Bringing FTIR measurements into GRUAN

(1) The ground-based FTIR remote sensing technique

(2) Generation of error estimates

(3) Example: The water vapour products within the project MUSICA

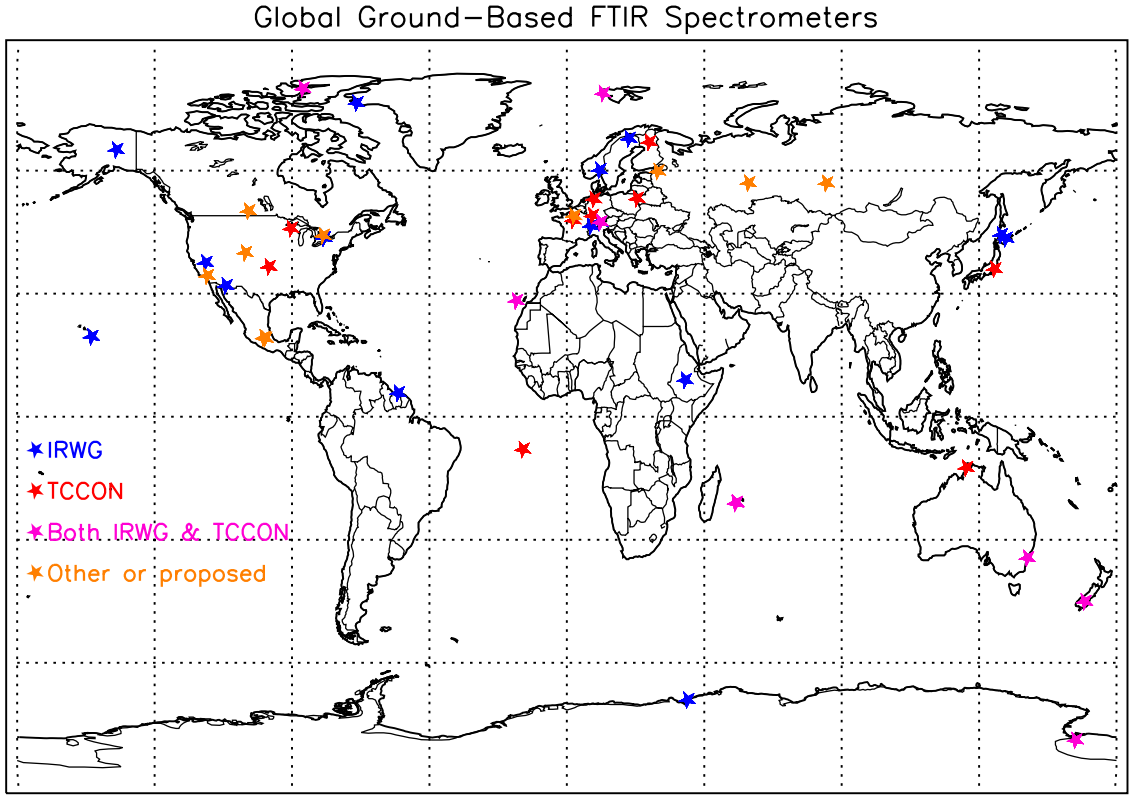
(4) Assets of the Technique:

- ✓ high quality,
- ✓ profiling capability,
- ✓ high measurement frequency

(5) Notes & Discussion Points

M. De Mazière, M. Schneider, J. Hannigan

Global FTS Stations



~Tropical

Izana	28	344
Mauna_Loa	20	204
Mexico_City	19	-99
Altzomoni	19	-99
Addis_Ababa	9	39
Paramaribo	6	305
Ascension	-8	-14
Darwin	-12	131
Reu_Maido	-21	55
Reu_St_Denis	-21	55

Arctic

Eureka	80	274
Ny_Alesund	79	12
Thule	77	291
Kiruna	68	20
Sodankyla	67	27
Poker_Flat	65	213

Antarctic

Syowa_Station	-69	40
Arrival_Heights	-79	167

Mid-Latitude

Harestua	60	11
St_Petersburg	60	30
Yekaterinburg	57	60
Tomsk	57	85
Bialystok	53	23
Bremen	53	9
Bratts_Lake	50	-104
Karlsruhe	49	8
Paris	49	2
Orleans	48	2
Garmisch	47	11
Zugspitze	47	11
Jungfraujoch	47	8
Park_Falls	46	270
Moshiri	44	142
Egbert	44	280
Rikubetsu	44	144
Toronto	44	281
Boulder	40	255
Barcroft	38	242
Lamont	37	263
Tsukuba	36	140
Table_Mtn	34	242
Kitt_Peak	32	248
Wollongong	-34	151
Lauder	-45	170

Many Common Members in TCCON & NDACC
MUSICA is a subset of NDACC groups…

Shared meetings for several years, common experience, problems & solutions

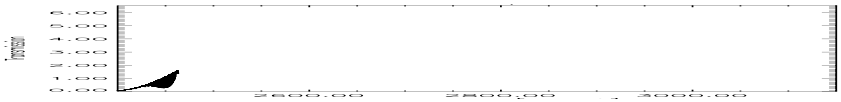
Institute	NDACC Sites	TCCON Sites	MUSICA
JPL	1	3+	
U. Wollongong	1	1	1
KIT Karl.	4	1	4
U. Bremen	4	3	1
BIRA	1	1	
NIES	1	1	1
KIT Gar.	1	1	
NIWA	2	1	2
U.T.	2	1	1
U Liege	1		1
	17	13	11

Instrumentation / Data Products

	TCCON	IRWG	MUSICA
Instrument	125HR(Bruker)	By spec. (Bruker)	By spec. (Bruker)
OPD*	45cm	250cm (max)	250cm (max)
Region**	Near-IR	mid-IR	mid-IR
Recording	DC	DC/AC	DC/AC
Bandwidth	3900-15000	700-4500	700-4500
Detectors	InGaAs/Si	InSb/MCT	InSb/MCT
Retrieval	NLLS / Scale of apriority	Full Optimal Est	Full Optimal Est
Species	CO2 (CH4, N2O, CO)	10 primary +	H2O
Product	Column/DAMF	Column/Profile	Column/Profile

**Low resolution instruments (~1 cm) are being developed (ie lower cost)*
**Possible MIR/NIR Instrument has been proposed*

Gb FTIR measurements within NDACC



Simultaneous observation at high spectral resolution in wide spectral bands yield absorption signatures of many trace gases (required)

Spectral Resolution:

0.0035-0.002 cm^{-1} required for profiling using presssure (Lorentz) broadening effect.

SNR:

300 – 2000 RMS

Spectral Range:

750–9000 cm^{-1}

Data Rate:

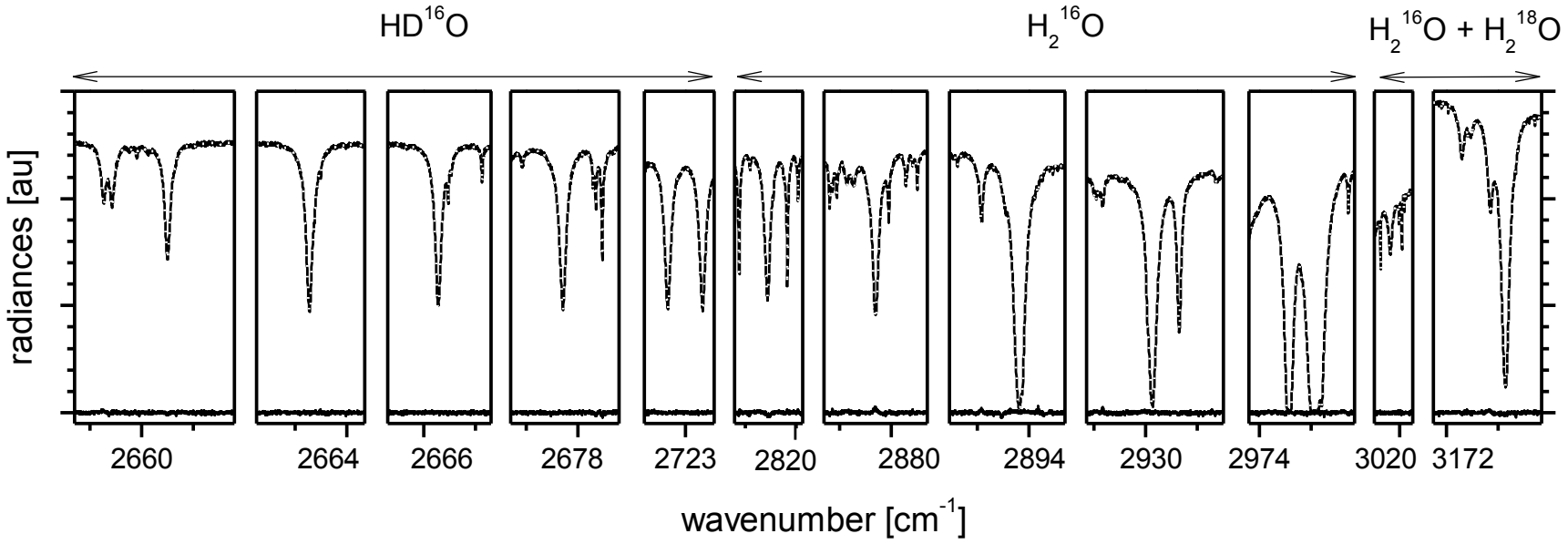
Daily but many sites all daylight hours

H_2O
HDO
O_3
N_2O
CH_4
HNO_3
CCl_2F_2
CCl_3F
$CHClF_2$
COF_2
$ClONO_2$
ClO
NO
NO_2
HCl
C_2H_6
HF
HCN
C_2H_2
CO
CO_2
OCS
NH_3
$COCl_2$
N_2

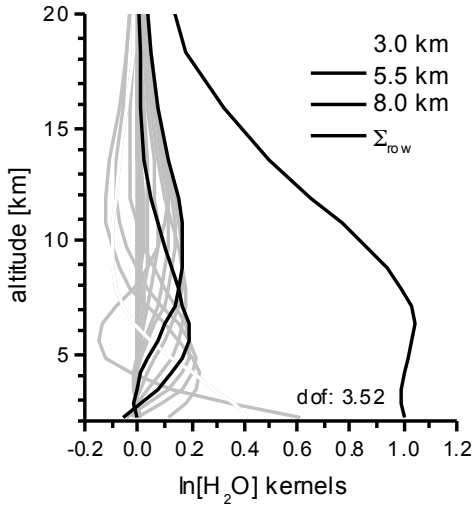
MUSICA ‘s ground-based FTIR spectral windows

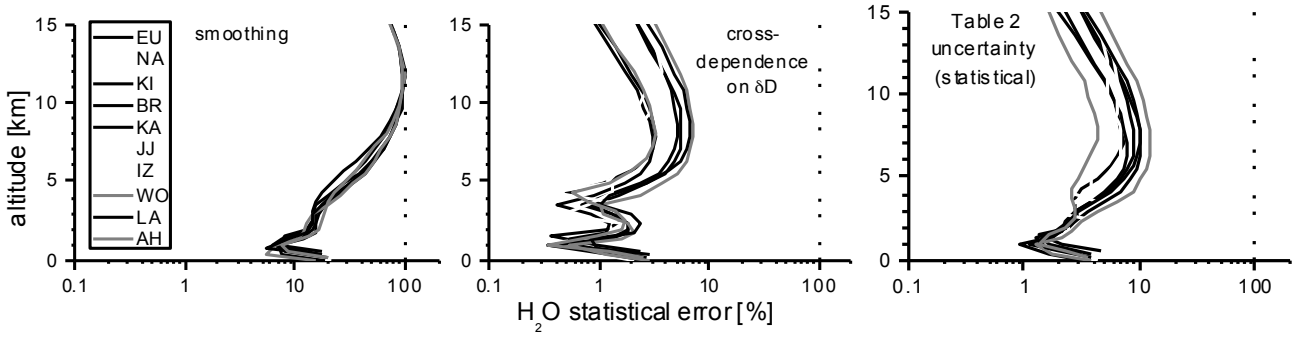
We measure high resolution broadband spectra. For the analysis we select spectral regions where the target species has well isolated absorption signatures:

Example of the spectral windows used for $H_2{}^{16}O$ and $HD^{16}O$ retrievals:



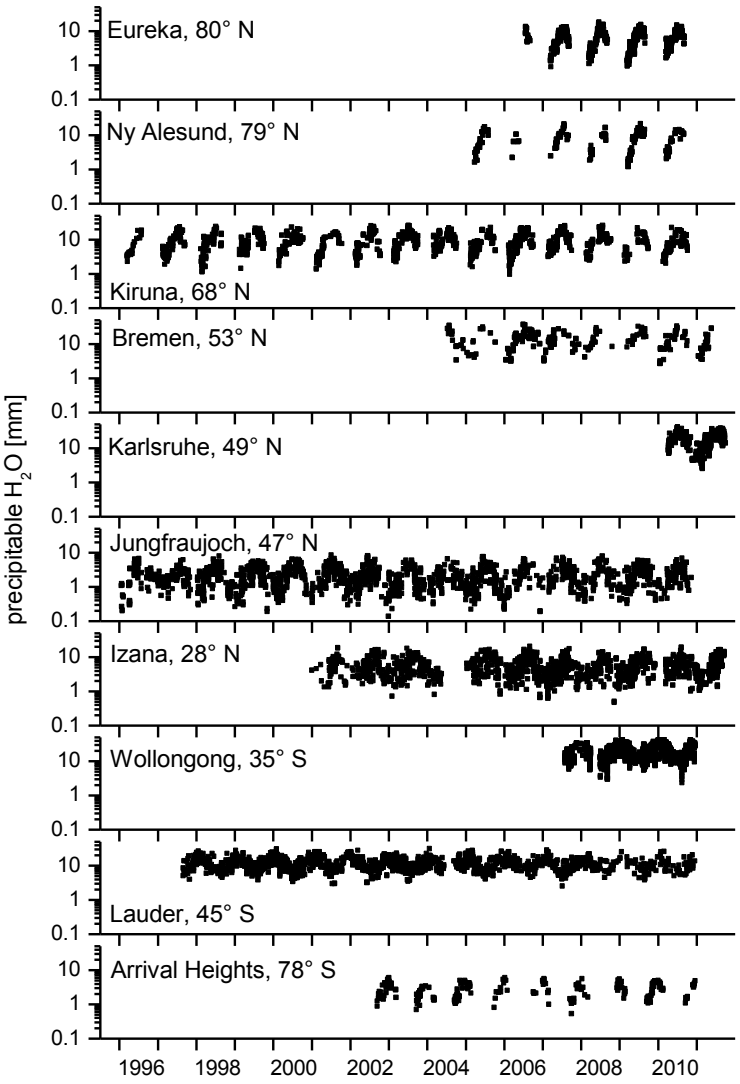
Vertical Sensitivity & Error assessment for MUSICA ‘s g-b FTIR water vapour product





Data quality is well assessed for each individual observation at all stations. For more details see Schneider et al. (2012), Sect. 4.1: „Characterisation of product type 1: Optimally estimated H2O profiles”

Current state of MUSICA gb FTS water vapour dataset: 10 stations, data since mid 90s, …



Total number of available water vapour profiles: ≈15000

Representative for ten globally distributed sites, :

NH, SH, polar, mid-laitudes, (sub)-tropics, land surface, ocean surface, lowland, high mountains, etc.

http://www.imk-asf.kit.edu/english/musica

Asset (1): very high quality as documented by retrieved O2 and pressure correlations

differential absorption principle

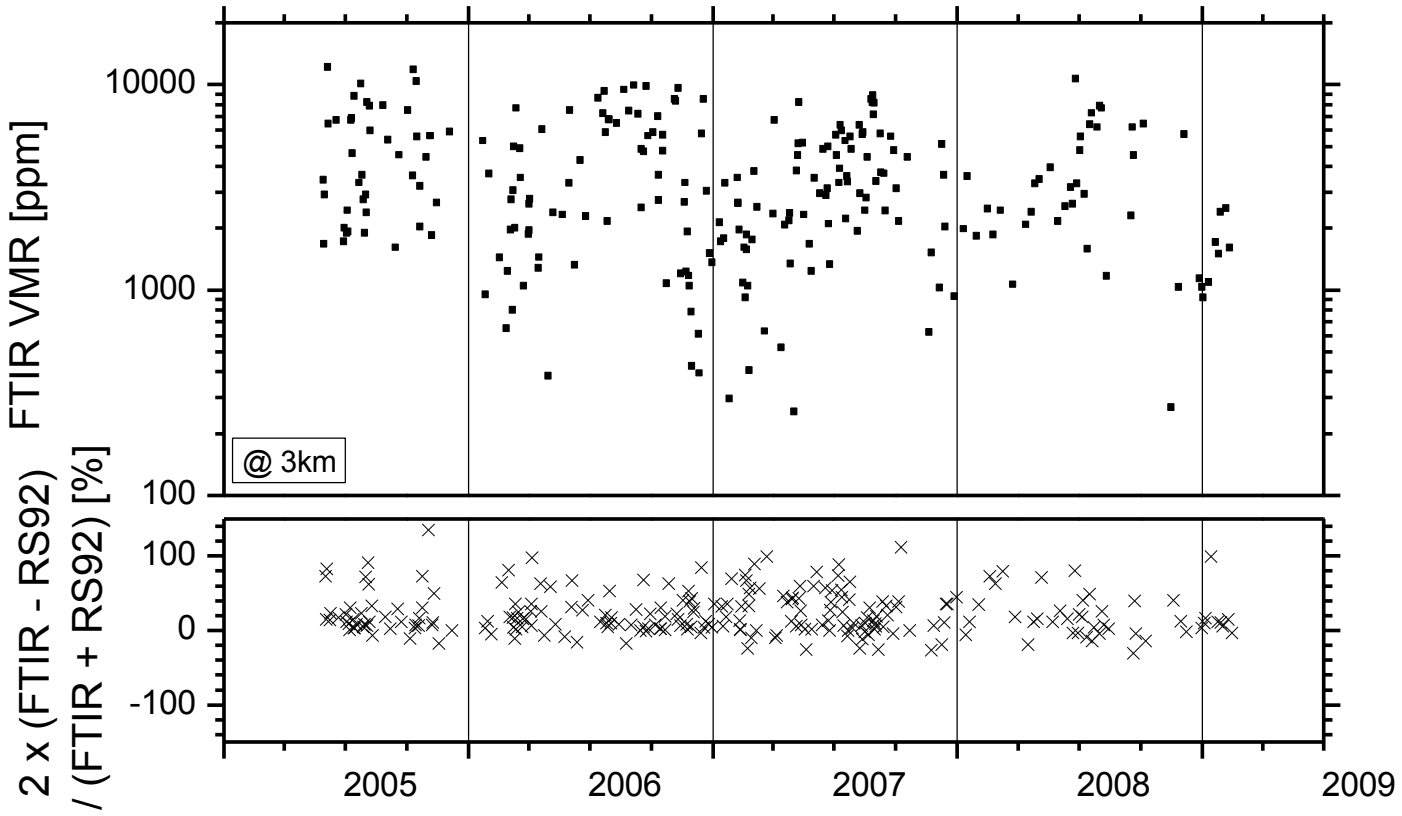
→ „self calibrating“

The plots are courtesy by E. Sepúlveda

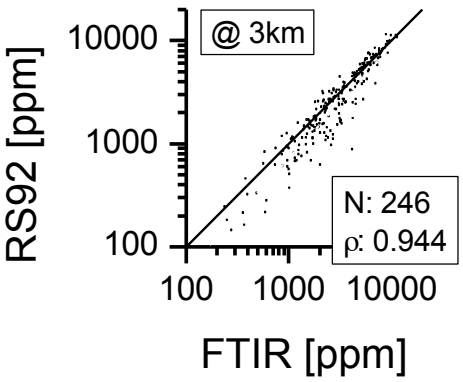
→ the gb FTS technique can produce very precise long-term data sets

Asset (2): „profiles“ of high quality, example study 2005-2009, FTS vs. Vaisala RS92

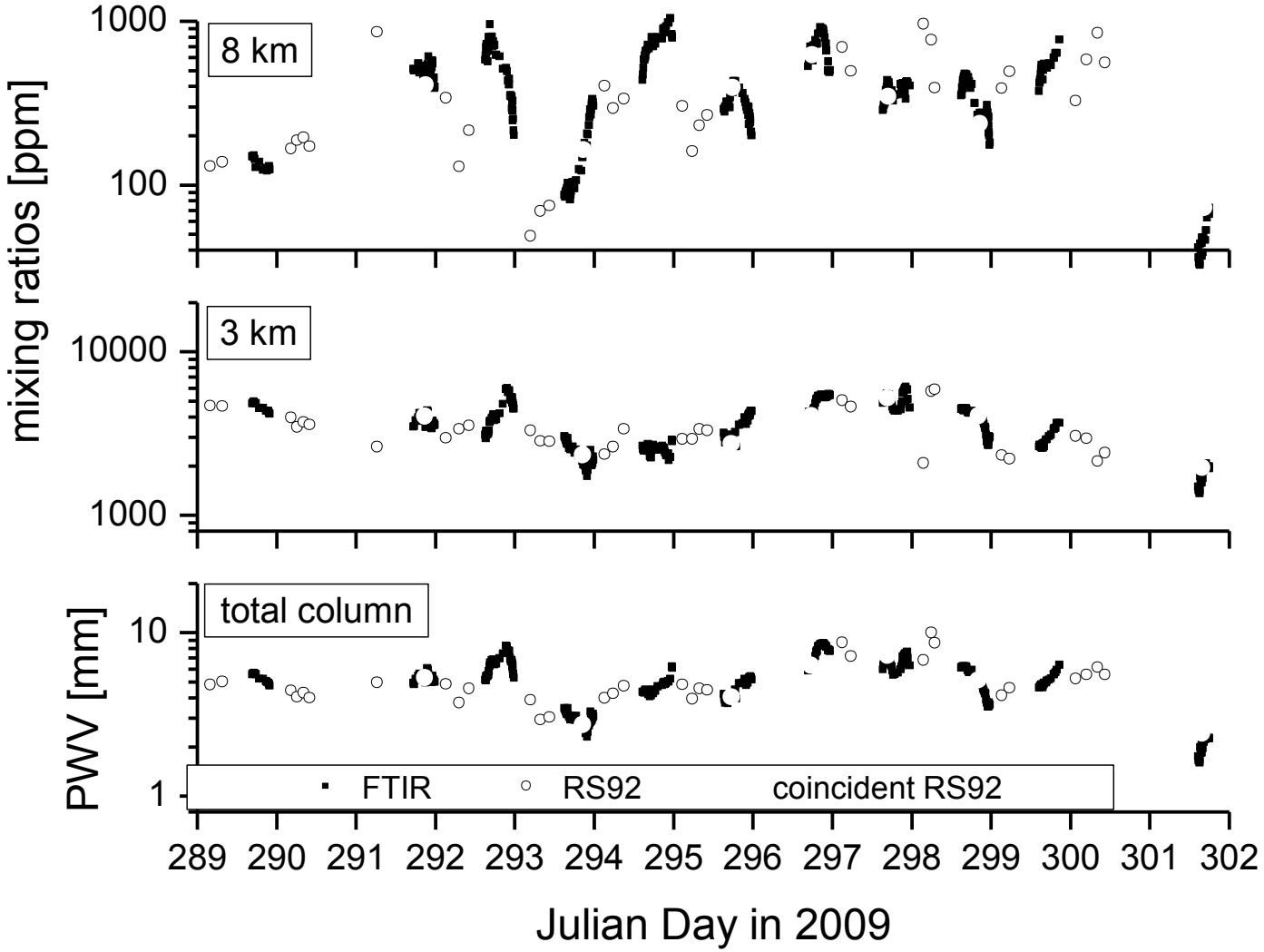
lower troposphere:



Schneider et al., AMT, 2010



Asset (3): high measurement frequency, example MOHAVE-2009 campaign



High measurement frequency is important for water vapour, because of the high variability!

Acknowledgement

FTIR spectra and RS92 data were provided by G. Toon, J.F. Blavier, and T. Leblanc, JPL, California, USA

Summary

- The ground-based FTIR remote sensing technique offers high precision and long-term stability
- Existing networks are in place and adaptable for evolving requirements
- Homogeneous data products are the existing goals that are furtheres by
  - Instrumentation standards,
  - Internal testing,
  - Consistant retrieval parameters,
  - Consistant error analysis.
- Water vapour (and HDO/H2O) profiles of a carefully documented quality are produced within the project MUSICA and available for ten globally distributed sites (for some stations dating back to the mid 90s)
- Valuable reference dataset due to combination of high quality, long-term availablity, profiling capability, and high measurement frequency

Notes & Discussion Points

- NDACC data are delivered in GEOMS compliant HDF files
- All data are referenced to SI units
- Ancillary data (surface temperature, pressure water vapor profile & column are included)

Issues raised by Holger:

- Central storage of raw data,
  - Not implemented (but all pi's save their raw data)
  - 'Level' of raw tbd (eg. spectrum or interferogram?)
  - Depending on level & measurement frequency, data rate could be to a Gb/day
- Quantified uncertainties with every data point
  - Desired by all - in process
- Traceability
  - As in HITRAN, NCEP – OK
  - Further calibration may be required by GRUAN
- Central processing,
  - Possible
    - in place for MUSICA, not wider NDACC
    - is an implemented part of TCCON but not standard
- Homogeneity of the measurements across the network:
  - Active, in everyone's interest – how to prove they are not?
- Redundant observations:
  - May be species dependent – try easiest first: water vapor, ozone

EXTRA SLIDES

For details please refer to the recent publications on the MUSICA dataset

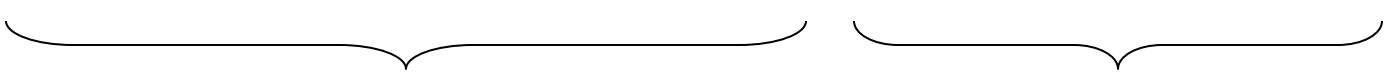
Schneider, M., S. Barthlott, F. Hase, Y. González, K. Yoshimura, O.E. García, E. Sepúlveda, A. Gomez-Pelaez, M. Gisi, R. Kohlhepp, S. Dohe, T. Blumenstock, A. Wiegele, E. Christner, K. Strong, D. Weaver, M. Palm, N.M. Deutscher, T. Warneke, J. Notholt, B. Lejeune, P. Demoulin, N. Jones, D.W.T. Griffith, D. Smale, and J. Robinson:
Ground-based remote sensing of tropospheric water vapour isotopologues within the project MUSICA,
Atmos. Meas. Tech., 5, 3007-3027, 2012.

Schneider, M. and F. Hase:
Optimal estimation of tropospheric H2O and δD with IASI / METOP,
Atmos. Chem. Phys., 11, 11207-11220, 2011.

Ground-based FTS retrieval principle

We invert the spectra by an optimal estimation method.

Minimise the cost function:



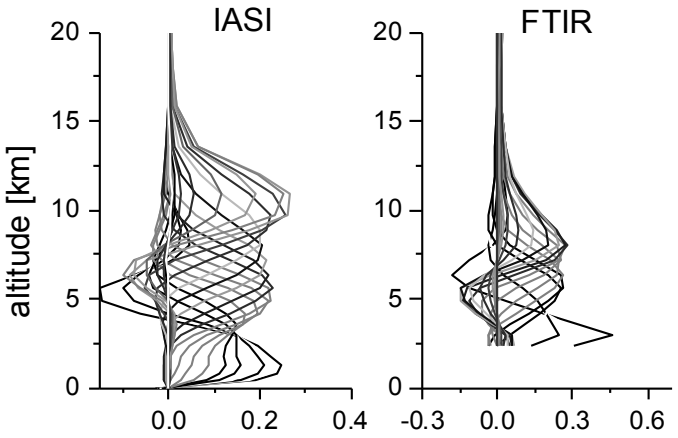
Rodgers (2000)

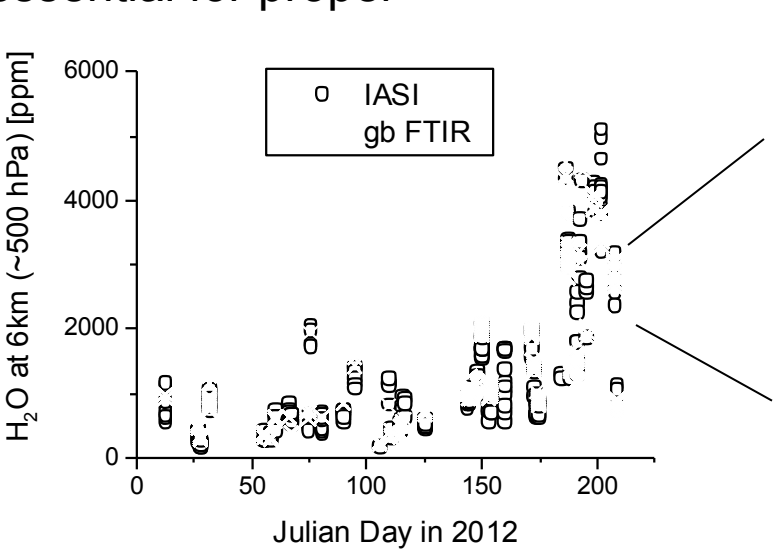
Ground-based FTIR: an important reference for validating satellite sensors

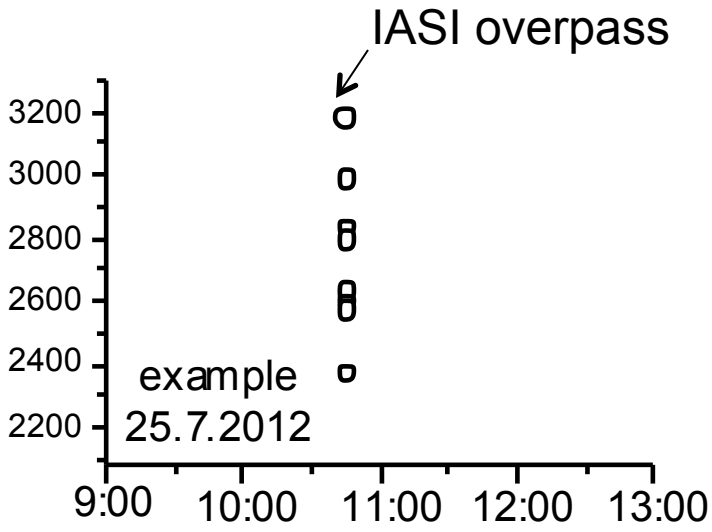
(1): High quality data

(2): Gb FTIR and satellite sensor kernels overlap, example FTIR and IASI:

(3): Gb FTIR can measure quasi continuously (during daytime), essential for proper validation:

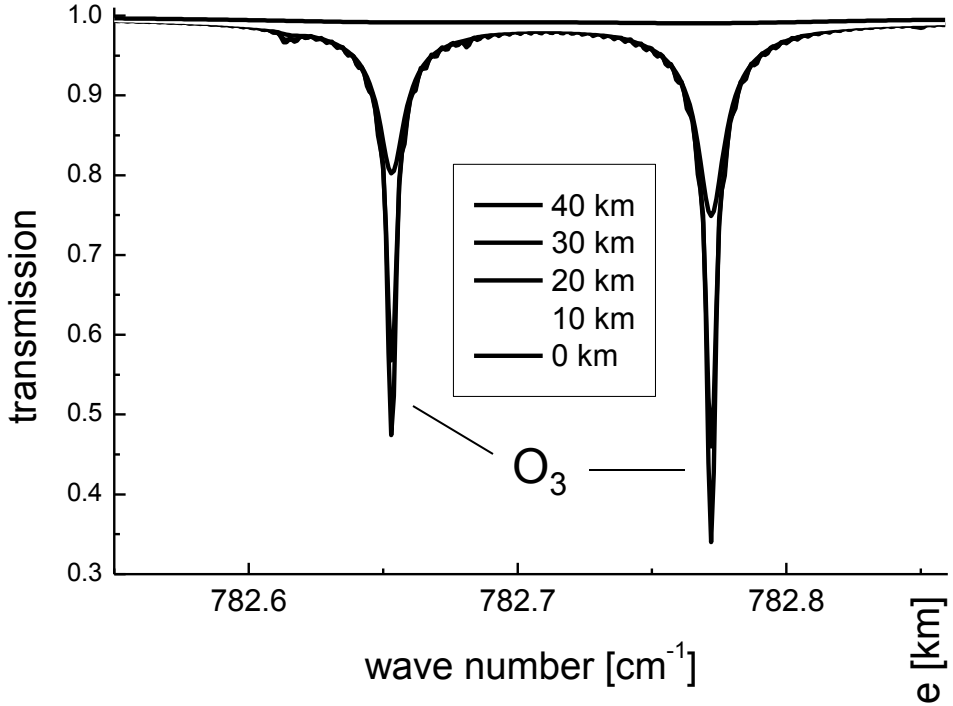




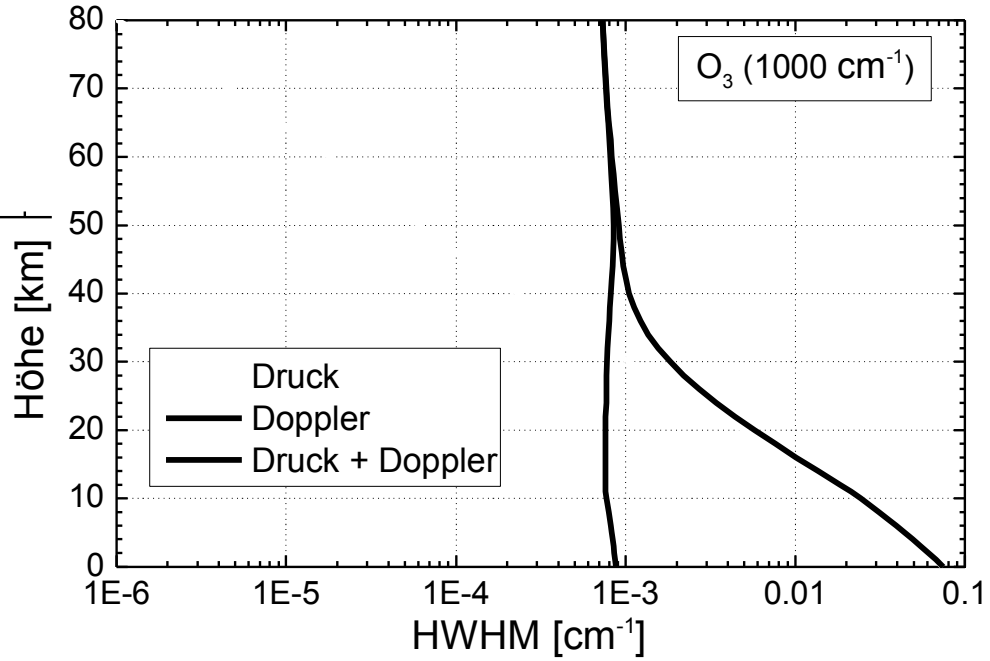


Spectra analysis: information on the absorbers ‘ vertical distribution

Example for O_3:



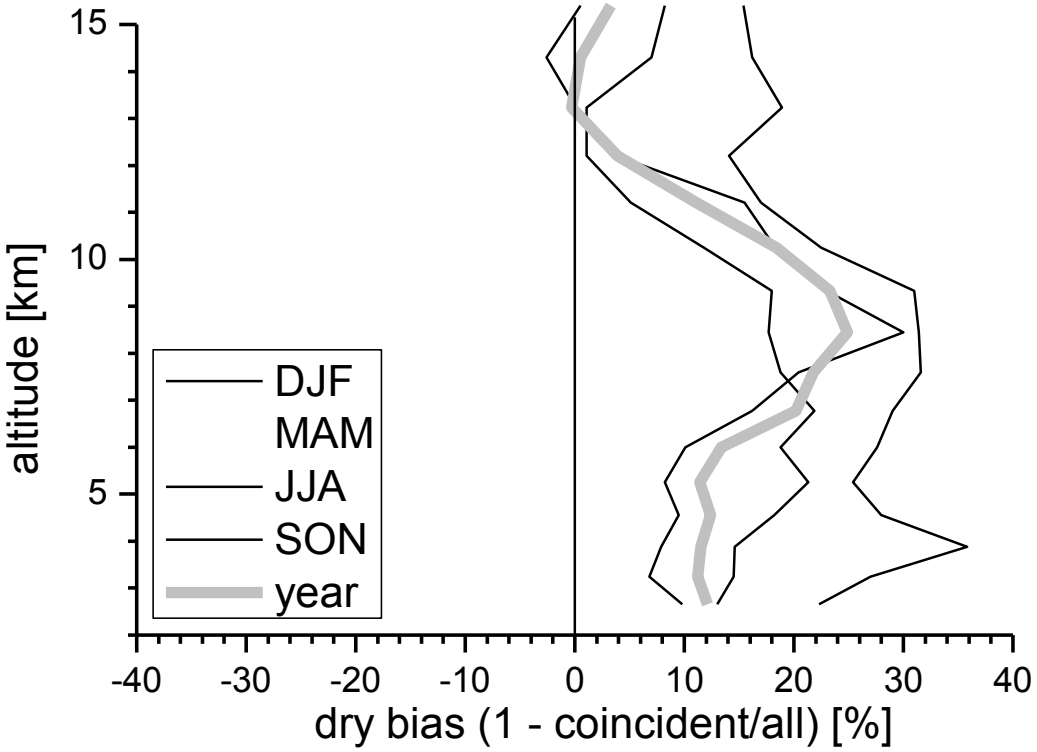
Due to the pressure broadening effect very high resolution spectra contain information about the absorbers vertical distribution



In the middle infrared the pressure broadening determines the line shape between the Earth ‘s surface and about 40 km altitude.

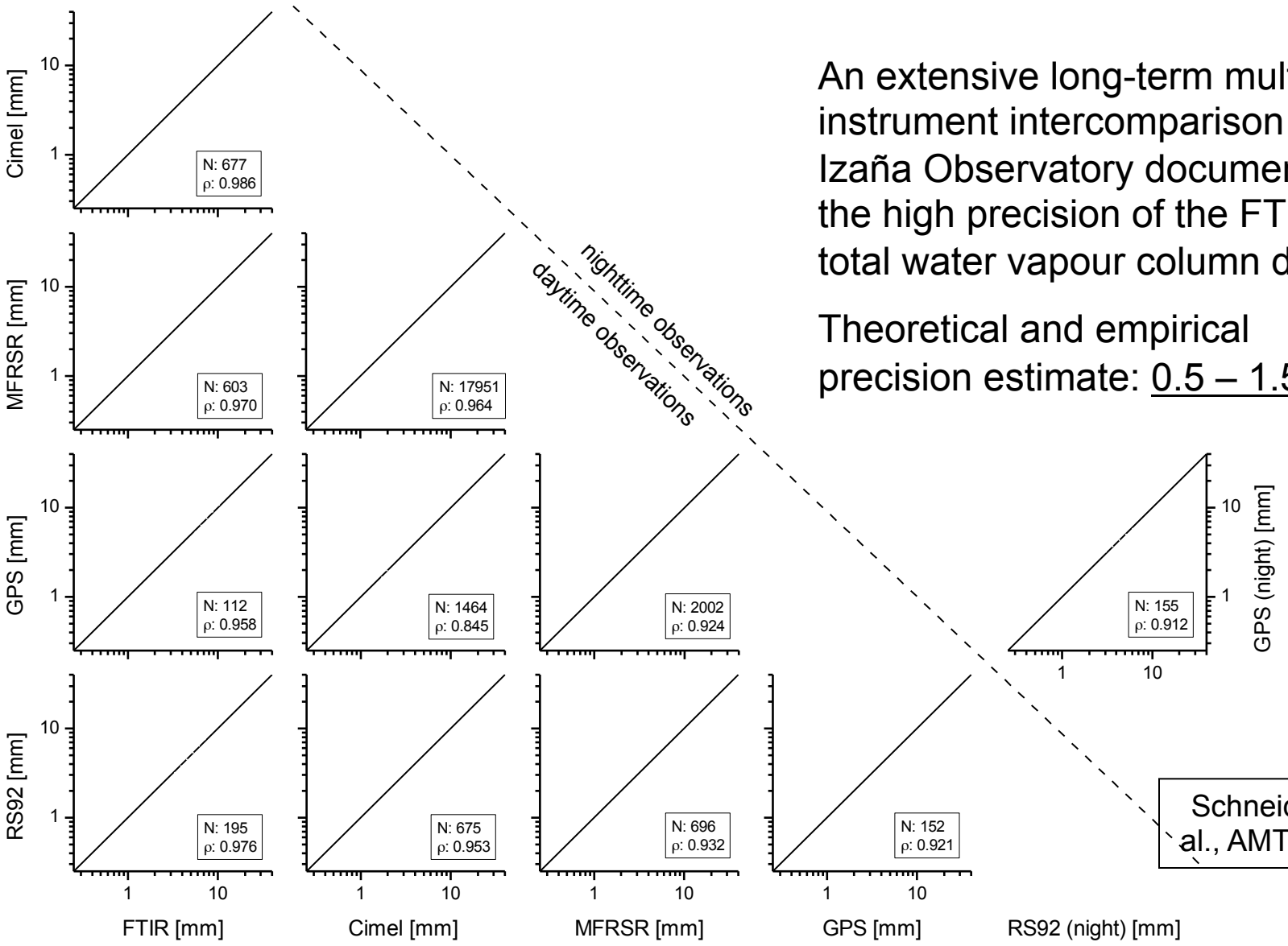
Limitation of the FTS technique: observation only exists for clear sky conditions

Estimated clear sky dry bias at the subtropical Izaña Observatory:



Schneider et al., AMT, 2010

Quality of H_2O total column amounts



An extensive long-term multi-instrument intercomparison at the Izaña Observatory documents the high precision of the FTIR total water vapour column data.

Theoretical and empirical precision estimate: 0.5 – 1.5%

Schneider et al., AMT, 2010

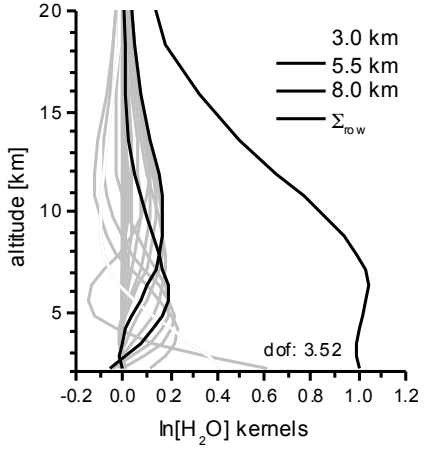
Global ground-based FTIR networks

There are two global networks measuring high resolution solar absorption spectra in the infrared applying very high quality instrumentation

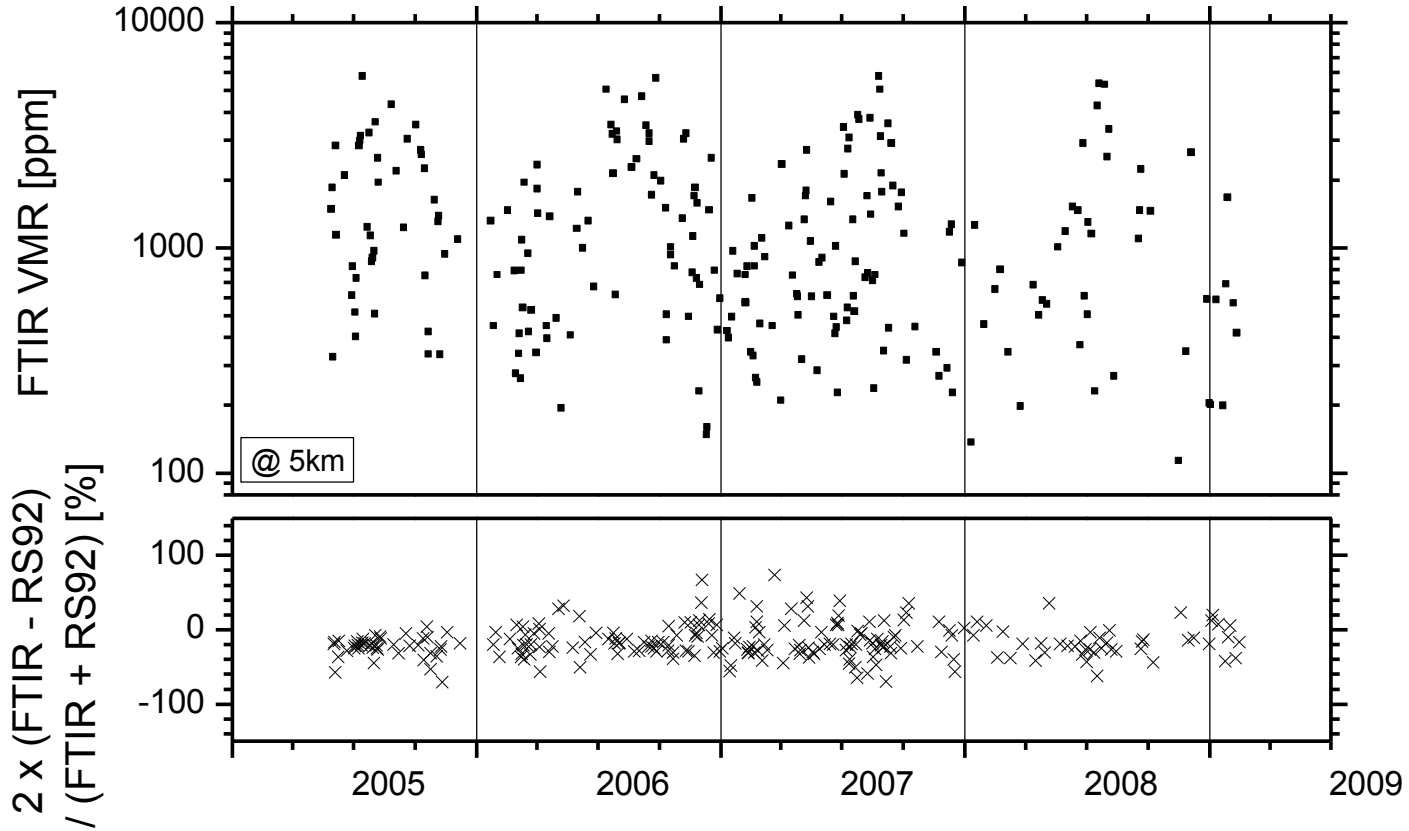
NDACC: Network for the Detection of Atmospheric Composition Change

TCCON: Total Carbon Column Observing Network

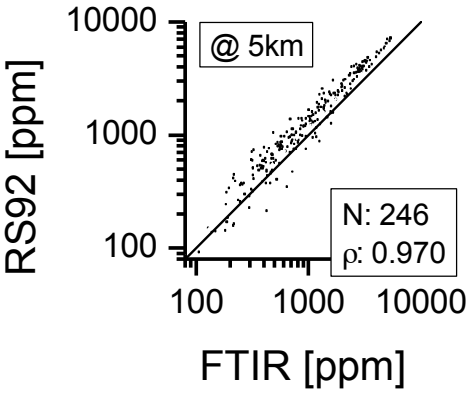
Typical averaging kernels for MUSICA ‘s gb FTIR water vapour product, example Izana



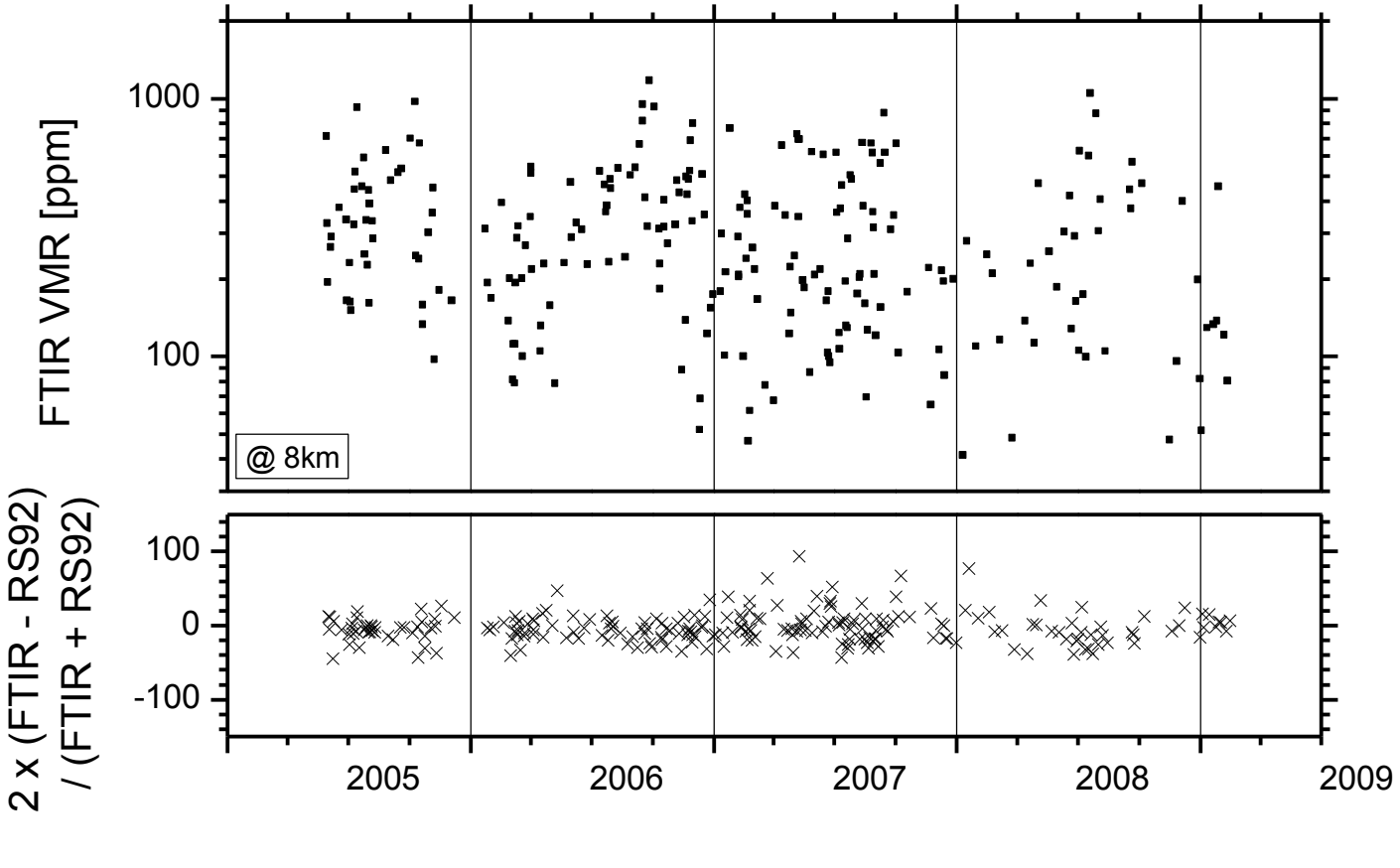
middle troposphere:



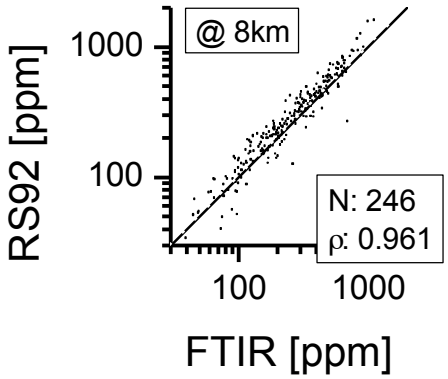
Schneider et al., AMT, 2010



upper troposphere:



Schneider et al., AMT, 2010

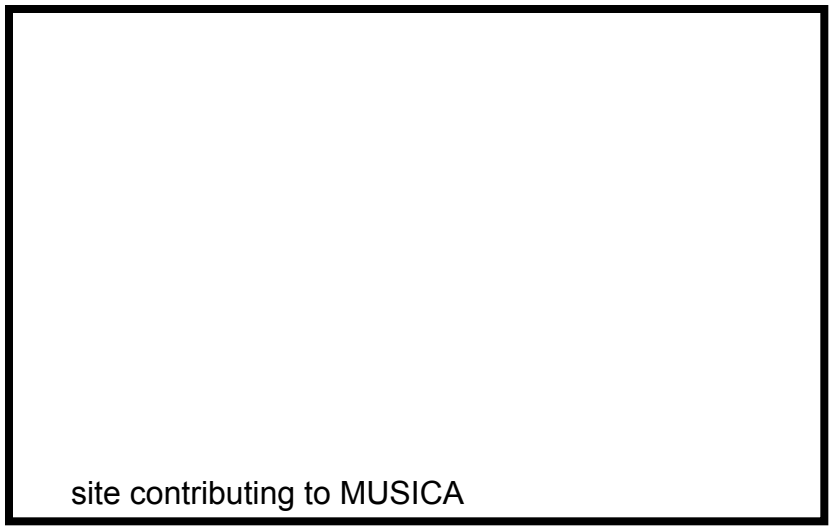


- central storage of raw data,
- quantified uncertainties with every data point,
- traceability,
- central processing,
- homogeneity of the measurements across the network,
- redundant observations.

Example: The project MUSICA: consistent ground- and space-based water vapour products

MUSICA (MUlti-platform remote Sensing of Isotopologues for investigating the Cycle of Atmospheric water) combines NDACC ground-based FTS observations and IASI / METOP observations (and in-situ observations for validation purposes).

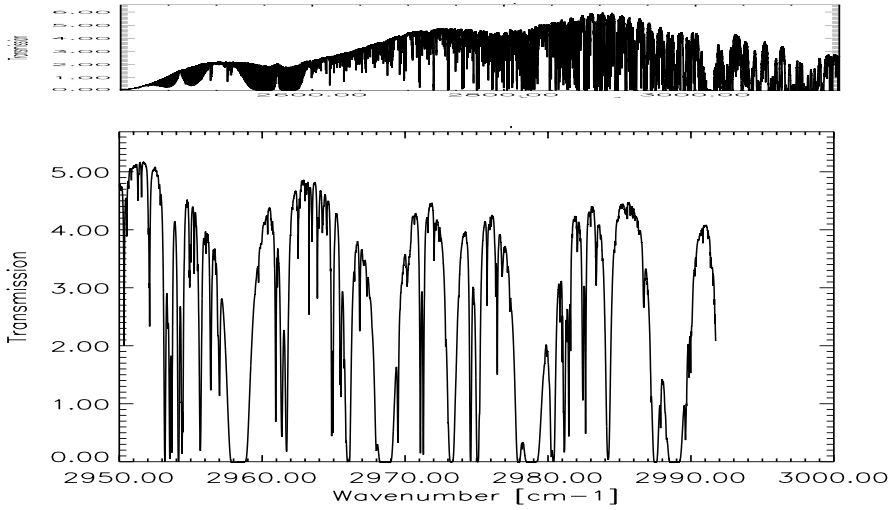
The MUSICA project team (M. Schneider et al.) at the Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany, and the Agencia Estatal de Meteorología (AEMET), Santa Cruz de Tenerife, Spain



Schneider and Hase (2011);
Schneider et al. (2012)

http://www.imk-asf.kit.edu/english/musica

Acknowledgement: MUSICA is funded by the European Research Council under the European Community's Seventh Framework Programme (FP7/2007-2013) / ERC Grant agreement n° 256961.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