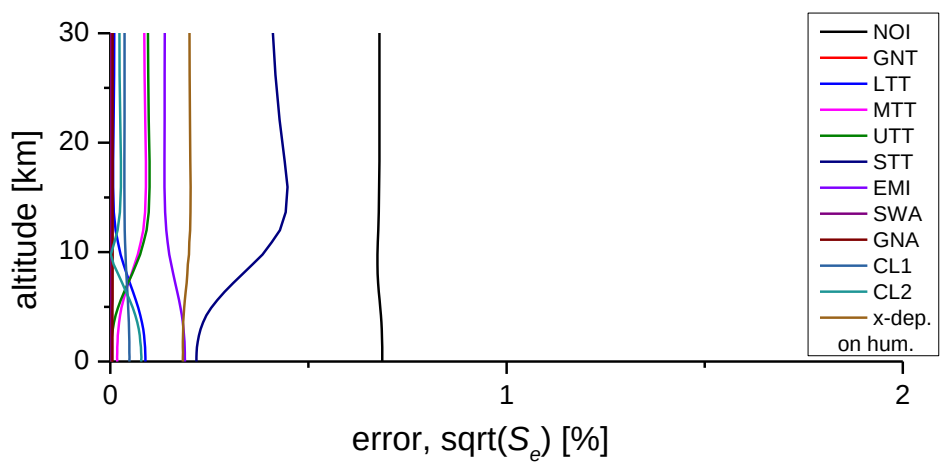
IASI CH_4 (raw product) , $S_e = G\epsilon\epsilon^T G^T$



Large errors, dominated by:

- CL2: high subvisible clouds
- LTT, MTT, UTT, STT: atmospheric temperature uncertainty
- GNT: ground temperature uncertainty
- x-dependence on humidity

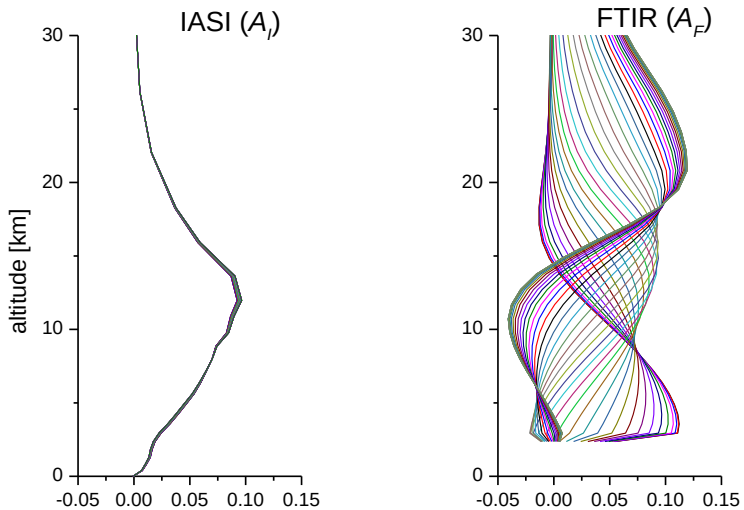
IASI CH_4' (corrected with N_2O residuals), $S_e = PG\epsilon\epsilon^T G^T P^T$ (Schneider et al., 2012)



Significantly reduced errors, dominated by:

- NOI: measurement noise, which increases by the "N_2O correction"!
- STT: temperature uncertainty in the stratosphere
- x-dependence on humidity

CH_4 kernels: IASI and FTIR

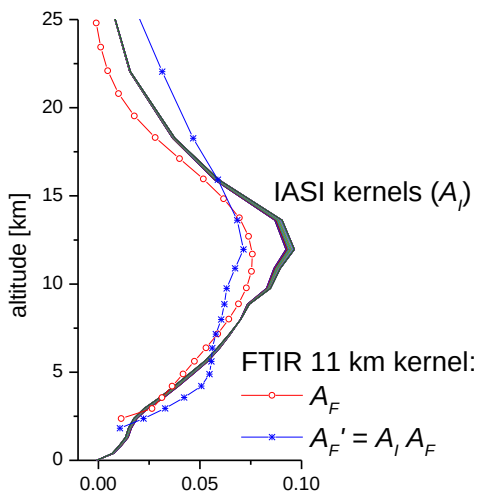


IASI:

- No profile, sensitive from the middle troposphere to the lowermost stratosphere
- FWHM of sensitivity pattern: ≈ 10 km

FTIR:

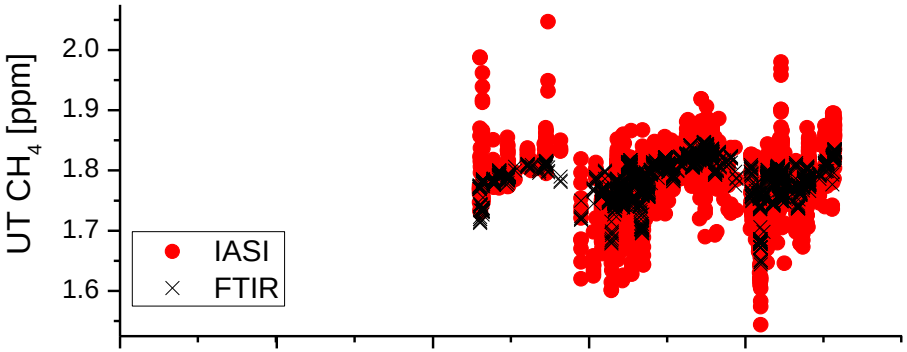
- Offers profiles (Sepúlveda et al. ,2012)
- But modest resolution (FWHM of AVKs: ≈ 10 km)

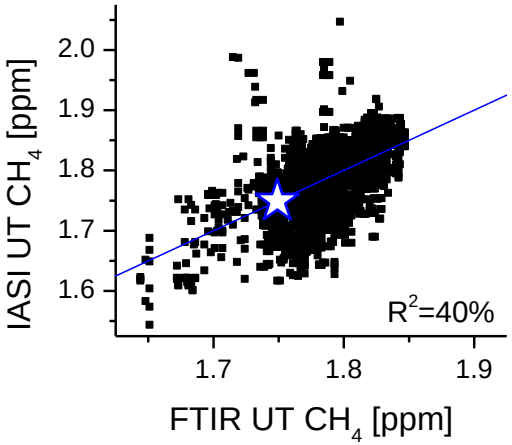


The FWHM of A_I (IASI) and A_F (FTIR) are similar. Smoothing the FTIR kernels with the IASI kernels ($A_F' = A_I A_F$) is not recommendable.
A "straightforward" comparison -- like for humidity -- is the better choice!

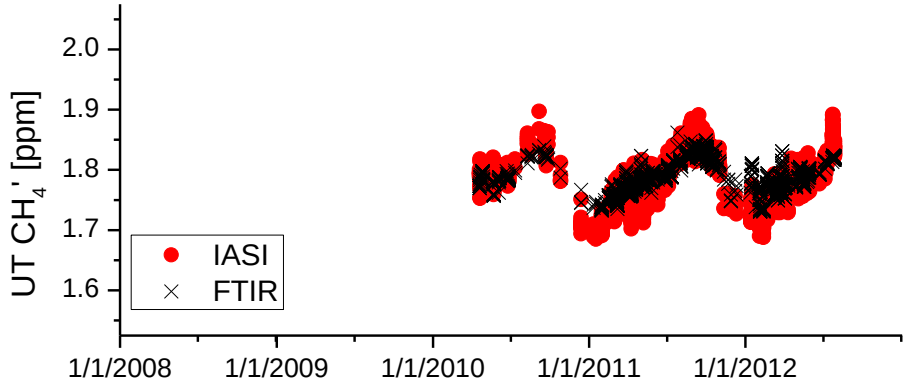
CH_4 validation for Karlsruhe (2756 coincidences)

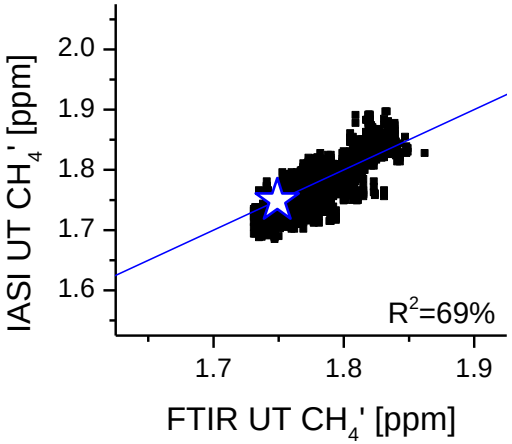
raw remote sensing products: $CH_4 = LTS(CH_4) + STS(CH_4)$





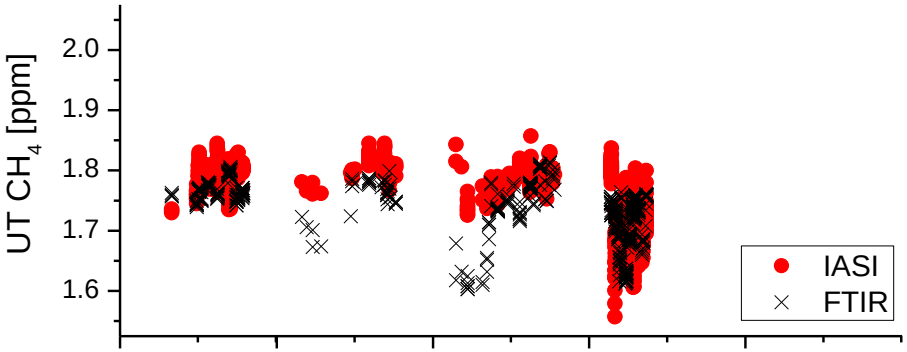
corrected remote sensing products: $CH_4' = LTS(CH_4) + \{STS(CH_4) - STS(N_2O))\}$

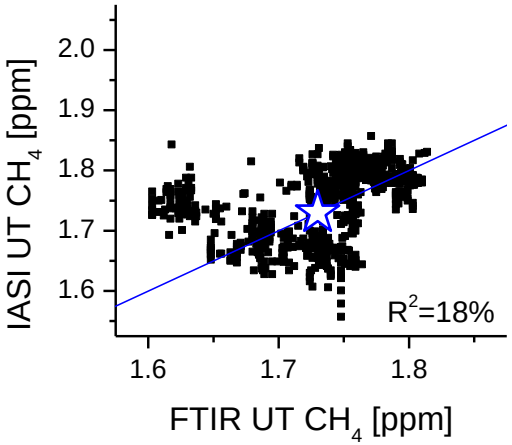




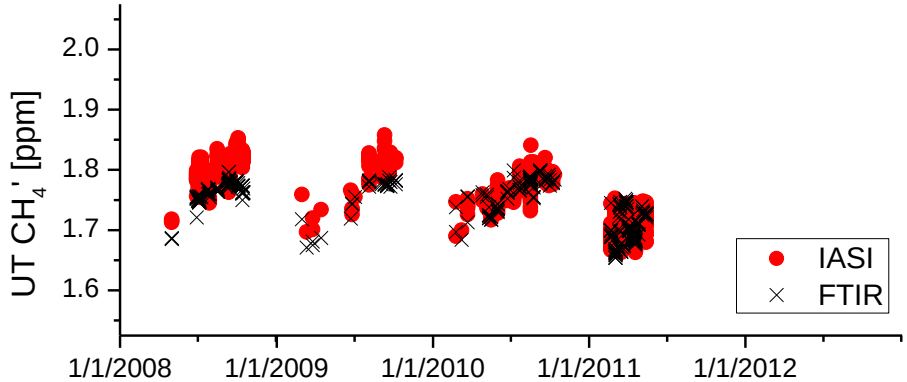
CH_4 validation for Kiruna (849 coincidences)

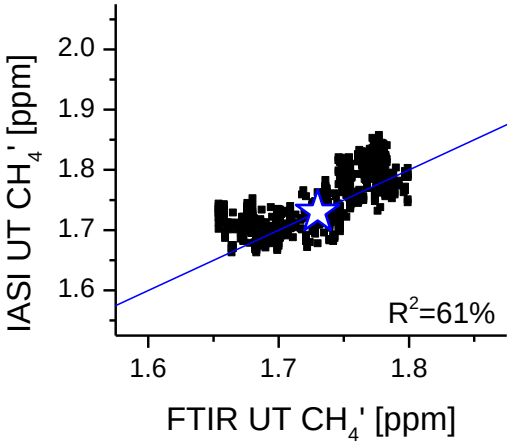
raw remote sensing products: $CH_4 = LTS(CH_4) + STS(CH_4)$





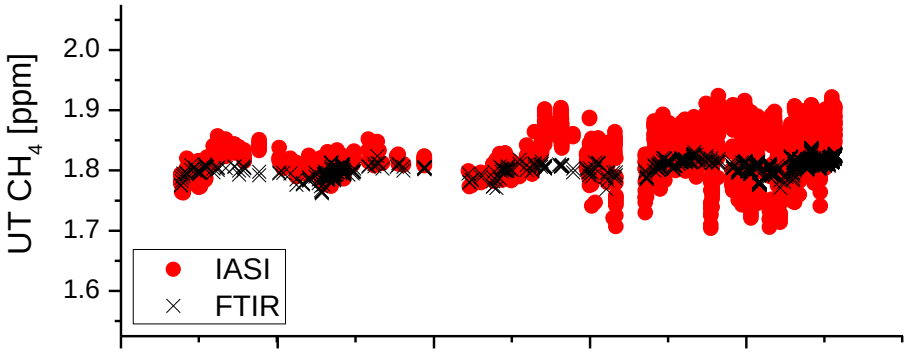
corrected remote sensing products: $CH_4' = LTS(CH_4) + \{STS(CH_4) - STS(N_2O))\}$

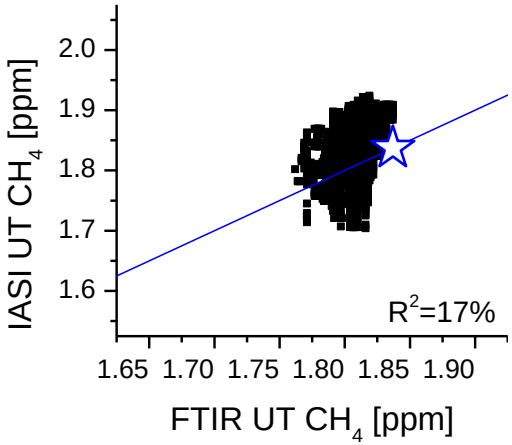




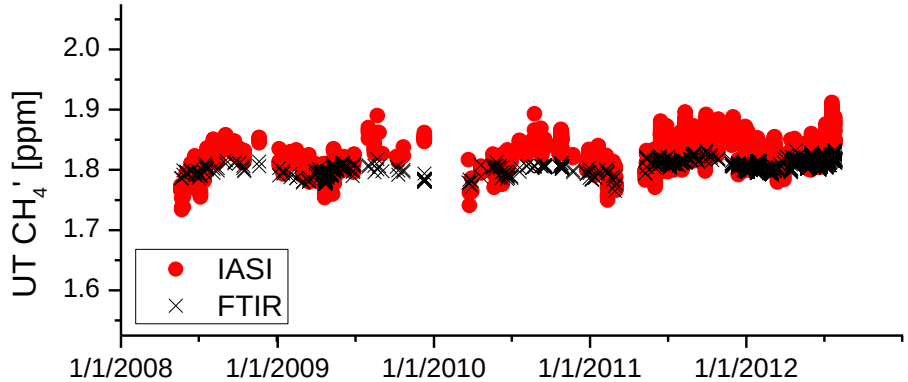
CH_4 validation for Izana (5325 coincidences)

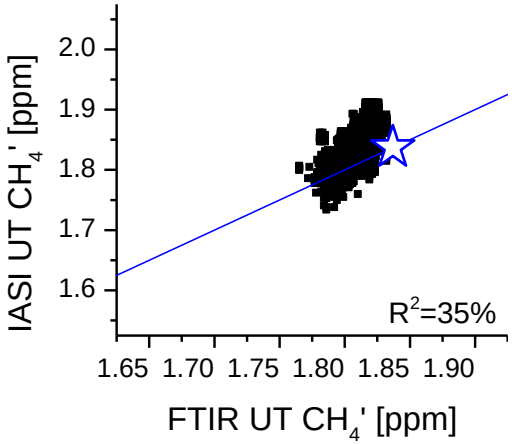
raw remote sensing products: $CH_4 = LTS(CH_4) + STS(CH_4)$





corrected remote sensing products: $CH_4' = LTS(CH_4) + \{STS(CH_4) - STS(N_2O))\}$





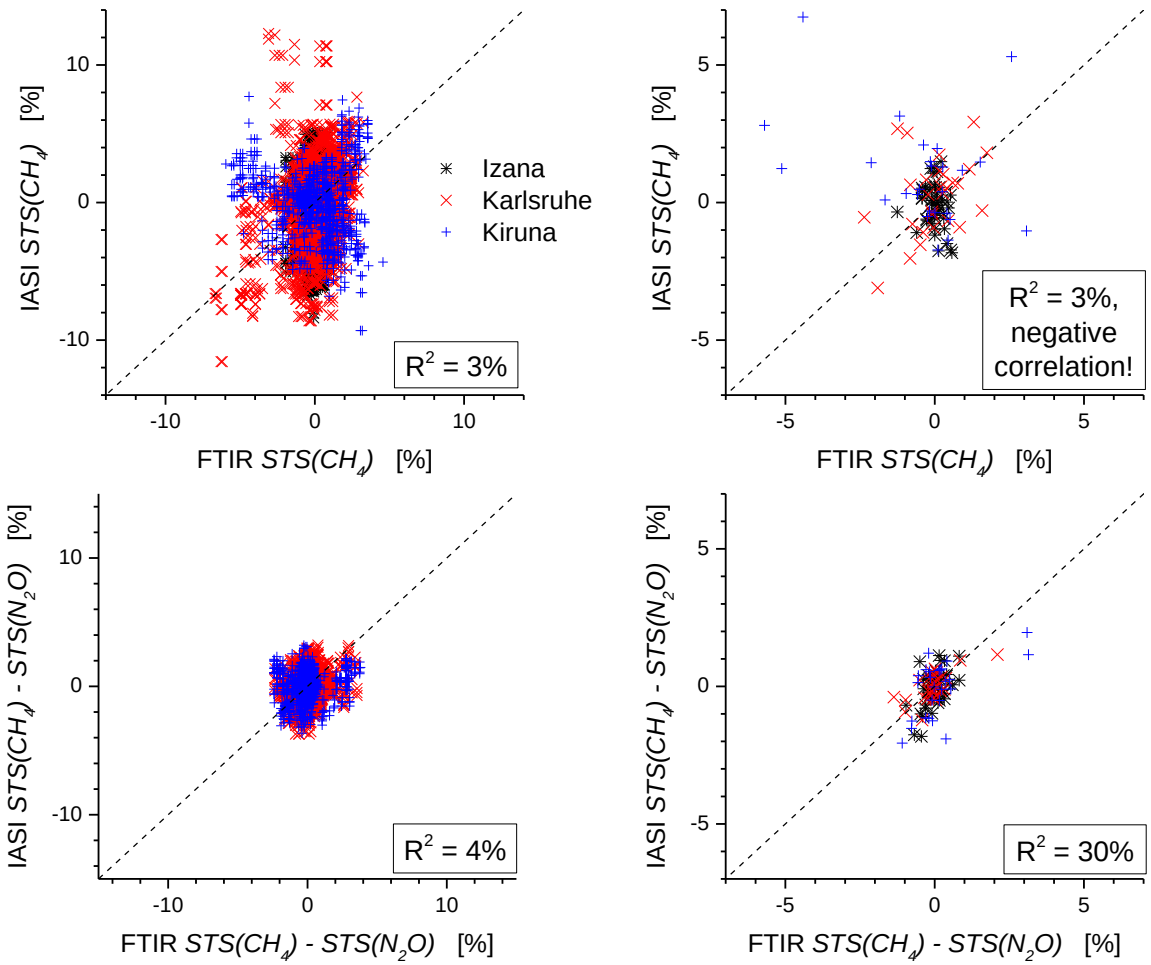
… still to be improved by investigating optimally comparable altitudes

Validation of *STS(CH_4)* and *{STS(CH_4) - STS(N_2O)}*

Remember: CH_4 = LTS(CH_4) + STS(CH_4) → CH_4' = LTS(CH_4) + { STS(CH_4) - STS(N_2O) }

all coincidences (N = 8930)

monthly mean (N = 101)



Averaging *STS(CH_4)*: information content does not increase!

Averaging *{STS(CH_4) - STS(N_2O)}*: Information content increases significantly!

Summary

- Our IASI retrieval provides tropospheric humidity profiles, middle tropospheric δD, and upper tropospheric CH_4

- The products are carefully validated by ground-based FTIR reference data

- Humidity and δD: the quality is well understood and there is a satisfactory agreement between IASI and FTIR

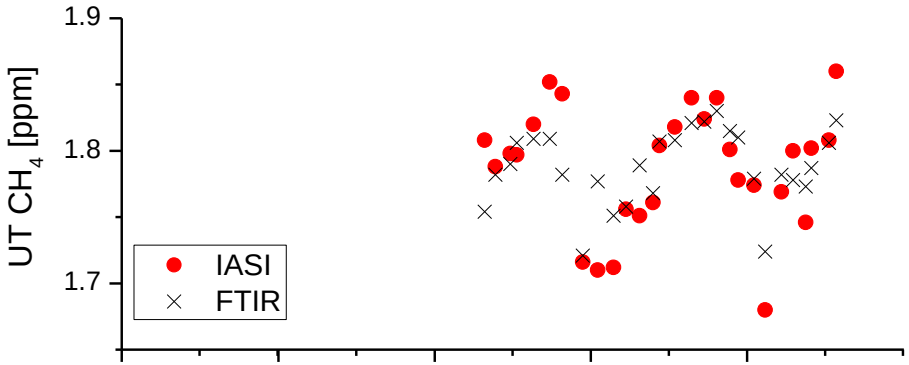
- CH_4 observations are rather difficult!
  - atmospheric CH_4 variability is weak and difficult to be observed in the measured IASI radiances
  - an a posteriori correction applying N_2O seems to be very useful …
  - … work is still in progress …

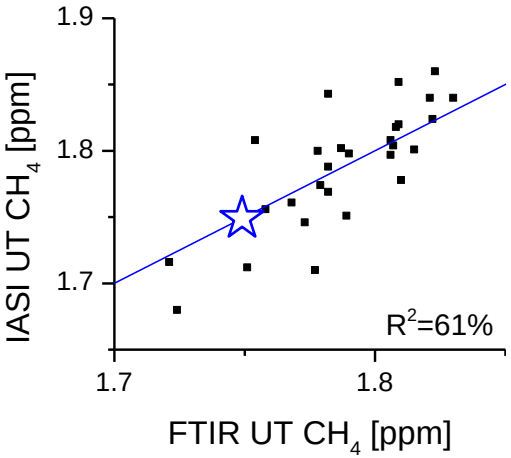
Thanks!

EXTRA SLIDES

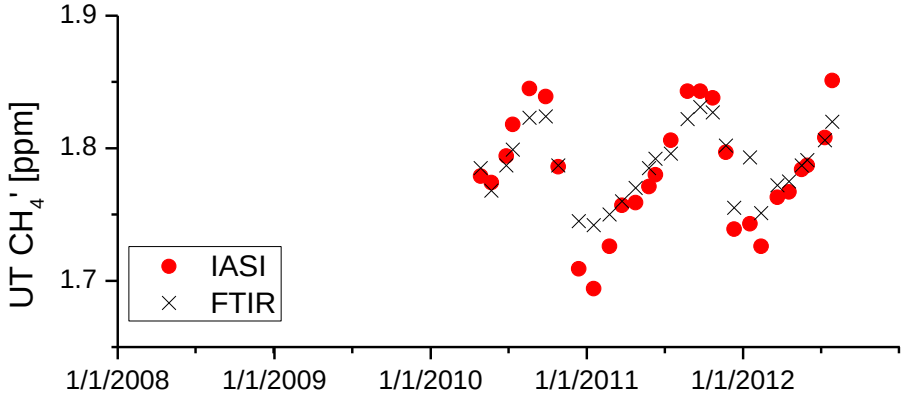
Monthly mean CH_4 validation for Karlsruhe

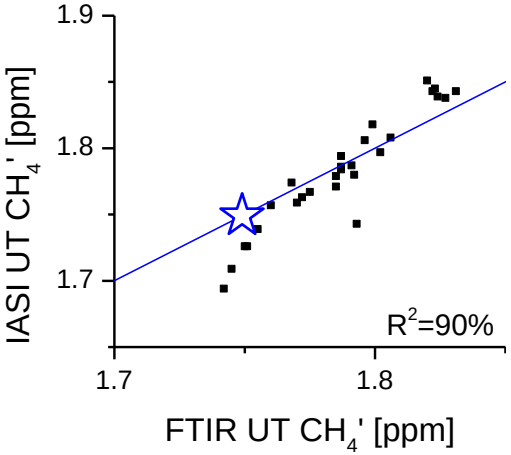
raw remote sensing products: $CH_4 = LTS(CH_4) + STS(CH_4)$





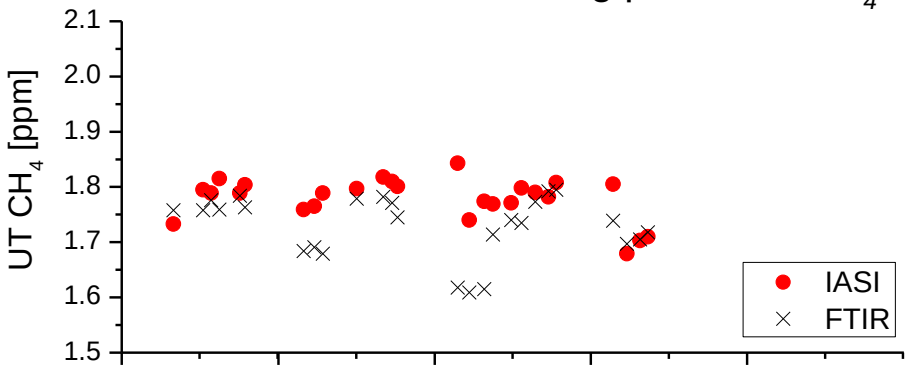
corrected remote sensing products: $CH_4' = LTS(CH_4) + \{STS(CH_4) - STS(N_2O))\}$

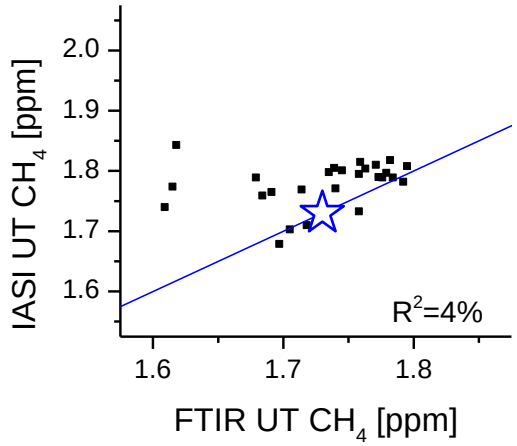




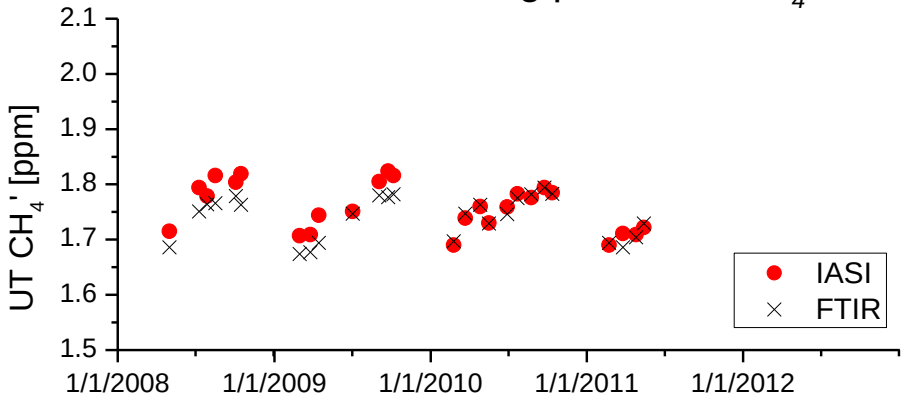
Monthly mean CH_4 validation for Kiruna

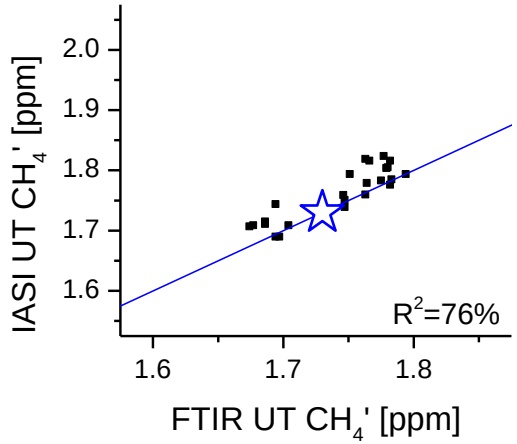
raw remote sensing products: $CH_4 = LTS(CH_4) + STS(CH_4)$





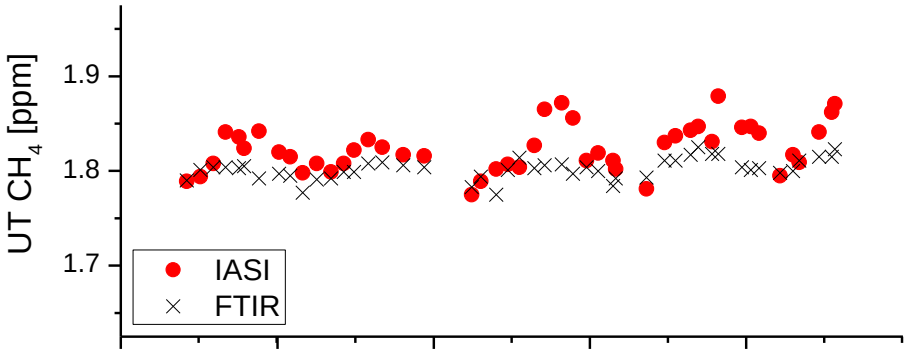
corrected remote sensing products: $CH_4' = LTS(CH_4) + \{STS(CH_4) - STS(N_2O))\}$

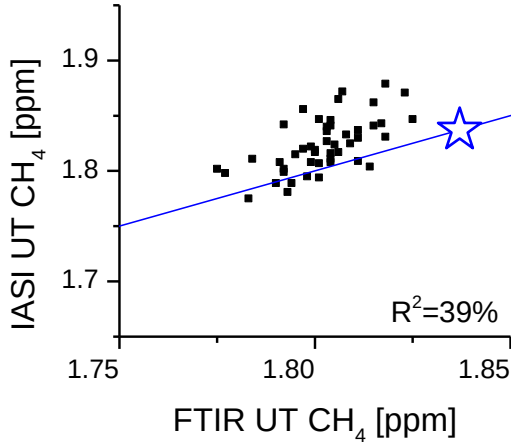




Monthly mean CH_4 validation for Izana

raw remote sensing products: $CH_4 = LTS(CH_4) + STS(CH_4)$





corrected remote sensing products: $CH_4' = LTS(CH_4) + \{STS(CH_4) - STS(N_2O))\}$