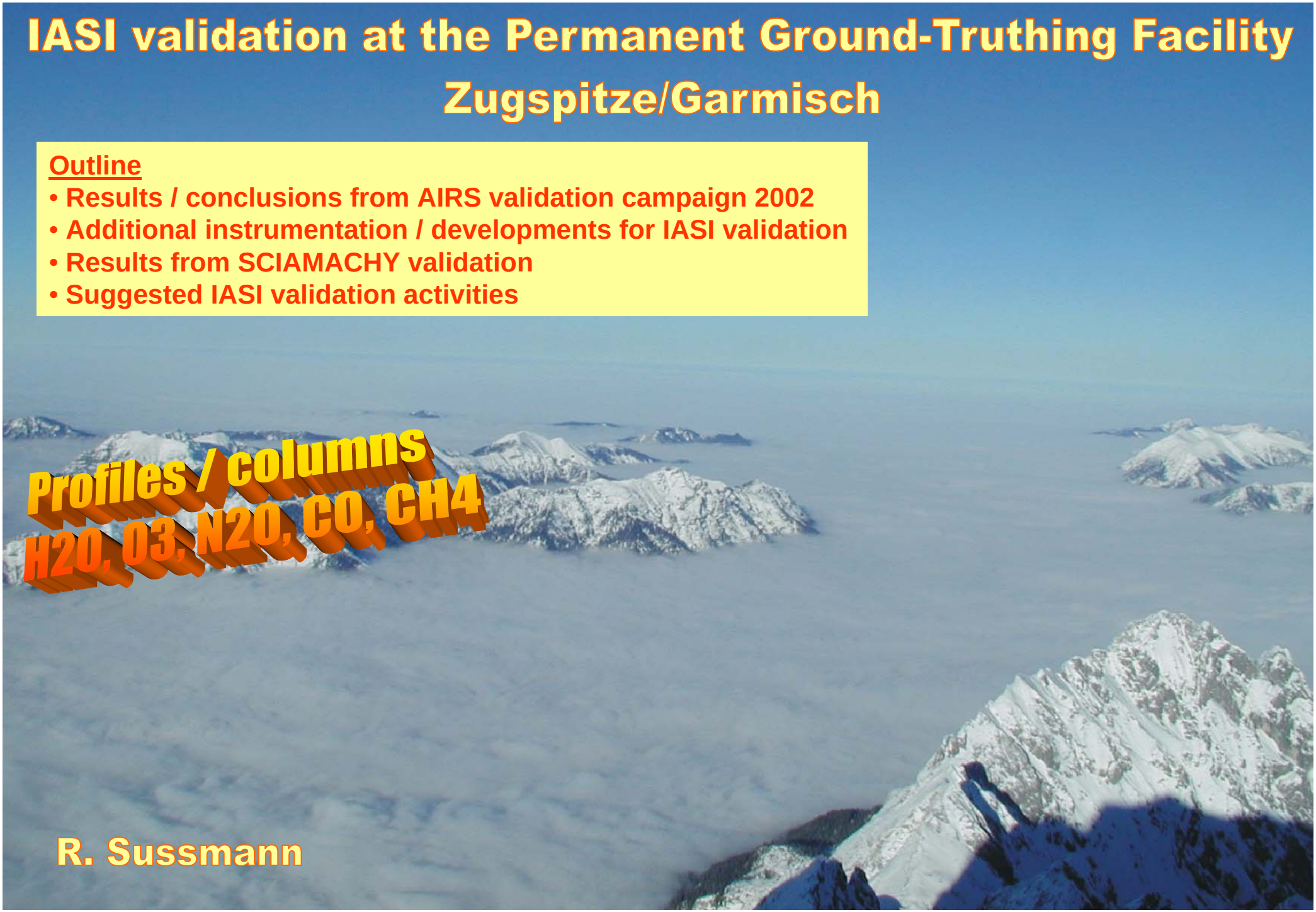
IASI validation at the Permanent Ground-Truthing Facility Zugspitze/Garmisch

Outline

- Results / conclusions from AIRS validation campaign 2002
- Additional instrumentation / developments for IASI validation
- Results from SCIAMACHY validation
- Suggested IASI validation activities



R. Sussmann

Permanent Ground-Truthing Facility Zugspitze/Garmisch according to the WMO requirements.
Validation and Synergistic use with Satellite Measurements

IMK-IFU Working Group „Variability and Trends“

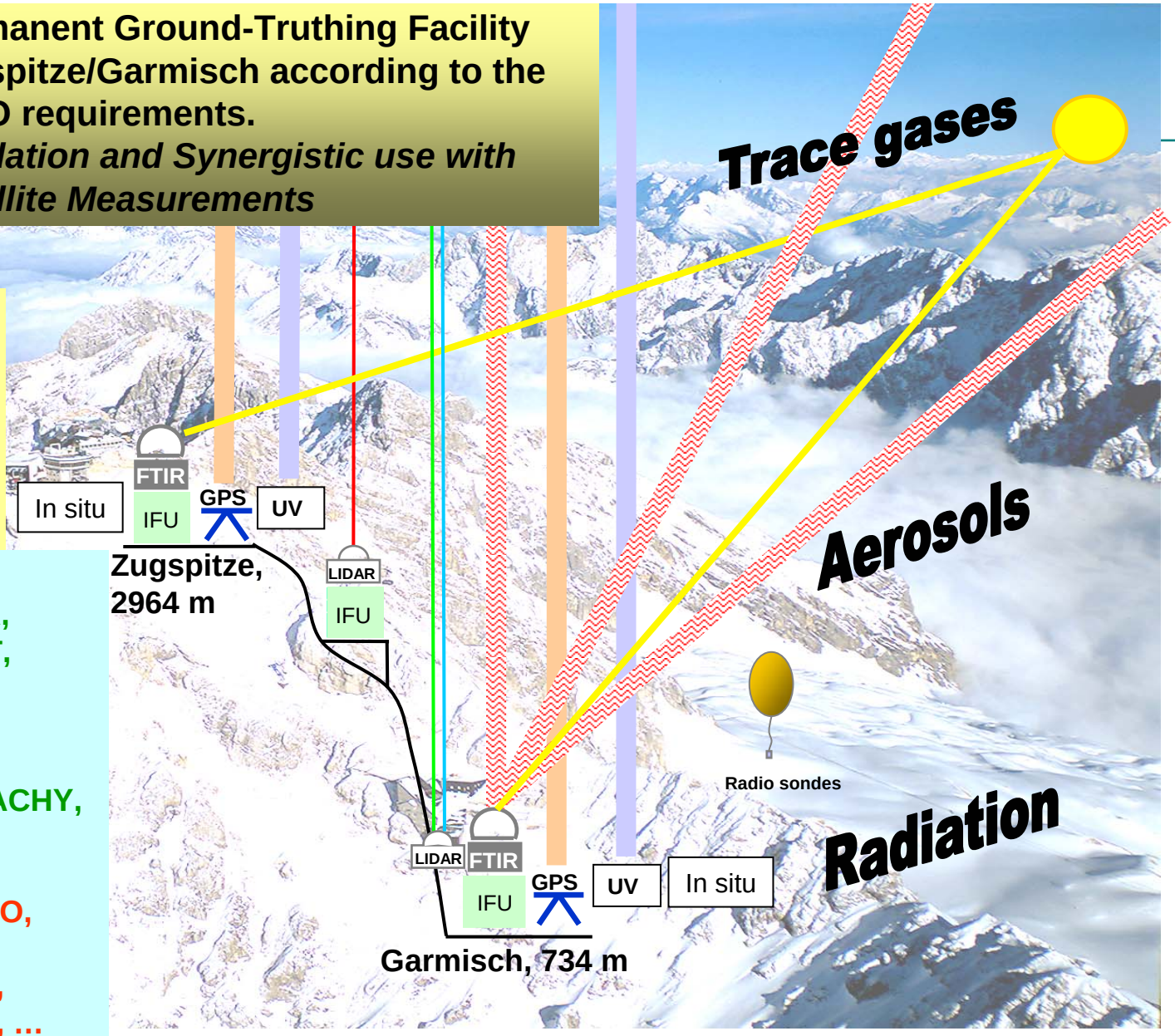
Head
- R. Sussmann

Scientists
- W. Junkermann
- H.E. Scheel
- T. Trickl
- H. Vogelmann
- P. Werle

Engineers
- H. Giehl
- M. Rettinger
- A. Rockmann

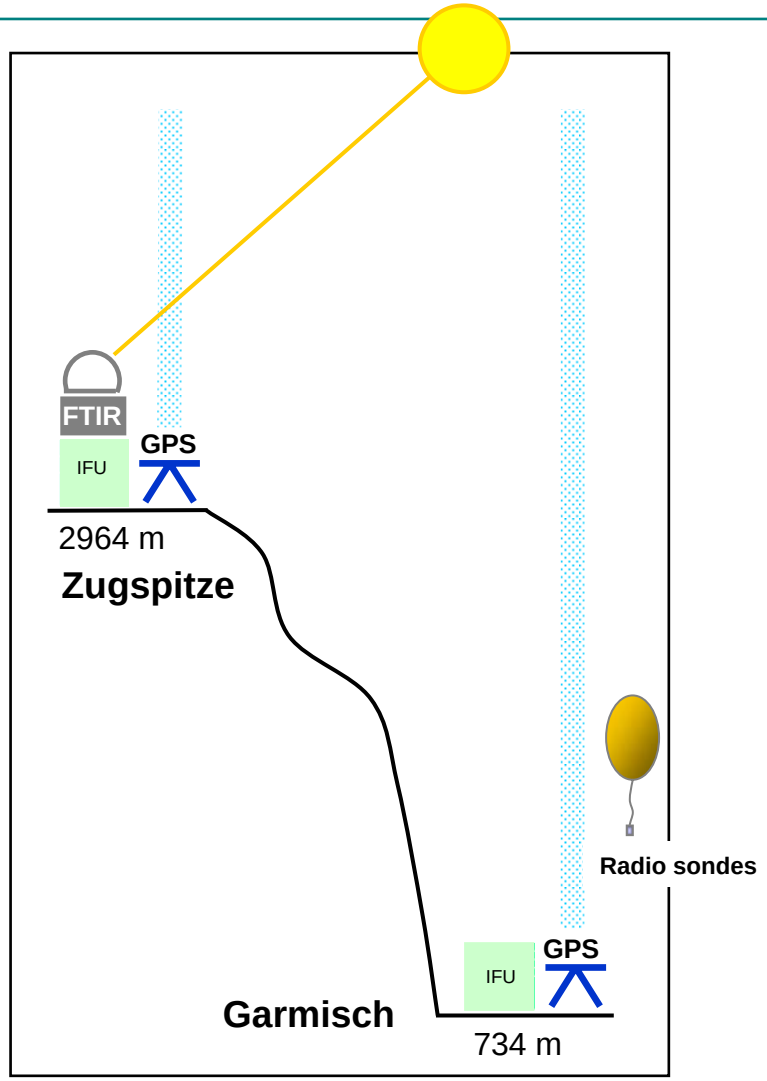
PhD students
- W. Stremme
- T. Borsdorff

MAPS,
CRISTA,
MOPITT,
SAGE,
GOME,
AIRS,
SCIAMACHY,
ACE,
IASI,
CALIPSO,
OCO,
TCCON,
GOSAT, ...



AIRS validation campaign 2002: Instrumentation

47.4 °N, 11.0 °E



Ralf Sussmann and Claude Camy-Peyret, Ground-Truthing Center Zugspitze, Germany for AIRS/IASI Validation, EUMETSAT Contract No. EUM/CO/01/892/PS, Phase I Report, 17 April 2002

Ralf Sussmann and Claude Camy-Peyret, Ground-Truthing Center Zugspitze, Germany for AIRS/IASI Validation, EUMETSAT Contract No. EUM/CO/01/892/PS, Phase II Report, 28 March 2003

AIRS validation at Zugspitze/Garmisch: Schedule

Campaign duration:
3 Months (19 Aug 2002 - 17 Nov 2002)

Data delivery: within 12 h for both day- and night-overpasses

Validation measurements:
7 days a week,
2-hours-period around each overpass delivered,
for 2 EOS-Aqua overpasses per day

- In-Situ Met Data (Garmisch + Zugspitze): 1-min-values
- Cloud/weather information (Zugspitze: hourly; Garmisch: 1 fish eye image per overpass)
- Radio Sondes (Garmisch): 4 sondes a day (two per overpass)
- GPS Garmisch+ Zugspitze, permanent operation, half hourly mean values
- Zugspitze FTIR: clear sky operation, typically, 20-min-integration intervals

PTU with 1-min resolution for Zugspitze and Garmisch
plus wind for Garmisch

17.10.2002 11:34:05	11.52	919.44	81.40	1.00	73.00	Example
17.10.2002 11:35:05	11.82	919.43	80.09	1.20	43.00	
17.10.2002 11:36:05	11.40	919.37	81.02	1.10	55.00	
17.10.2002 11:37:05	11.40	919.29	81.82	1.50	45.00	
17.10.2002 11:38:05	11.57	919.22	80.92	2.20	28.00	
17.10.2002 11:39:05	11.30	919.19	81.01	2.20	22.00	
17.10.2002 11:40:05	11.23	919.22	82.17	2.10	29.00	
. . .						

delivered within
12 hours

AIRS validation at Zugspitze/Garmisch: Cloud/weather information

1100|71|-|9|-|62|61|60|-|59|-|-|59|-|-|59|-|-|59|-|
1200|71|-|9|-|62|61|60|-|59|-|-|59|-|-|59|-|-|59|-|
1300|73|-|9|-|62|61|60|-|59|-|-|59|-|-|59|-|-|59|-|
1400|75|-|9|-|62|61|60|-|59|-|-|59|-|-|59|-|-|59|-|

Each file content is according to the format:

UTC|ww|h|N|Nh|CL|CM|CH|N1|C1|h1|N2|C2|h2|N3|C3|h3|N4|C4|h4|

where

"ww" is the weather at the time of observation (UTC) or during the hour before according to the following number index:

00 no observation

. . .

71 light snow without interruptions
72 moderate snow with interruptions
73 moderate snow without interruptions
74 moderate to strong snow with interruptions
75 strong snow without interruptions

. . .

Example

delivered within 12 hours

AIRS validation at Zugspitze/Garmisch: Radio Sounding

Sonde 1 launched 1h before overpass
Sonde 2 launched 5 min before overpass

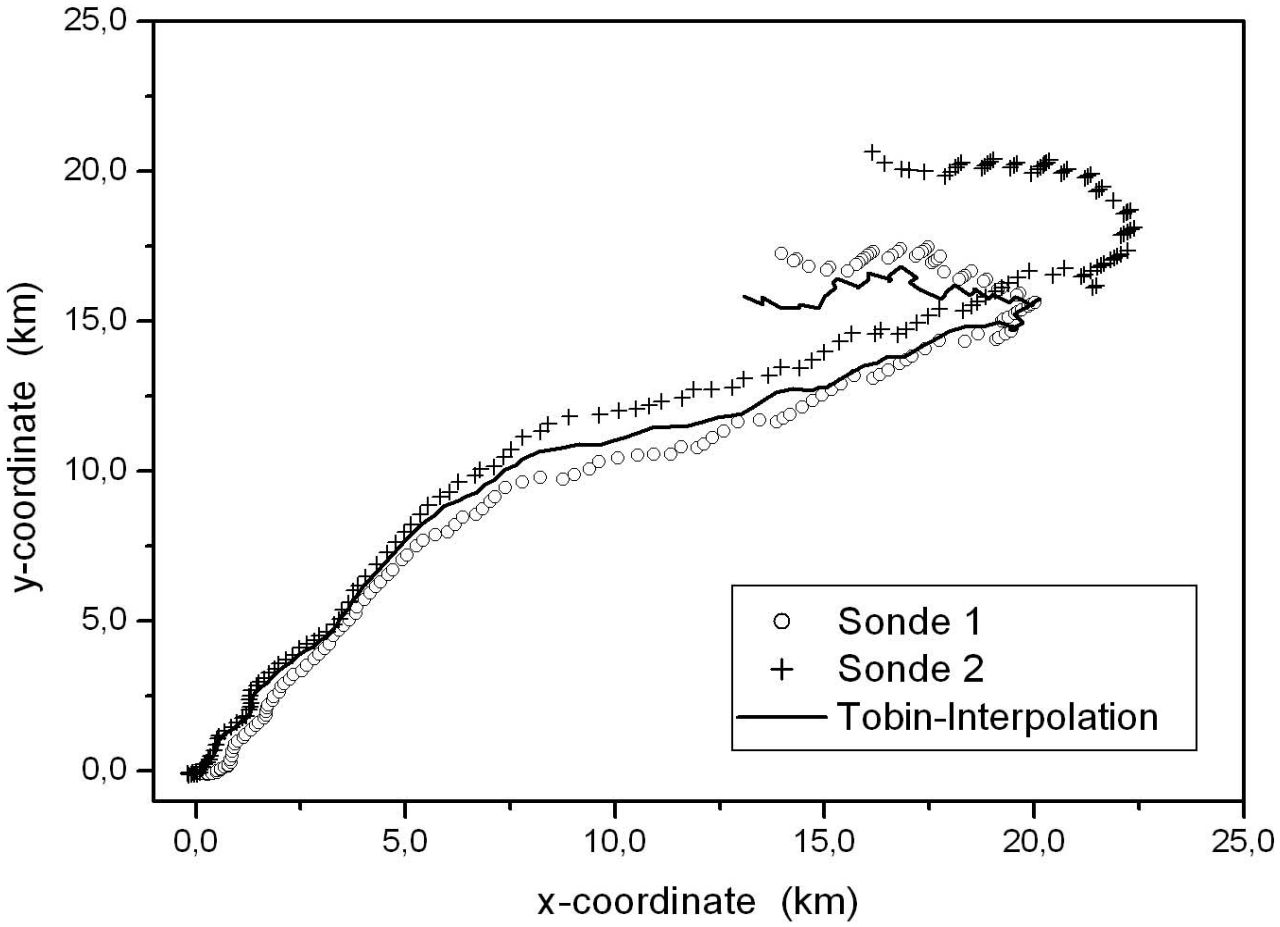
Vaisala RS 80-30 G sondes
TOTEX-800-g balloons
2 x Digicora III (Marvin 21, SPS220G)

TOBIN-Inter-/Extrapolation between both soundings:

$$q_{Tobin}(z, t_{op}) = q_{sonde}(z, t_0) + (dq(z)/dt)\ (t_{op} - t_0)$$

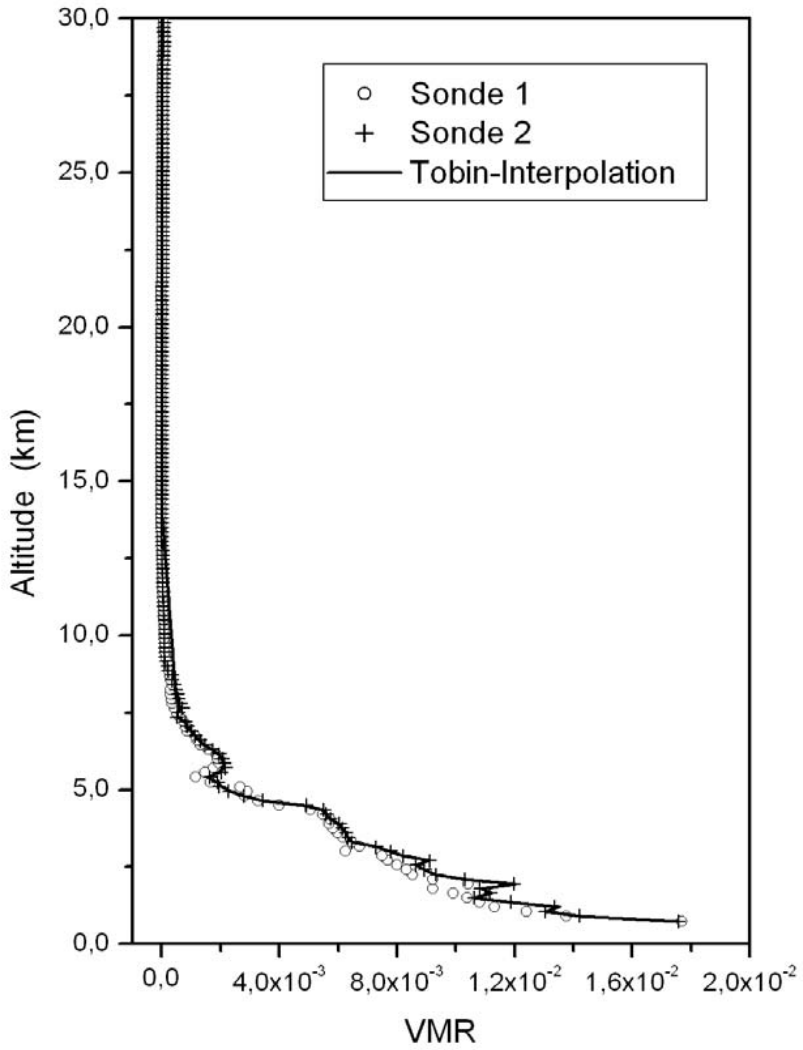
Tobin, D., W. Feltz, B. Knuteson, H. Revercomb, *"ARM T/q Best Estimate Profiles for AIRS validation"*, 1 March 2000

AIRS validation at Zugspitze/Garmisch: Radio Sounding



delivered within 12 hours

AIRS validation at Zugspitze/Garmisch: Radio Sounding



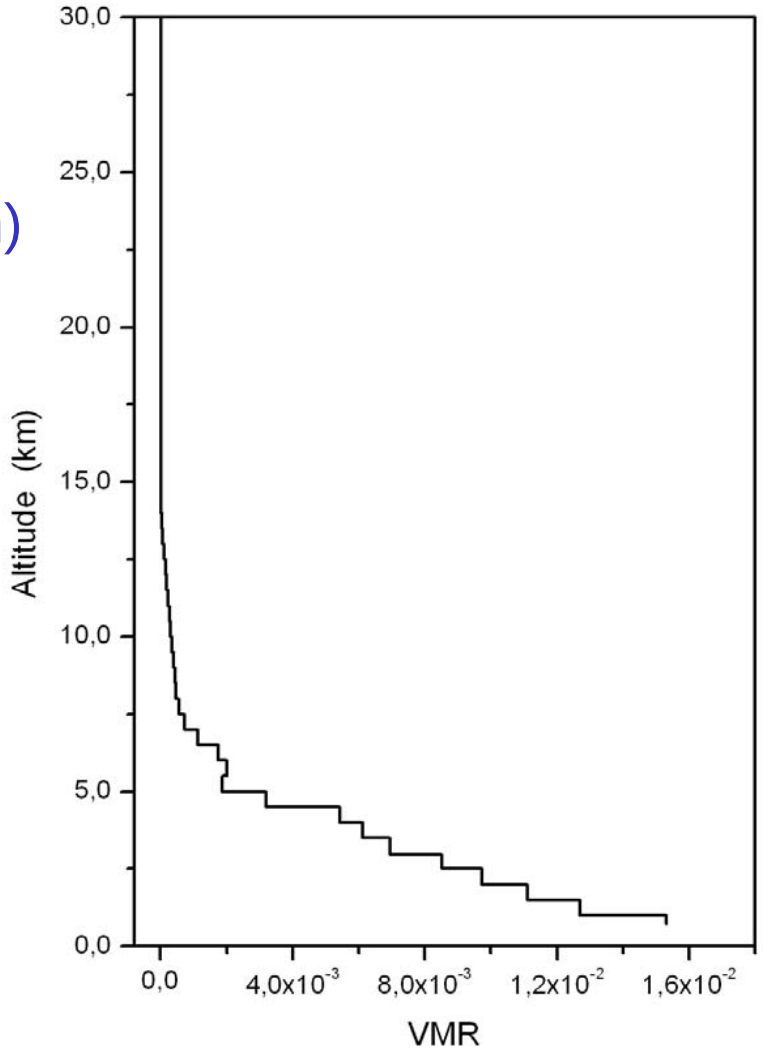
delivered within
12 hours

AIRS validation at Zugspitze/Garmisch: Radio Sounding

0.5-km-thick layer averages

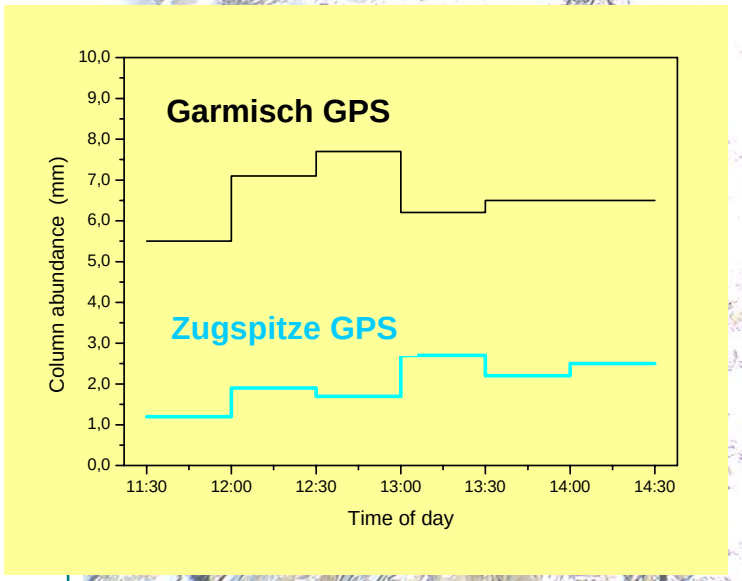
(Curtis-Godsen approximation)

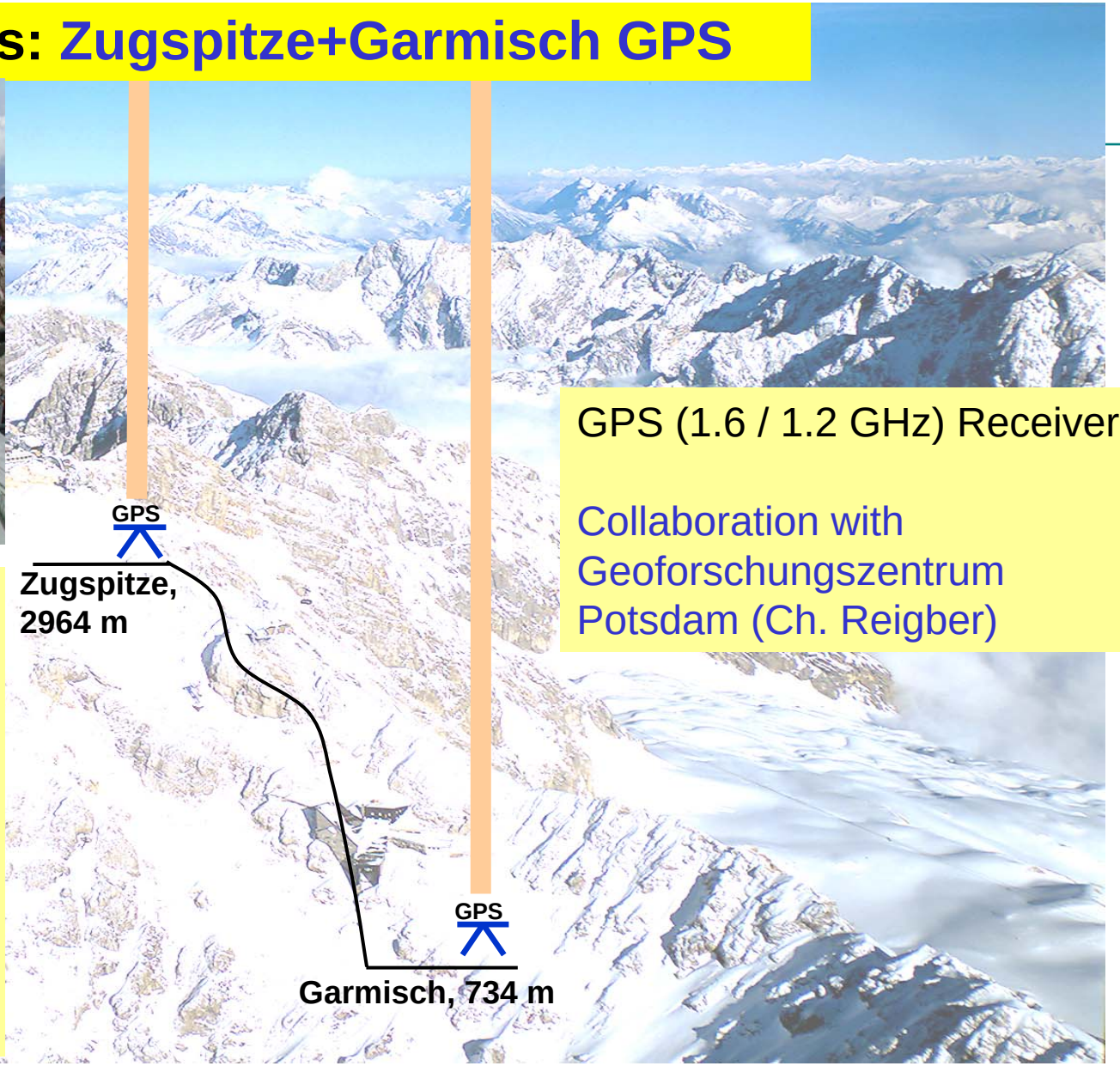
$$\overline{\mathrm{VMR}_i} = \frac{\int_{\Delta z_i} \mathrm{VMR}(z)\,\rho_{air}(z)\,dz}{\int_{\Delta z_i} \rho_{air}(z)\,dz}$$



delivered within 12 hours

Water vapor columns: Zugspitze+Garmisch GPS





GPS (1.6 / 1.2 GHz) Receivers

Collaboration with
Geoforschungszentrum
Potsdam (Ch. Reigber)

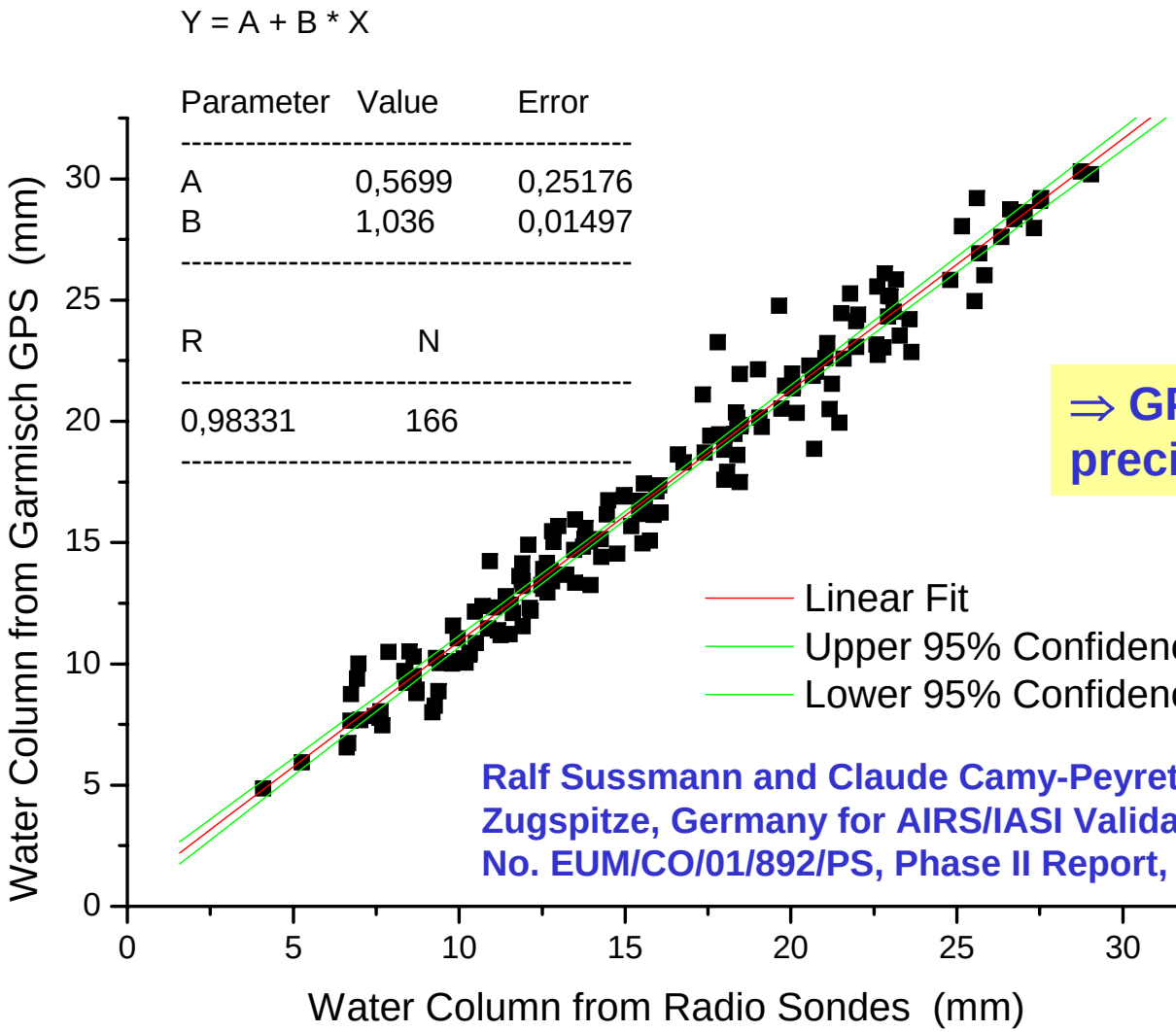
IMK-IFU, Research Center Karlsruhe, Garmisch-Partenkirchen, Ralf Sussmann

IASI validation at Permanent Ground-Truthing Facility Zugspitze/Garmisch

Water vapor columns: Validation of Garmisch GPS with radio sondes

Columns above Garmisch, 734 m

2-h-mean values



⇒ GPS bias 1-2 mm, precision 1 mm

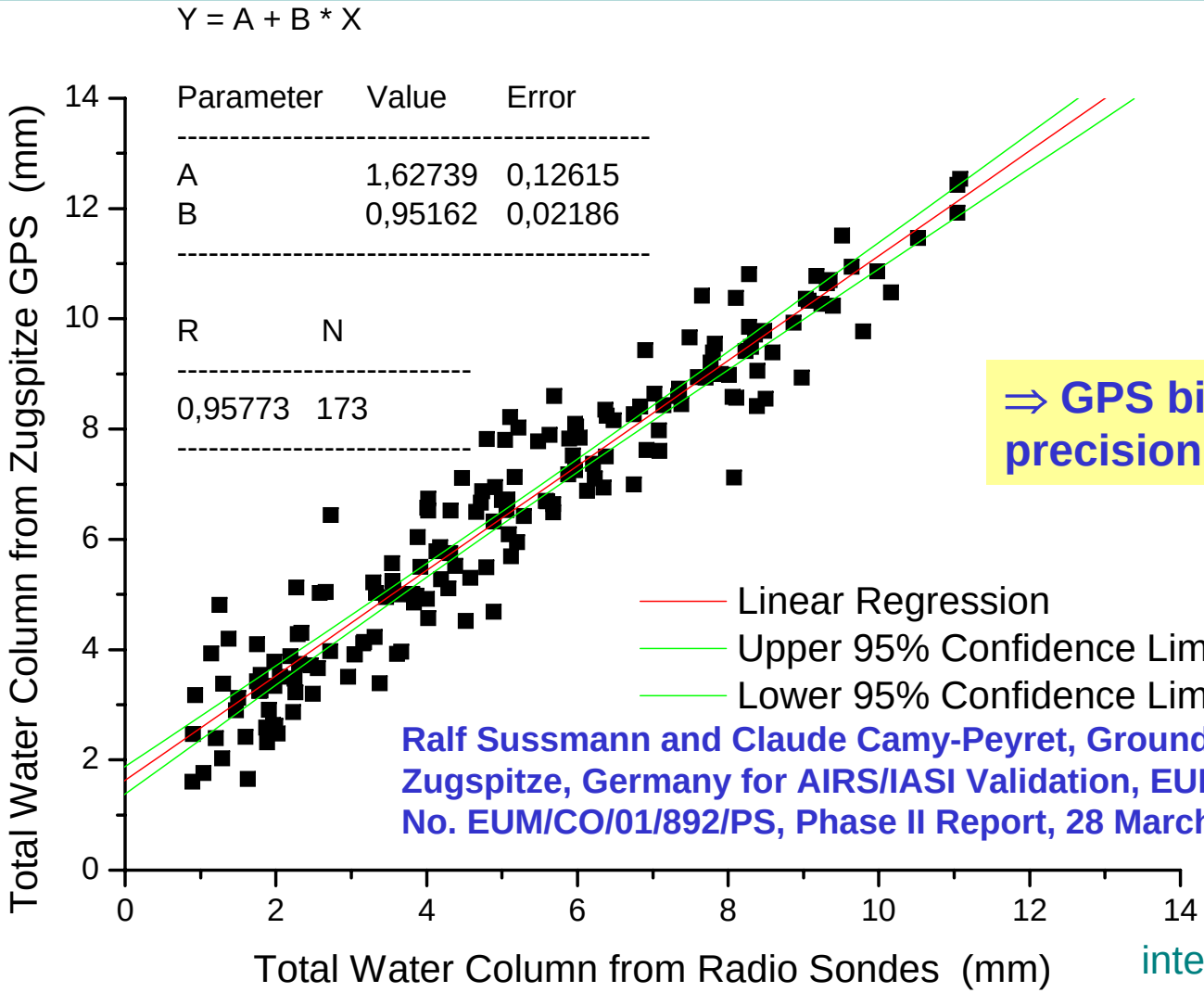
Ralf Sussmann and Claude Camy-Peyret, Ground-Truthing Center Zugspitze, Germany for AIRS/IASI Validation, EUMETSAT Contract No. EUM/CO/01/892/PS, Phase II Report, 28 March 2003

integrated Tobin-profiles

Water vapor columns: Validation of Zugspitze GPS with radio sondes

Columns above Zugspitze, 2964 m

2-h-mean values



⇒ GPS bias 1-2 mm, precision 1 mm

Ralf Sussmann and Claude Camy-Peyret, Ground-Truthing Center Zugspitze, Germany for AIRS/IASI Validation, EUMETSAT Contract No. EUM/CO/01/892/PS, Phase II Report, 28 March 2003

integrated Tobin-profiles

Water vapor columns: Validation of GPS – impact of T_s, T_m, and p_s errors

$$\Delta \mathrm{trop}^{\mathrm{sat}}{}_{\mathrm{rec}} = ZHD_{\mathrm{rec}}(p_s)\cdot \mathrm{m\_hyd}^{\mathrm{sat}}{}_{\mathrm{rec}}(elev) + ZWD_{\mathrm{rec}}\cdot \mathrm{m\_wet}^{\mathrm{sat}}{}_{\mathrm{rec}}(elev) \qquad \text{(eq. 1)}$$

$$PWV = \mathrm{F}(T_m) * ZWD \qquad \text{(eq. 2)}$$

$$T_m \approx 70.2 + 0.72\, T_s \qquad \text{(eq. 3)}$$

$$\Rightarrow \quad \frac{\partial PWV}{\partial p_s} = 0.35 \text{ mm}/1 \text{ mbar}$$

$\Rightarrow$ use p_s - averages, not snap shots!

$$\Rightarrow \quad \frac{\partial PWV}{\partial T_s} = 0.1 \text{ mm}/10 \text{ K}$$

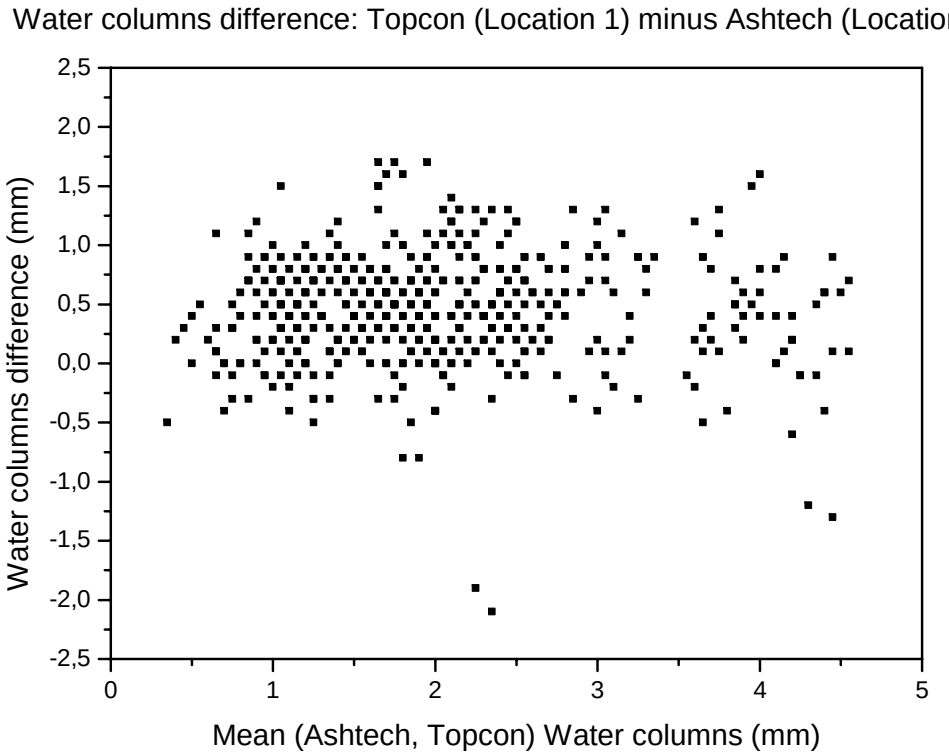
$\Rightarrow$ *different* T_m->T_s regressions for different sites and conditions have a minor impact:
e.g., using

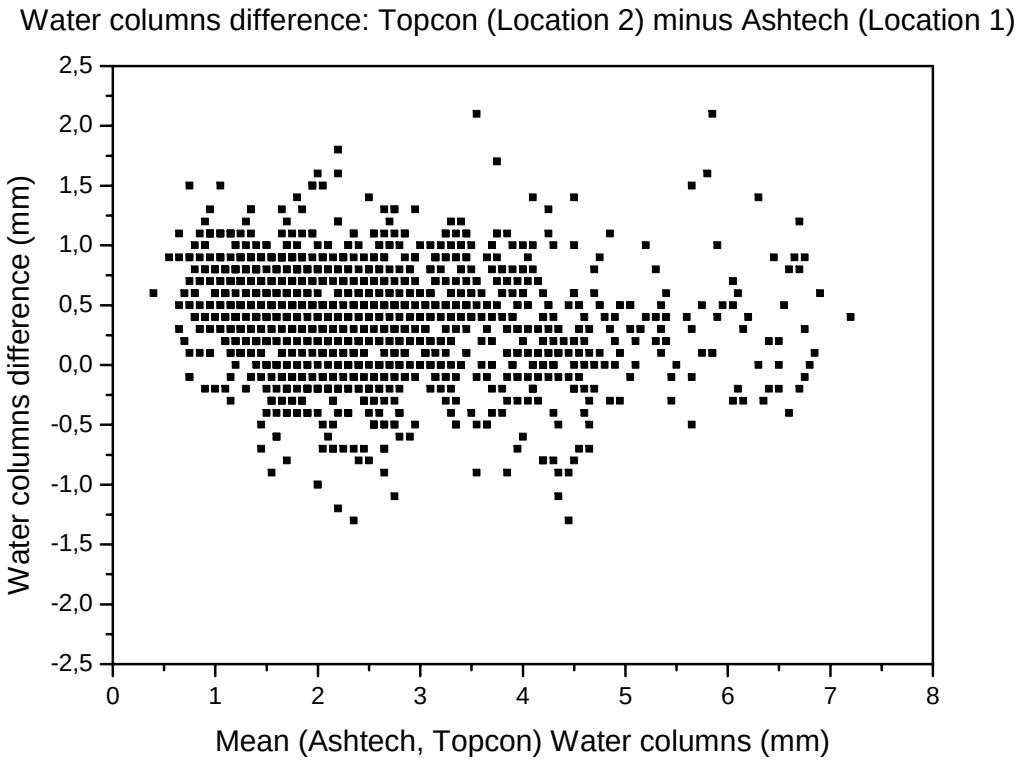
$$T^{\mathrm{Albany}}{}_m \approx 55.8 + 0.77\, T_s$$

instead of eq.(3) leads to a difference in T_m or T_s of only ≈ 1-2 K

Ralf Sussmann and Claude Camy-Peyret, Ground-Truthing Center Zugspitze, Germany for AIRS/IASI Validation, EUMETSAT Contract No. EUM/CO/01/892/PS, Phase II Report, 28 March 2003

Water vapor columns: Validation of GPS – impact of antenna type





- **antenna-type matters (in-accurate „geometry factor“), not mounting location**
- **there is an inherent ±0.5 mm scatter even without scatter of auxiliary parameters p_s, T_s**

Ralf Sussmann and Claude Camy-Peyret, Ground-Truthing Center Zugspitze, Germany for AIRS/IASI Validation, EUMETSAT Contract No. EUM/CO/01/892/PS, Phase II Report, 28 March 2003

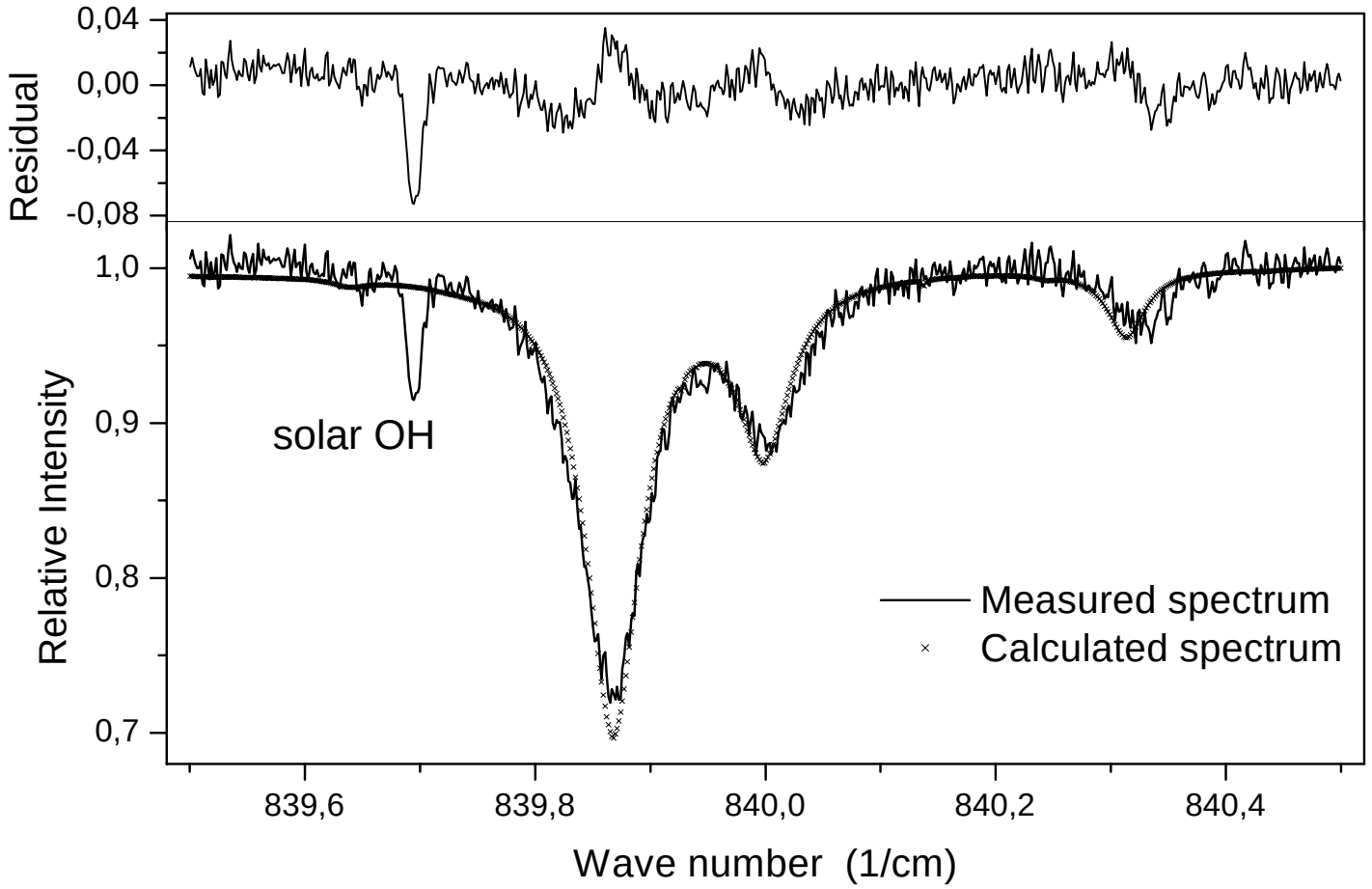
Zugspitze Solar FTIR: NDSC Primary-Status Instrument

0.00186 cm^{-1} resolution
(OPD = 486 cm) Bruker
IFS120HR FT-spectrometer

- SFIT2.39
- FASCATM 2.03 raytracing

AIRS validation at Zugspitze/Garmisch: Zugspitze Solar FTIR

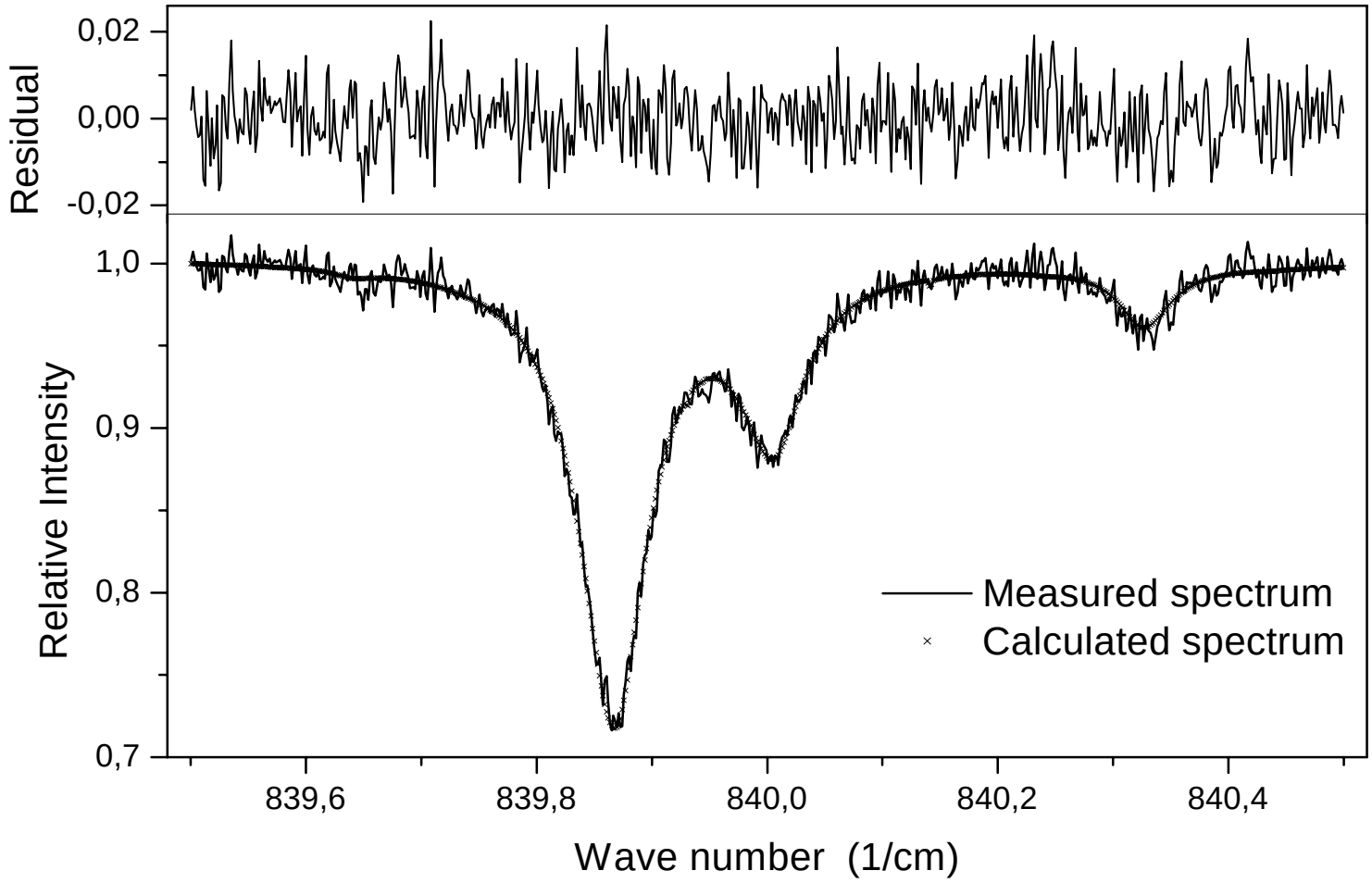
HITRAN96



010-010
R10, R14
water lines

Water vapor columns/profiles: Solar FTIR retrieval

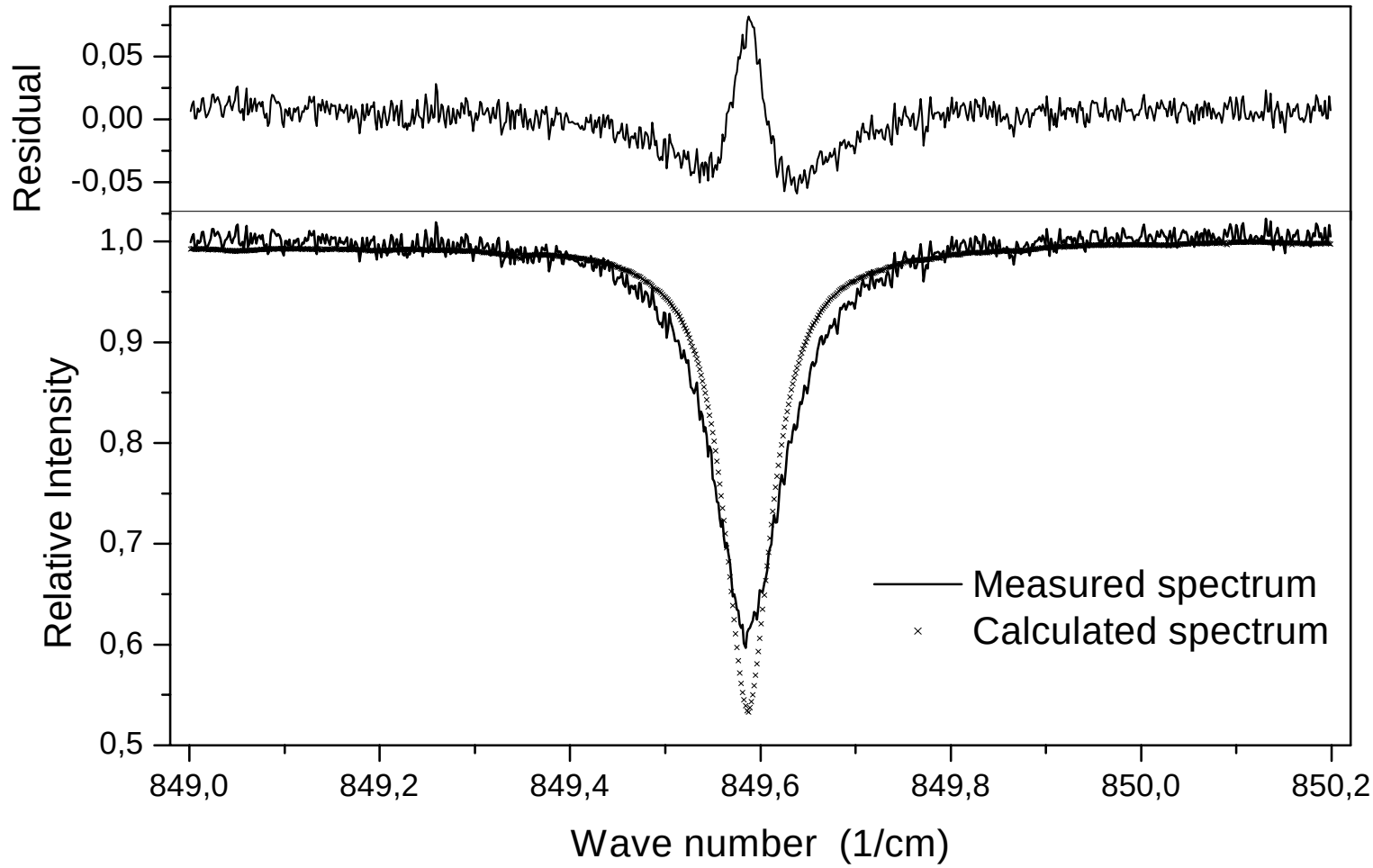
HITRAN2000, solar OH removed



010-010
R10, R14
water lines

AIRS validation at Zugspitze/Garmisch: Zugspitze Solar FTIR

HITRAN96

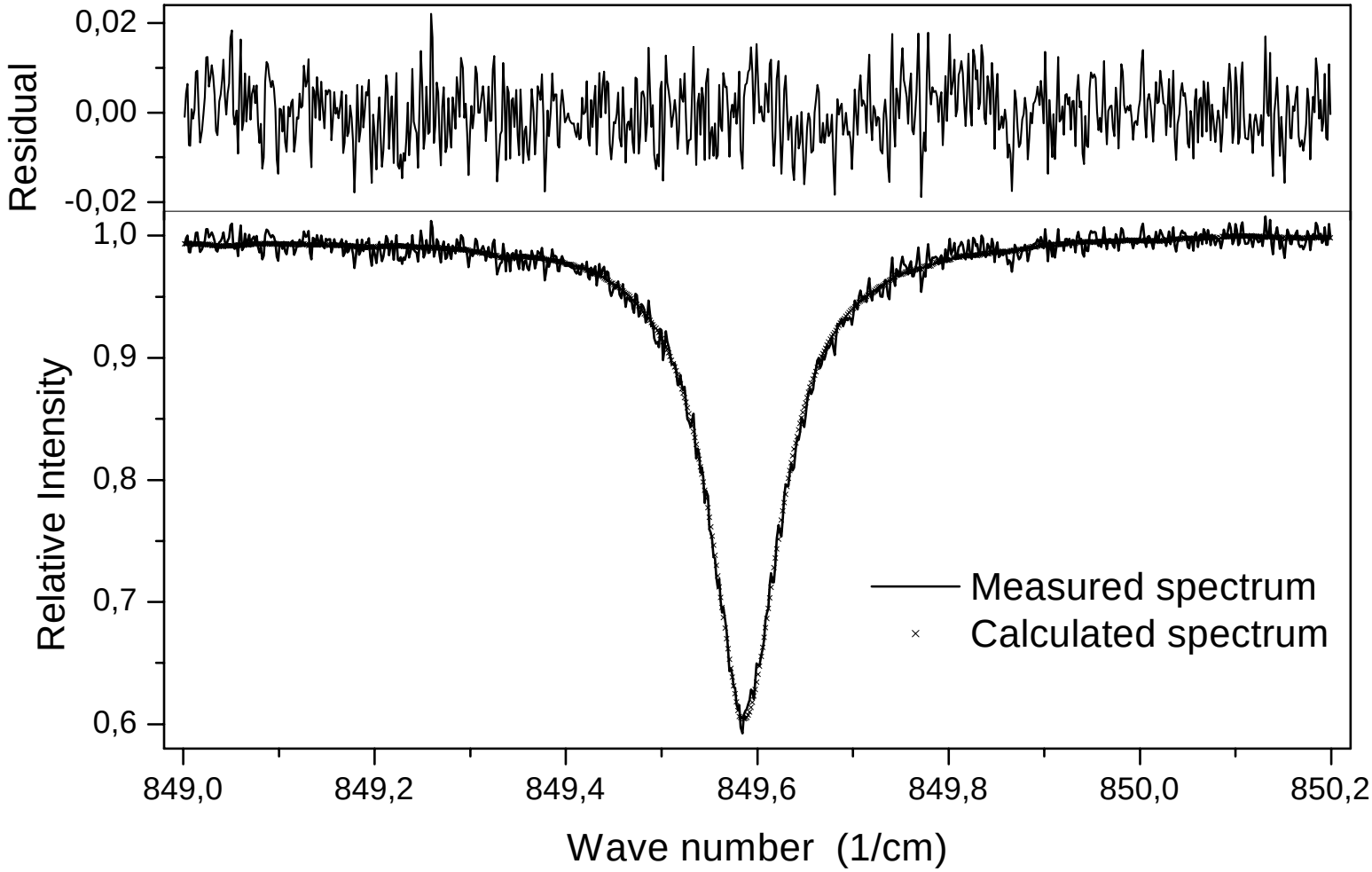


010-010
R11
water line

IMK-IFU, Research Center Karlsruhe, Garmisch-Partenkirchen, Ralf Sussmann

Water vapor columns/profiles: Solar FTIR retrieval

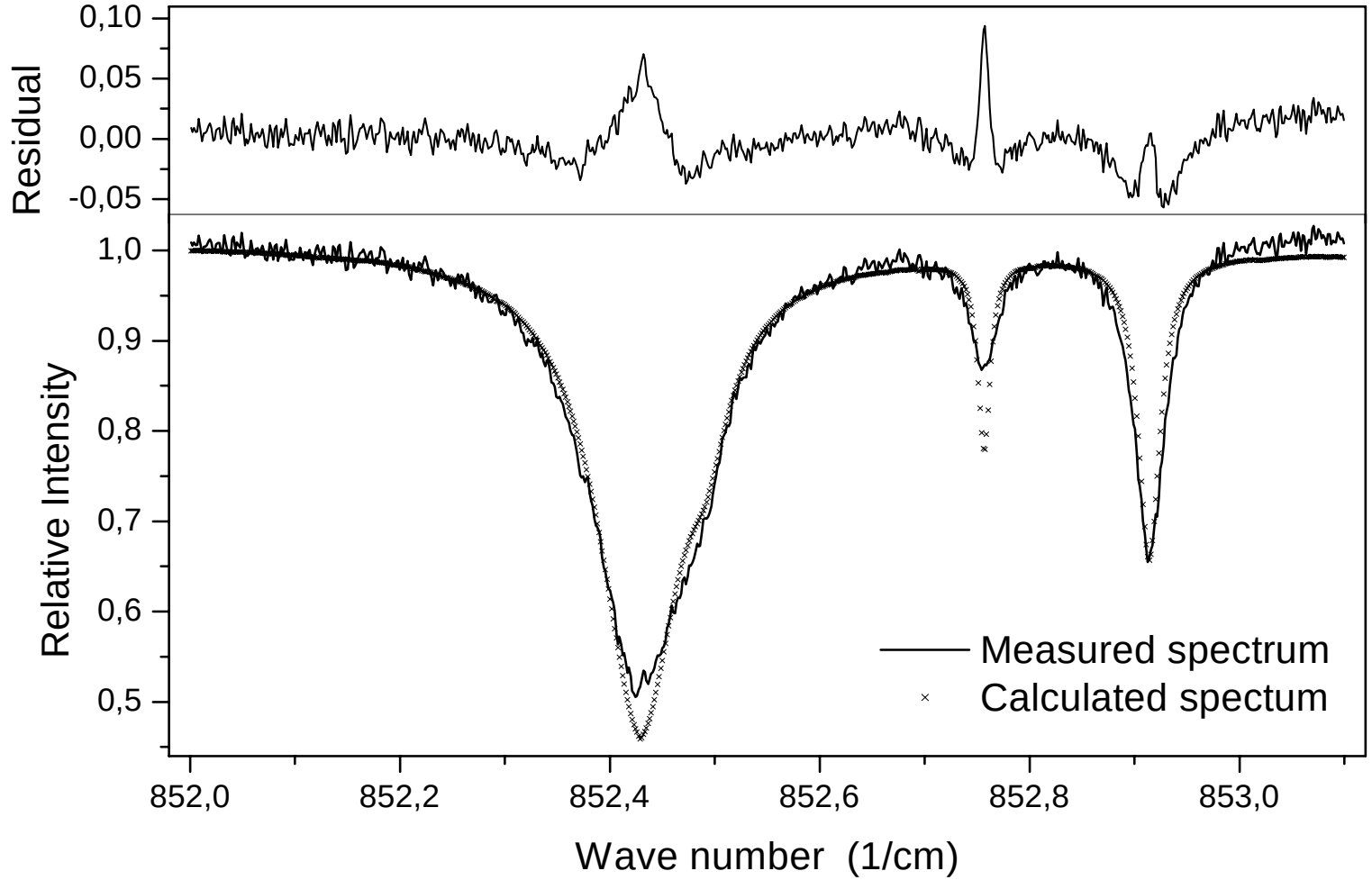
HITRAN2000



010-010
R11
water line

AIRS validation at Zugspitze/Garmisch: Zugspitze Solar FTIR

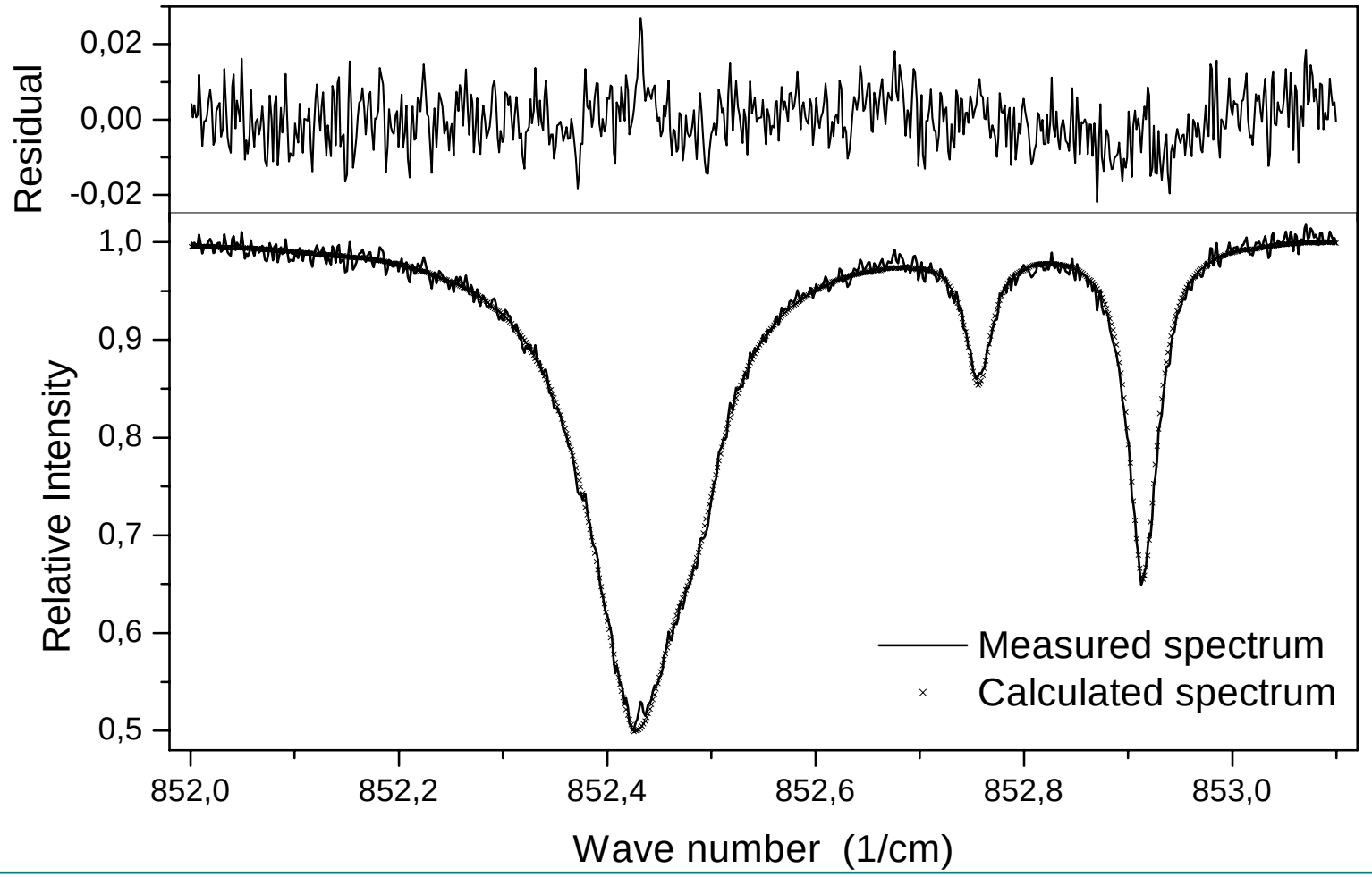
HITRAN96



010-010
R10, R13, R16
water lines

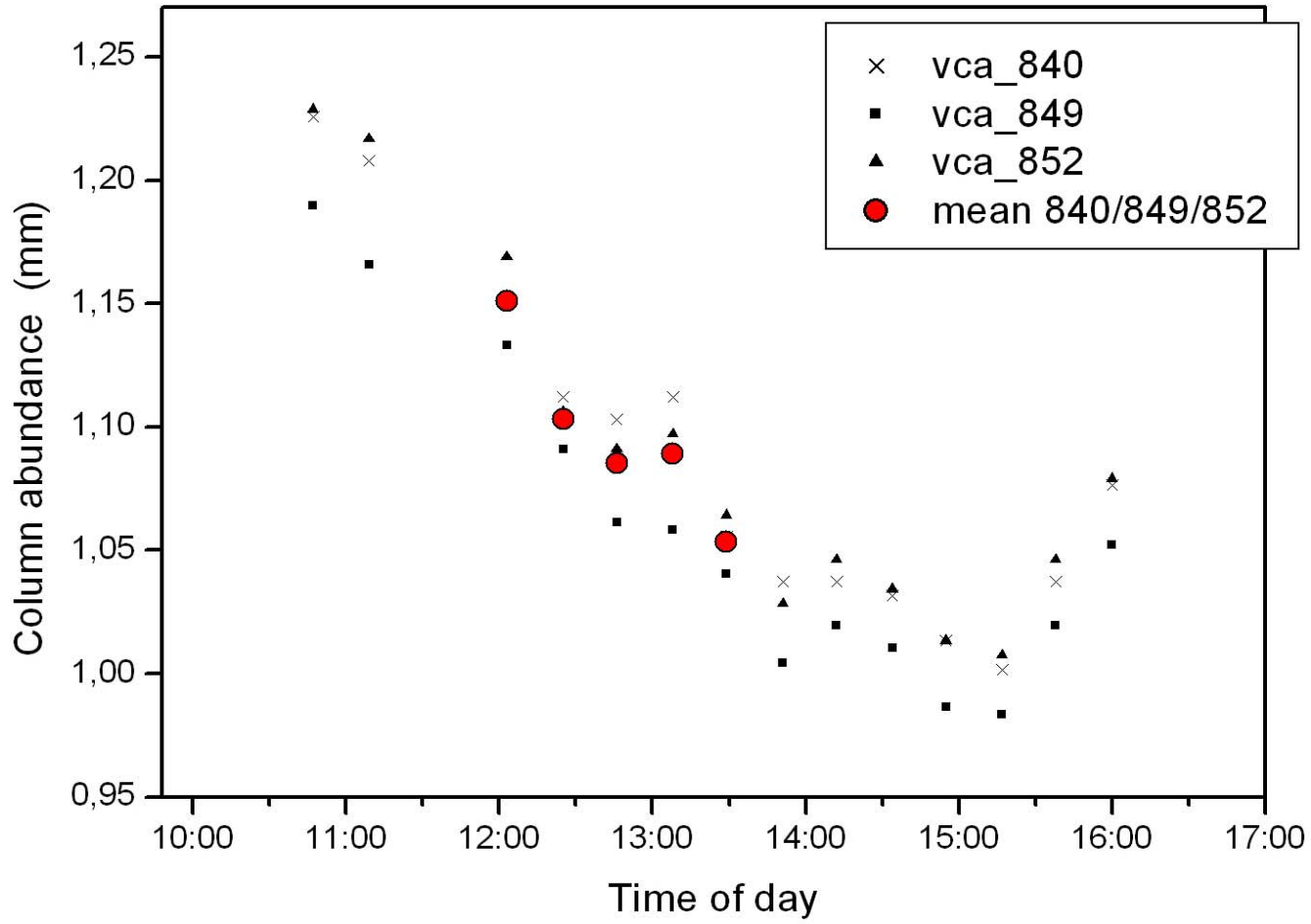
Water vapor columns/profiles: Solar FTIR retrieval

HITRAN2000



010-010
R10, R13, R16
water lines

AIRS validation at Zugspitze/Garmisch: water columns from Zugspitze Solar FTIR



Example

delivered within 12 hours

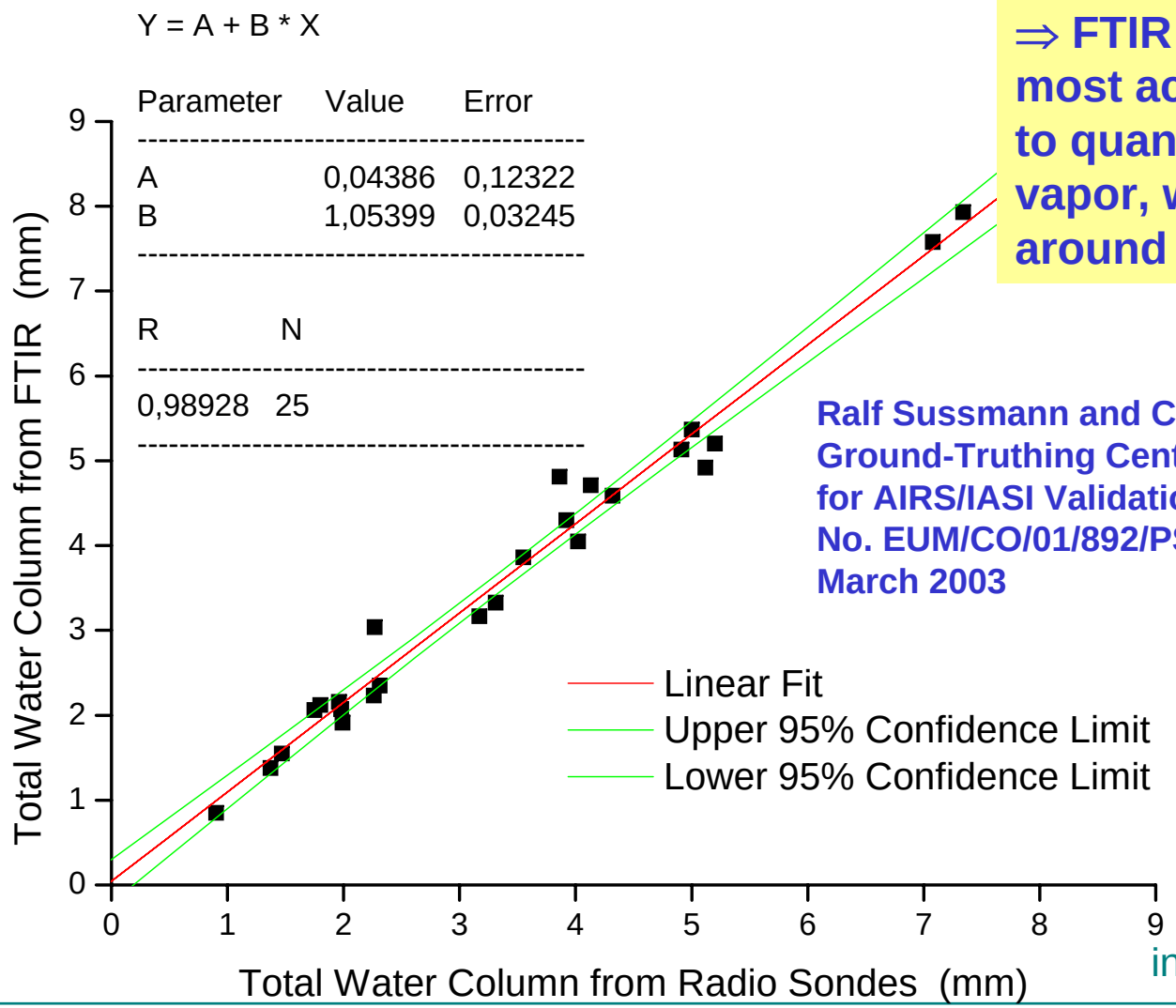
IMK-IFU, Research Center Karlsruhe, Garmisch-Partenkirchen, Ralf Sussmann

IASI validation at Permanent Ground-Truthing Facility Zugspitze/Garmisch

Water vapor columns Zugspitze/Garmisch: Validation of solar FTIR with sondes

Columns above Zugspitze, 2964 m

2-h-mean values



integrated Tobin-profiles

⇒ FTIR is probably the most accurate technique to quantify columnar water vapor, with an accuracy around 0.1 mm

Ralf Sussmann and Claude Camy-Peyret, Ground-Truthing Center Zugspitze, Germany for AIRS/IASI Validation, EUMETSAT Contract No. EUM/CO/01/892/PS, Phase II Report, 28 March 2003

AIRS validation at Zugspitze/Garmisch: lessons learned on water measurements

- don´t calibrate sondes to GPS, esp. for high altitude sites or dry conditions
- calibrate (high altitude) GPS against ensemble of coincident sondes
- take care of p_s measrements for GPS
- solar FTIR yields very high accuracy columns
- place a FTIR to Garmisch since GPS is not accurate
- set up retrieval for solar FTIR-profiles up to UT/LS (need covariance plus additional weak lines in retrieval $\Rightarrow$ use our radio sonde data set from AIRS validation campaign)
- push Zugspitze water vapor lidar (up to UT/LS)

Zugspitze operational since 1995
typ. 130 measurement days per year

H_2O columns and profiles

FTIR
IFU

Zugspitze 2964 m

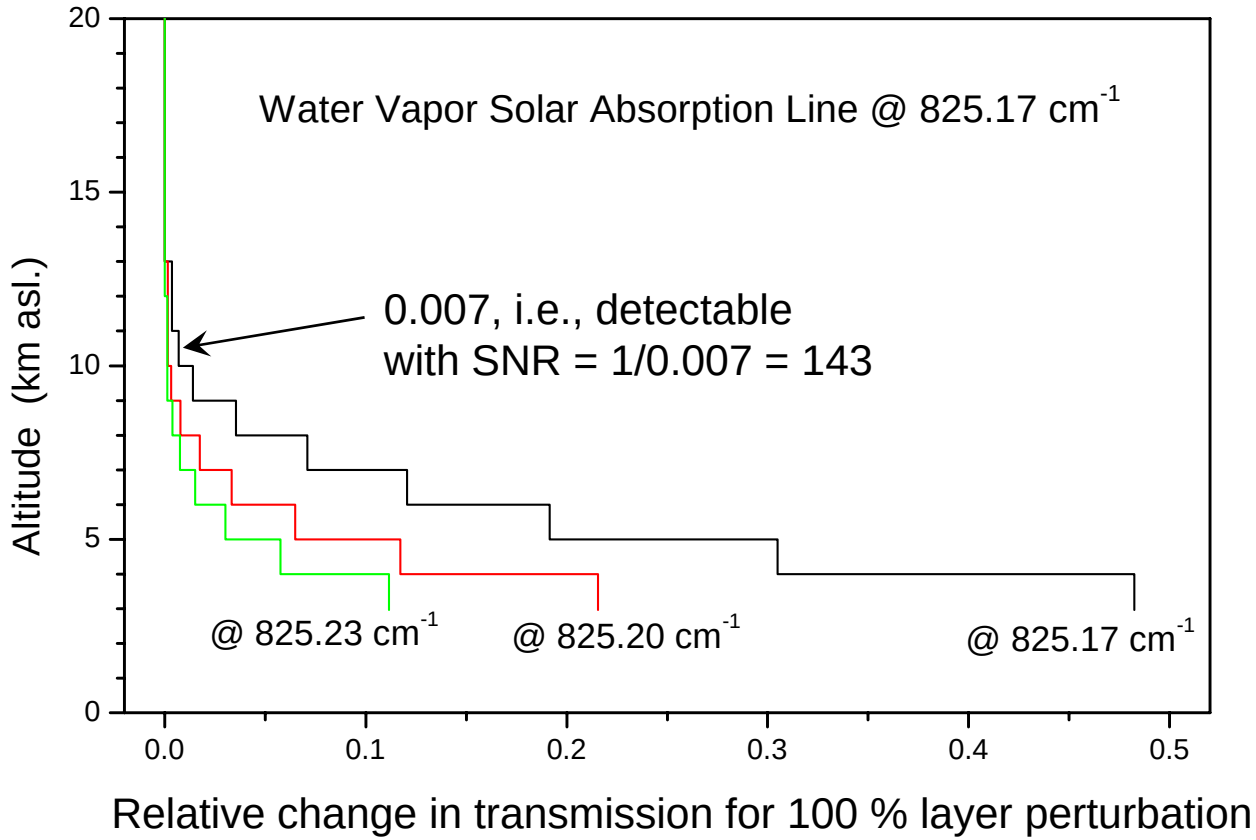
Garmisch operational since 2004
94 measurement days in 2004
147 measurement days in 2005

"Differential FTIR" with Zugspitze: H_2O columns and profiles

FTIR
IFU

Garmisch 734 m

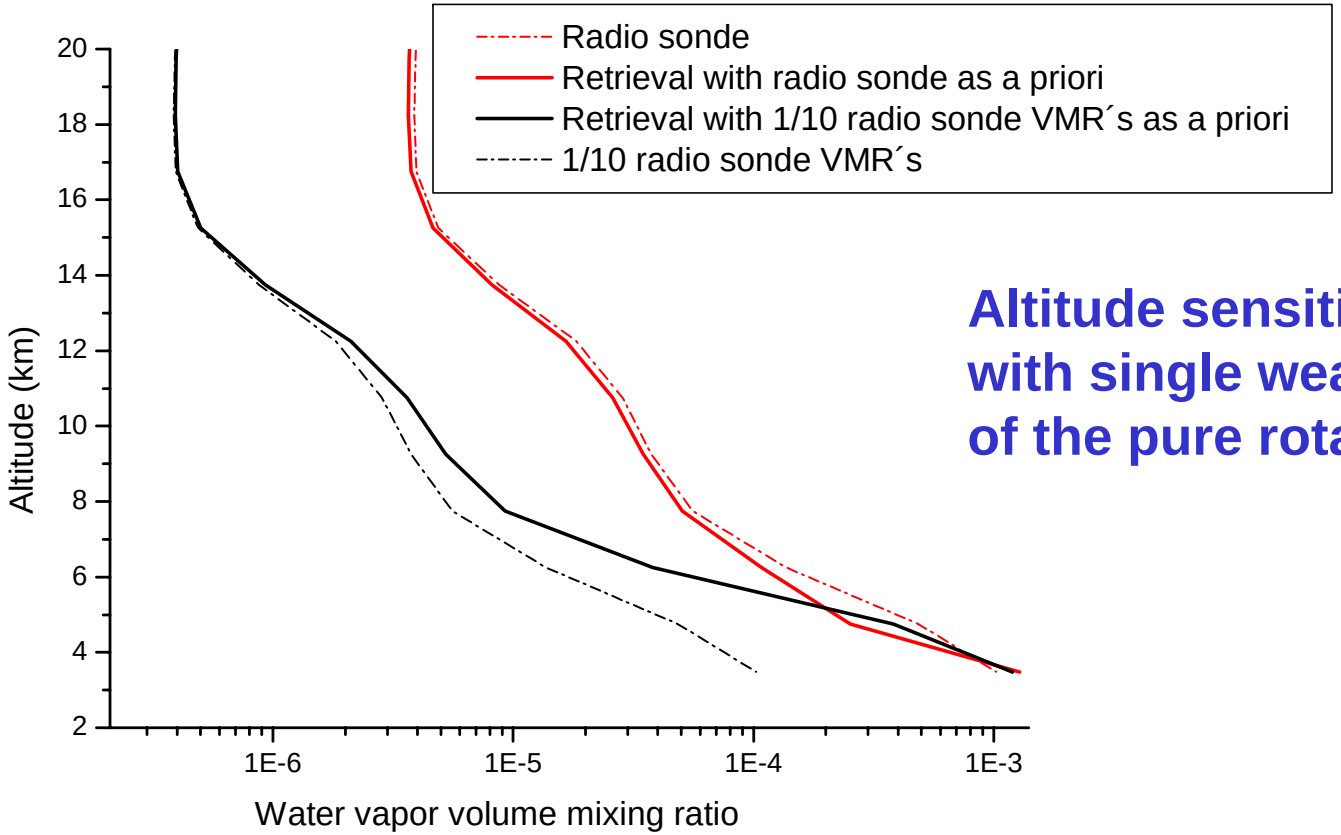
Water vapor profiles from Zugspitze solar FTIR: altitude range - weighting functions



⇒ with SNR > 200 information up to > 12 km should be attainable

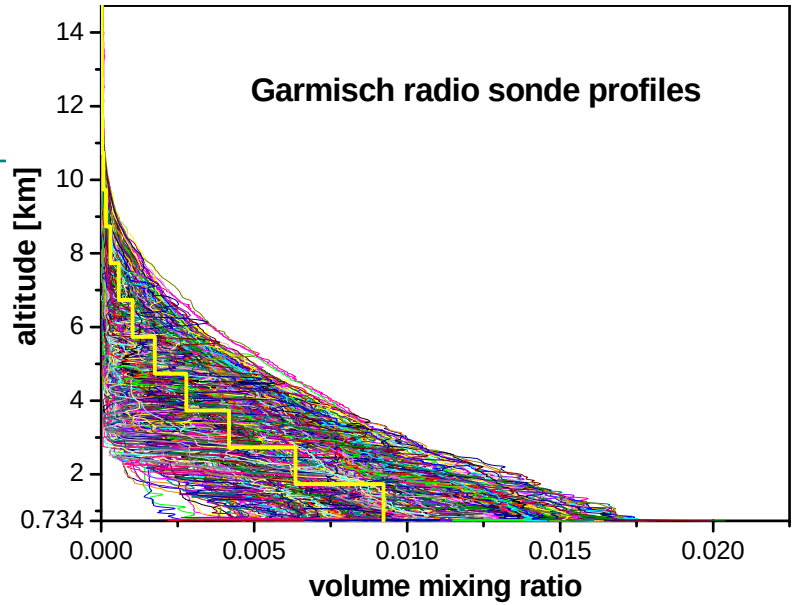
Water vapor profiles from Zugspitze solar FTIR: altitude range – a priori contribution

altitude range (high-altitude site): 12-14 km, depending on humidity
degrees of freedom of signal: 3-4
vertical resolution: decreasing with altitude, *e.g*, 1 km, 2 km, 4 km, 7 km



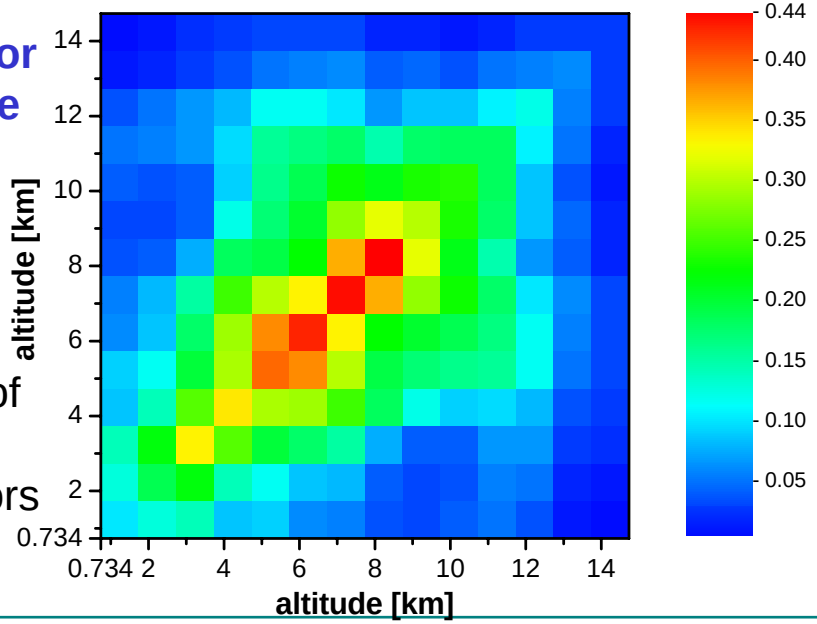
Altitude sensitivity experiment with single weak 841.9 cm^{-1} line of the pure rotation band

water vapor profiles from solar FTIR

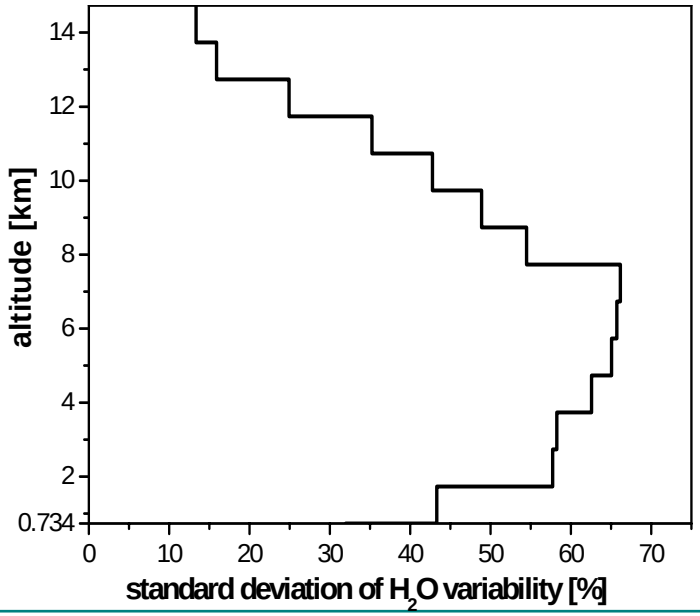


- **regularisation: optimal estimation**
- **a priori profile: use GPS to scale a priori**
- **validate FTIR profiles with lidar**

water vapor covariance



Unit: coariances of VMR-layer scaling factors



VMR

IMK-IFU, Research Center Karlsruhe, Garmisch-Partenkirchen, Ralf Sussmann

IASI validation at Permanent Ground-Truthing Facility Zugspitze/Garmisch

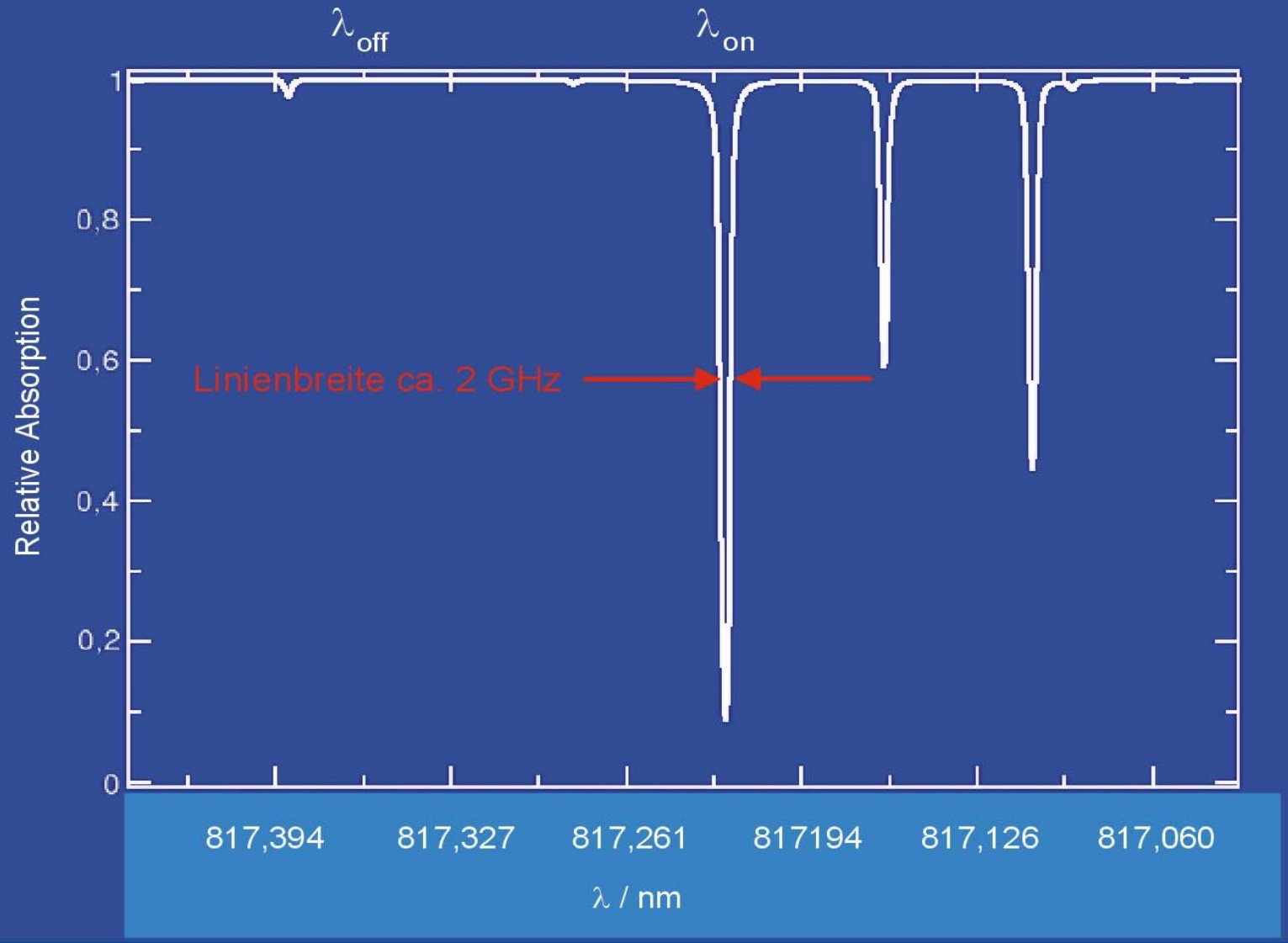
Schneefernerhaus

2675 m asl.

water vapor

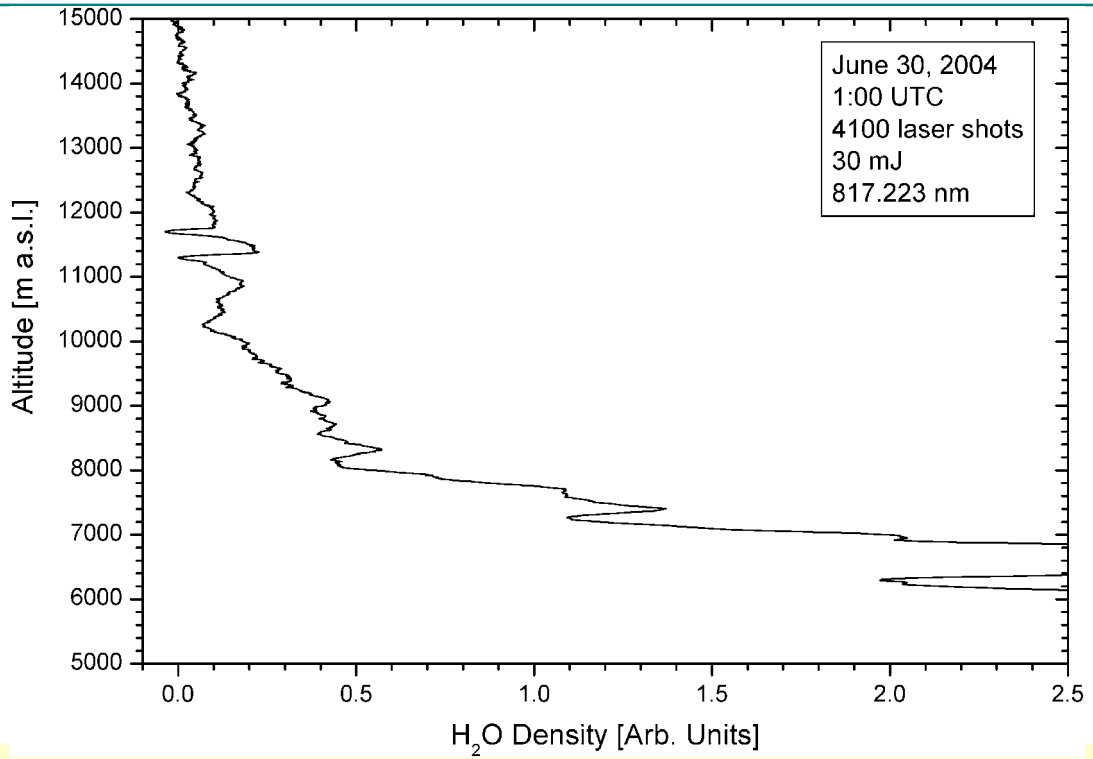
differential absorption lidar

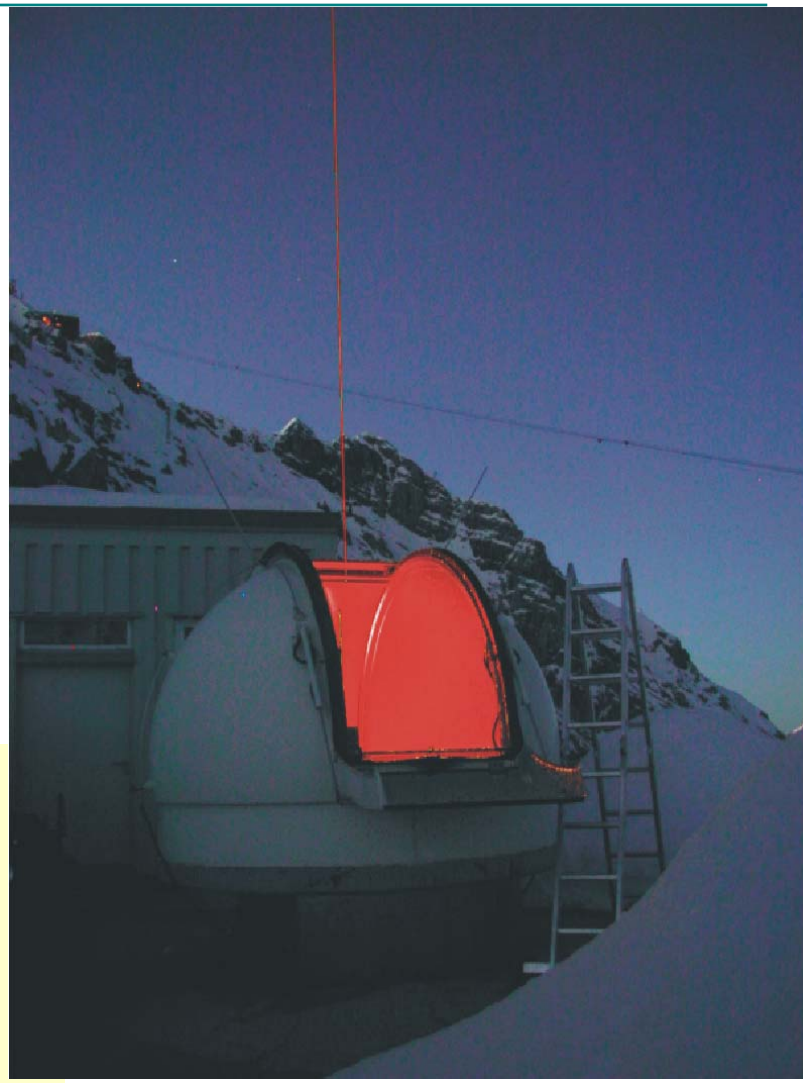
Verwendete Absorptionslinie:



Hohe Anforderungen an das LASER-System !

Water vapor profiles at Zugspitze: Differential-absorption lidar at the Zugspitze



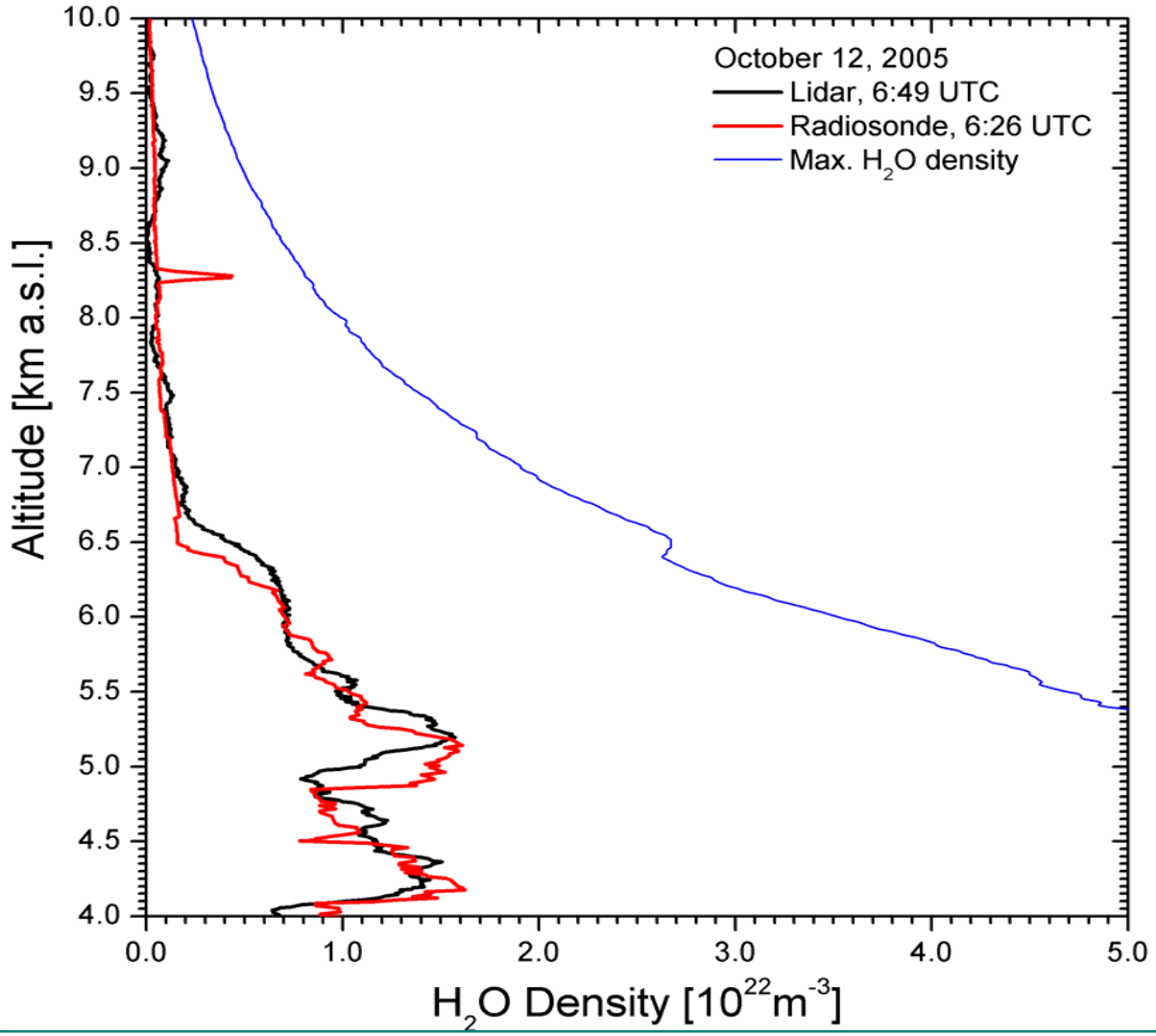


- measurement range up to >12 km
- vertical resolution 50 m (near field) to 250 m (far field)
- accuracy 5% (near field) to 10% (far field), depending on humidity
- 10-min-integration

IMK-IFU, Research Center Karlsruhe, Garmisch-Partenkirchen, Ralf Sussmann

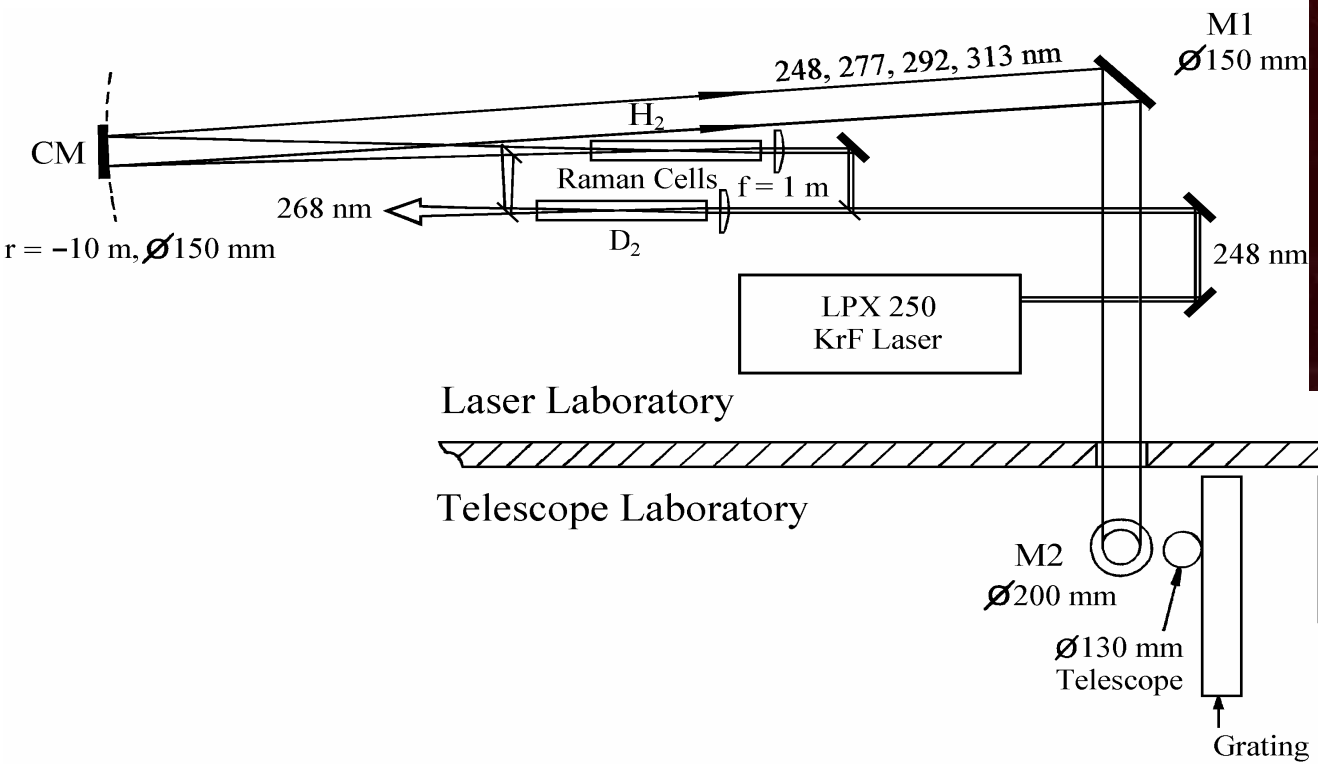
IASI validation at Permanent Ground-Truthing Facility Zugspitze/Garmisch

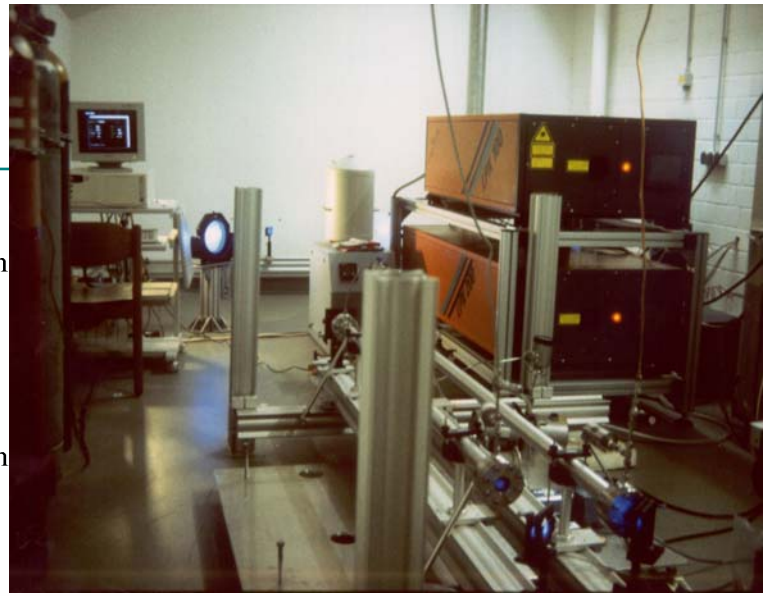
Water profiles Zugspitze: Validation of lidar with radio sondes



Slight vertical displacement above 4.8 km due to orographic effects

O_3 profiles at Garmisch: Tropospheric O_3 lidar





Detectors:
Hamamatsu
H5783P-06
PMTs

Optimized for tropospheric profiling: range up to 16 km

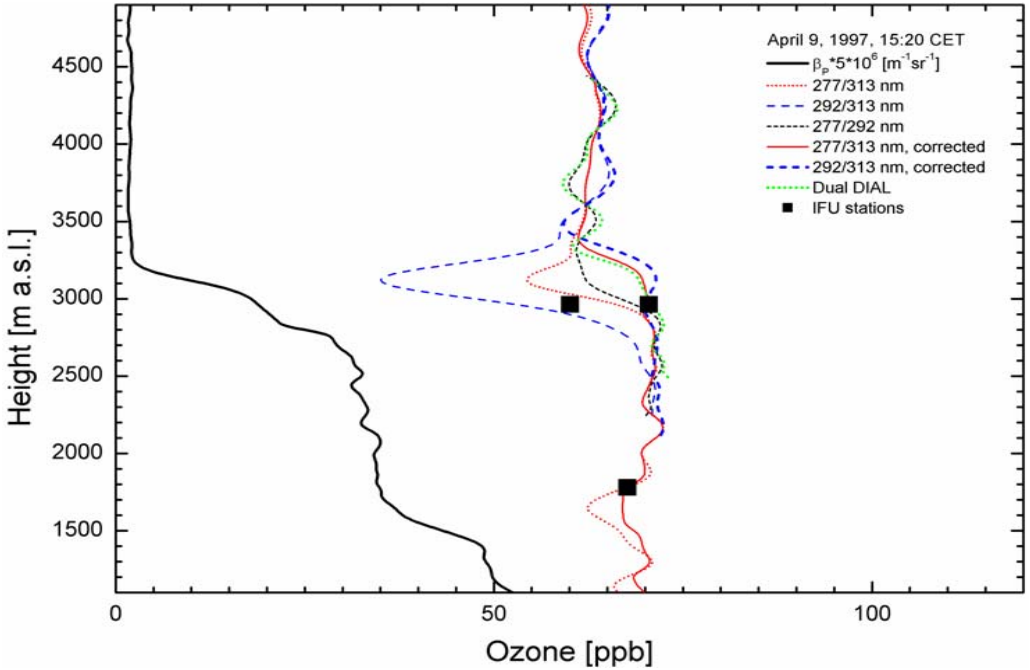
Near-field telescope: 3 analog channels

Far-field telescope: 3 analog channels, 2 photon-counting channels (700 MHz)

O_3 profiles at Garmisch: Validation of tropospheric O_3 lidar

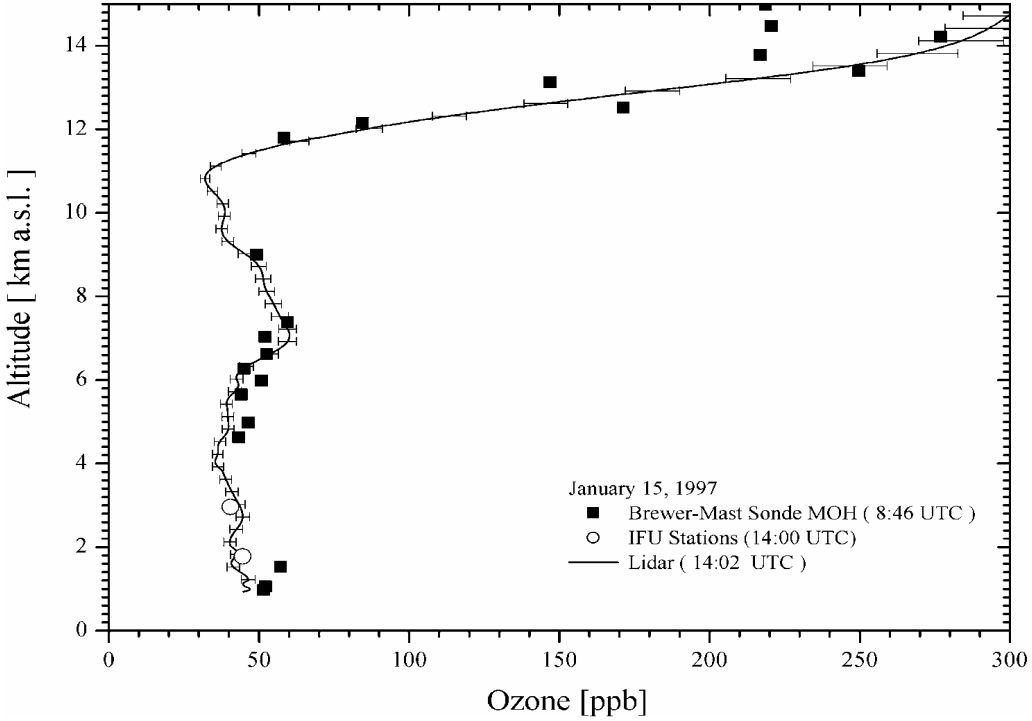
Advanced aerosol correction:

Eisele and Trickl, Appl. Opt. 44 (2005)

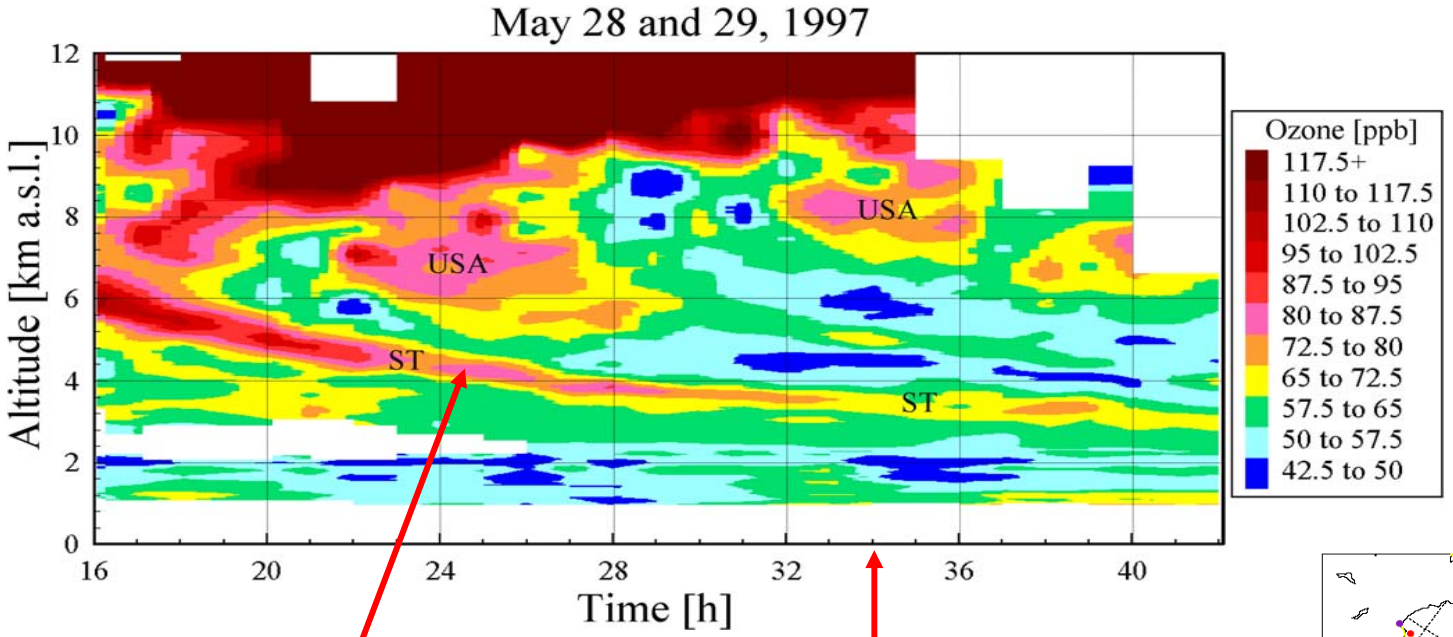


Validation: Errors mostly stay below 5 % (3 ppb) in the lower troposphere.

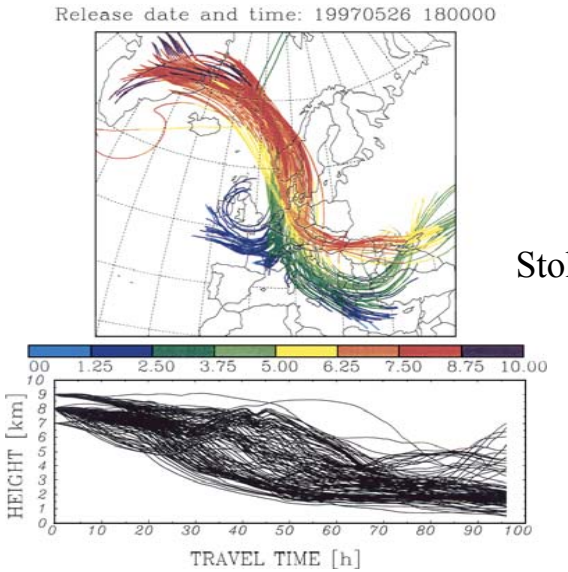
Eisele, Trickl, et al., J. Atmos. Sci. (1999)



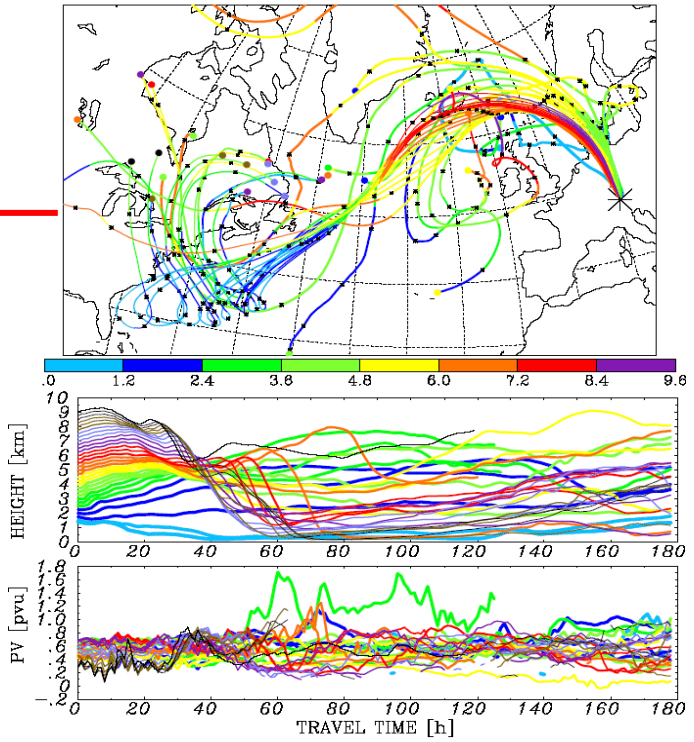
O_3 lidar profiles Garmisch: Stratospere-troposphere and Transatlantic Transport



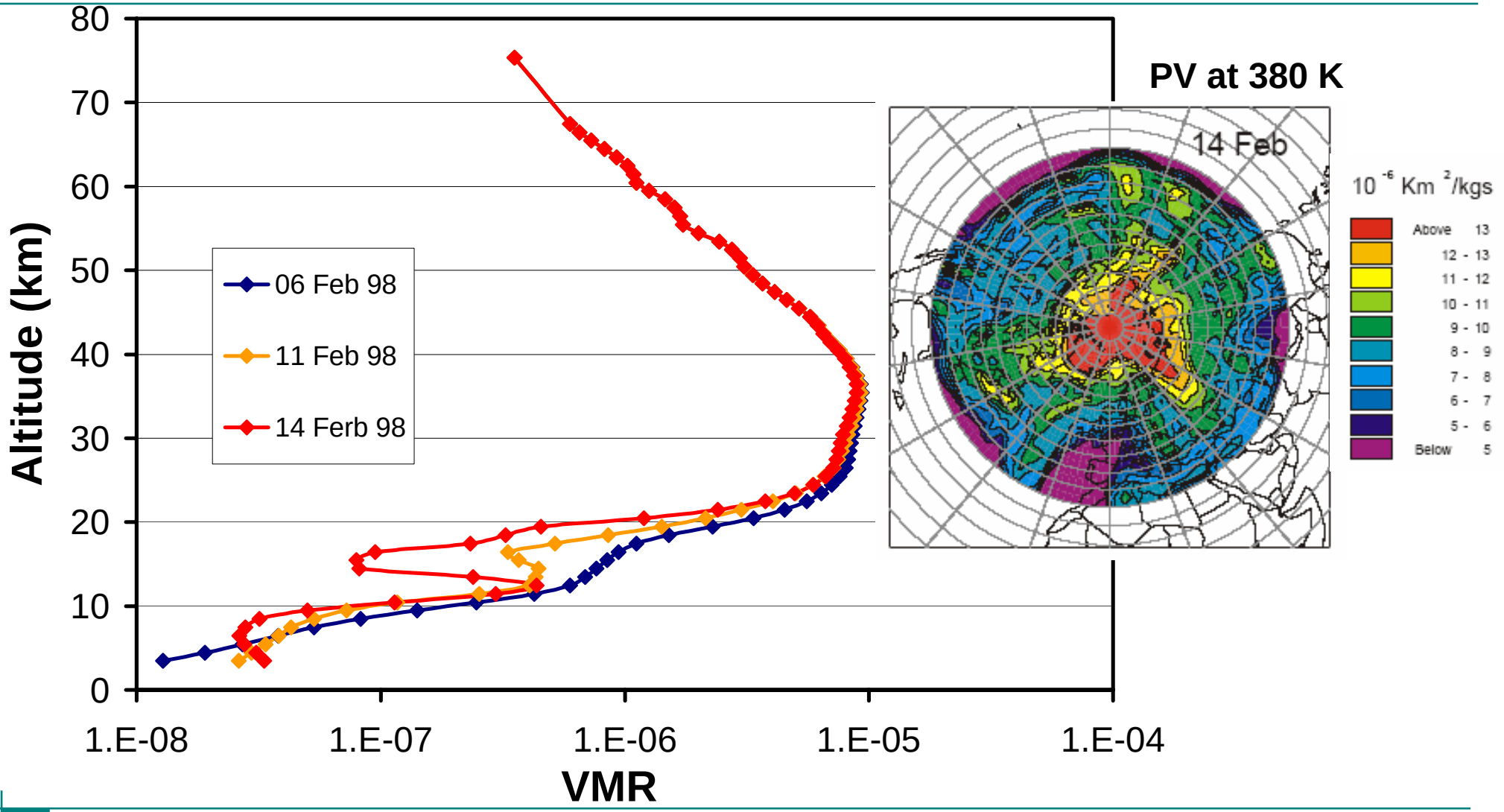
Time series up to four days



Stohl and Trickl, J. Geophys. Res. 1999



O_3 columns/profiles (Zugspitze+Garmisch FTIR): Subtropical intrusion Feb 1998



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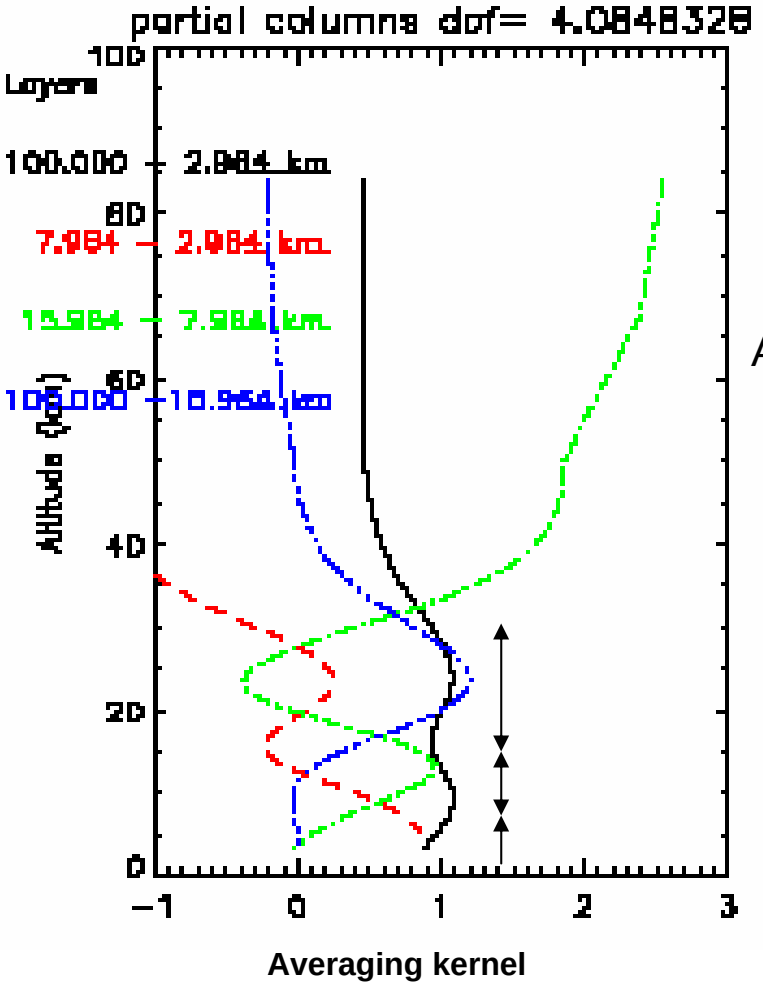
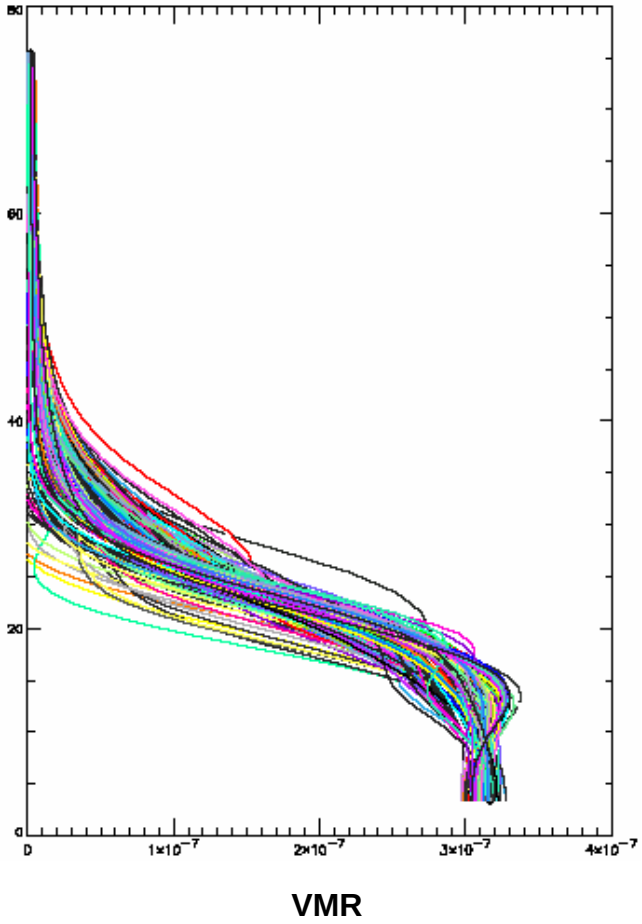
IASI validation at Permanent Ground-Truthing Facility Zugspitze/Garmisch

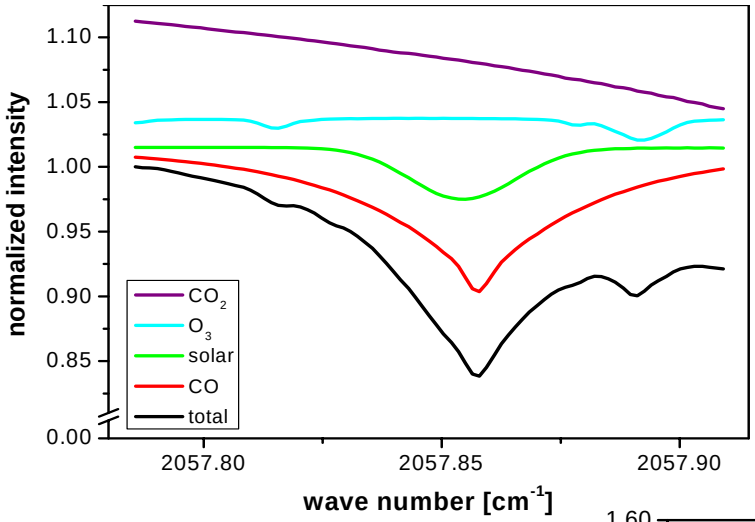
N_2O profiles Zugspitze+Garmisch FTIR: retrieval

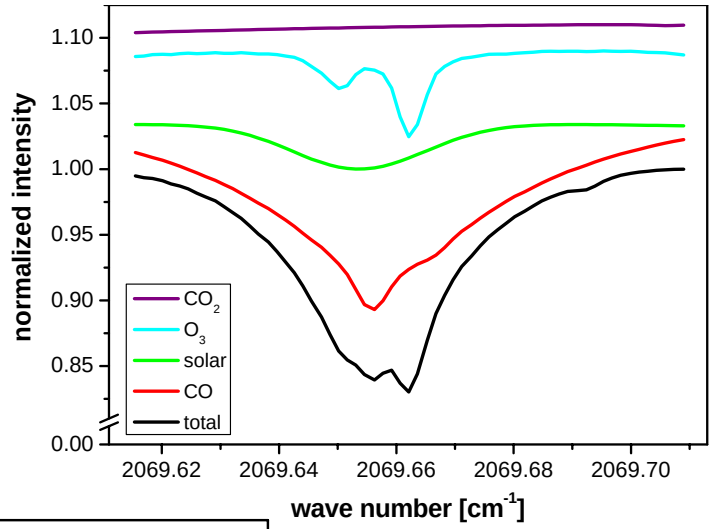


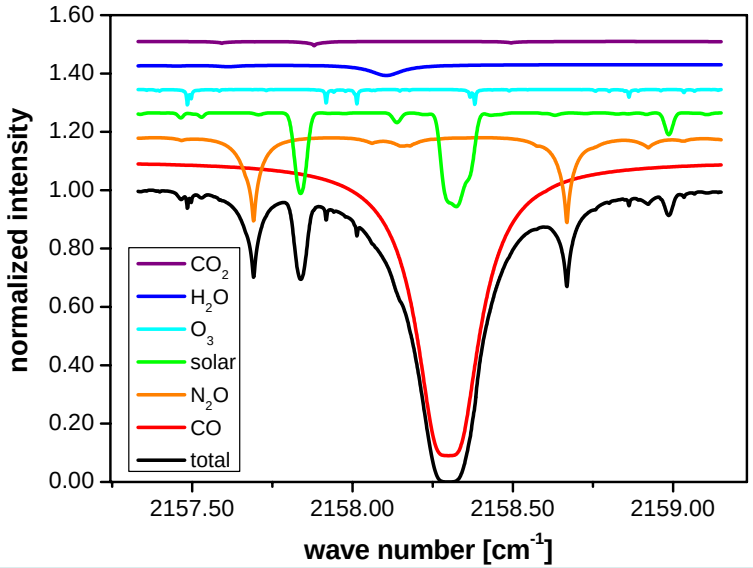
Altitude:	Dofs:
8.96 km	1.0598609
16.96 km	2.1855644
25.96 km	3.2838593



CO profiles/columns Zugspitze+Garmisch FTIR: retrieval







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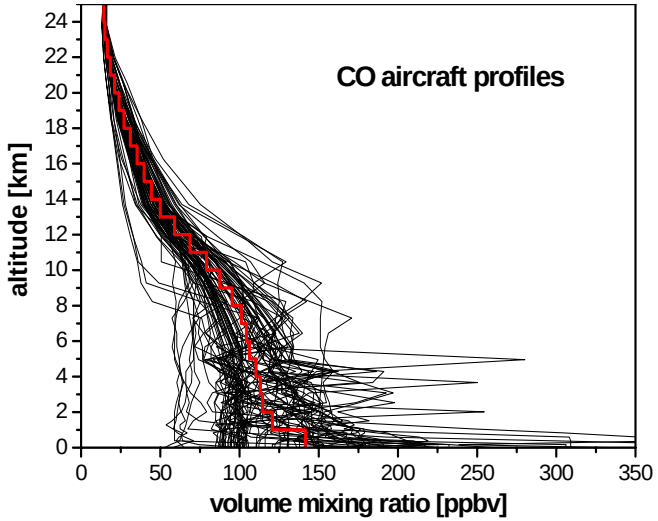
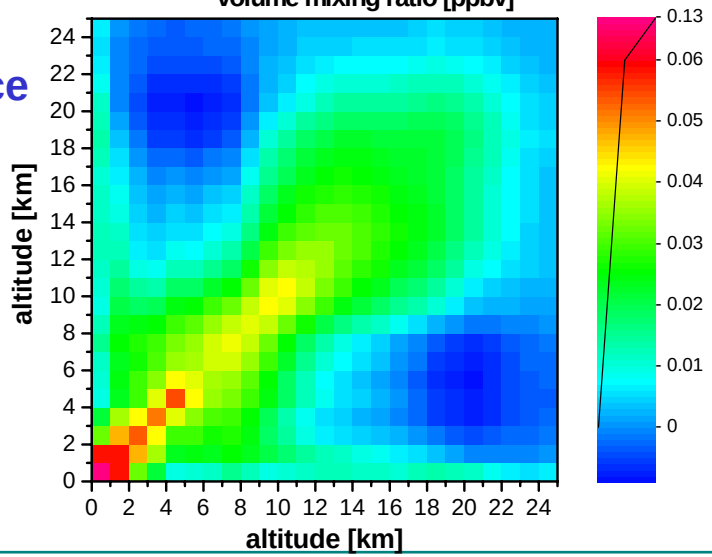
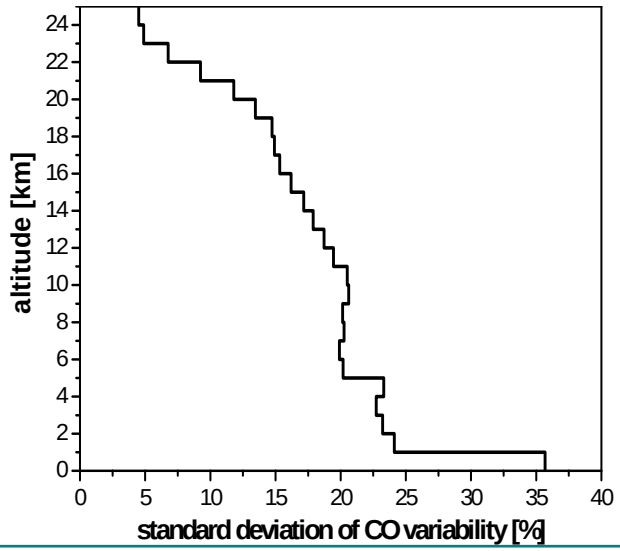
CO profiles/columns Zugspitze+Garmisch FTIR: retrieval



Optimal estimation: construct a priori covariance from aircraft profiles

CO covariance





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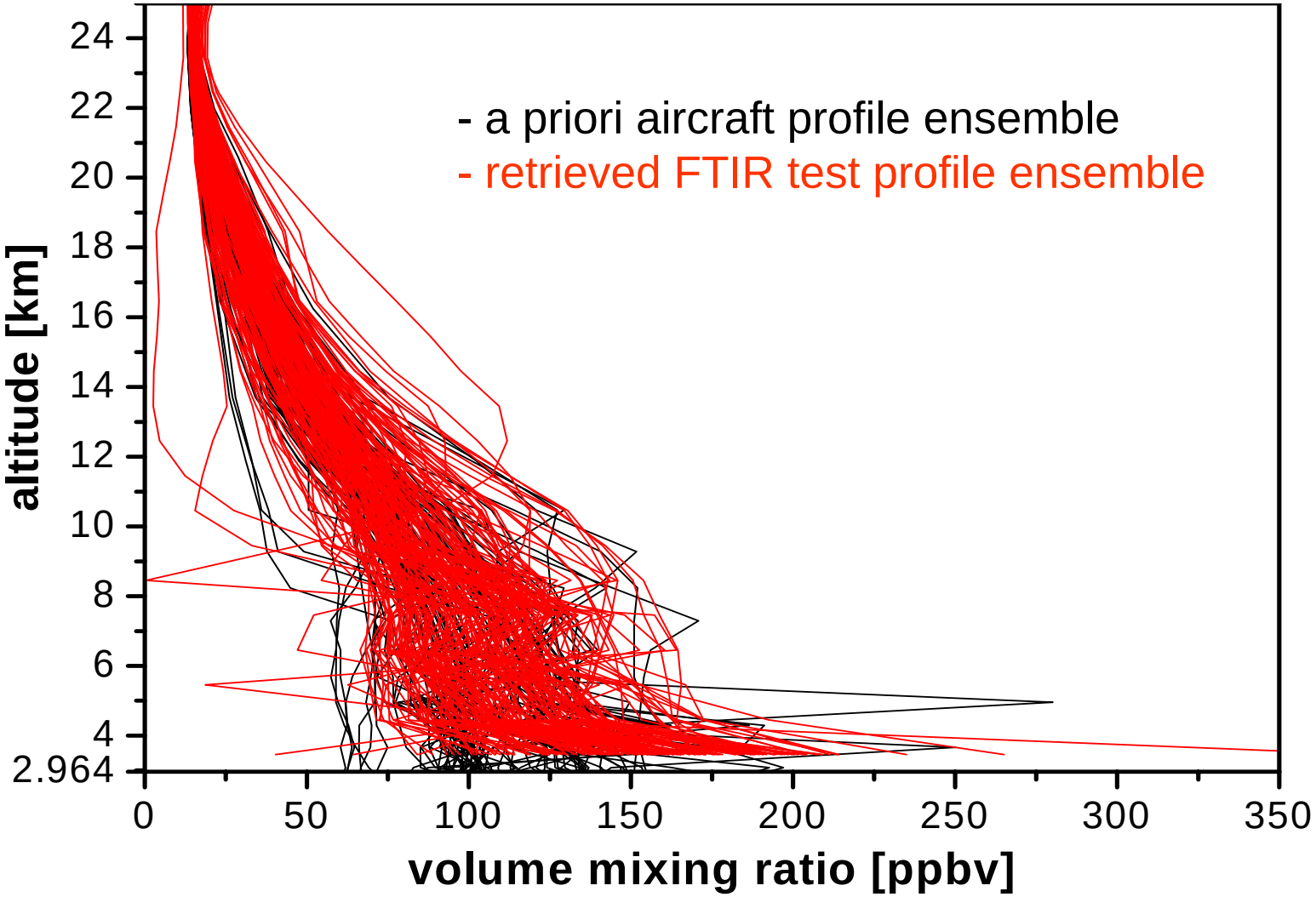
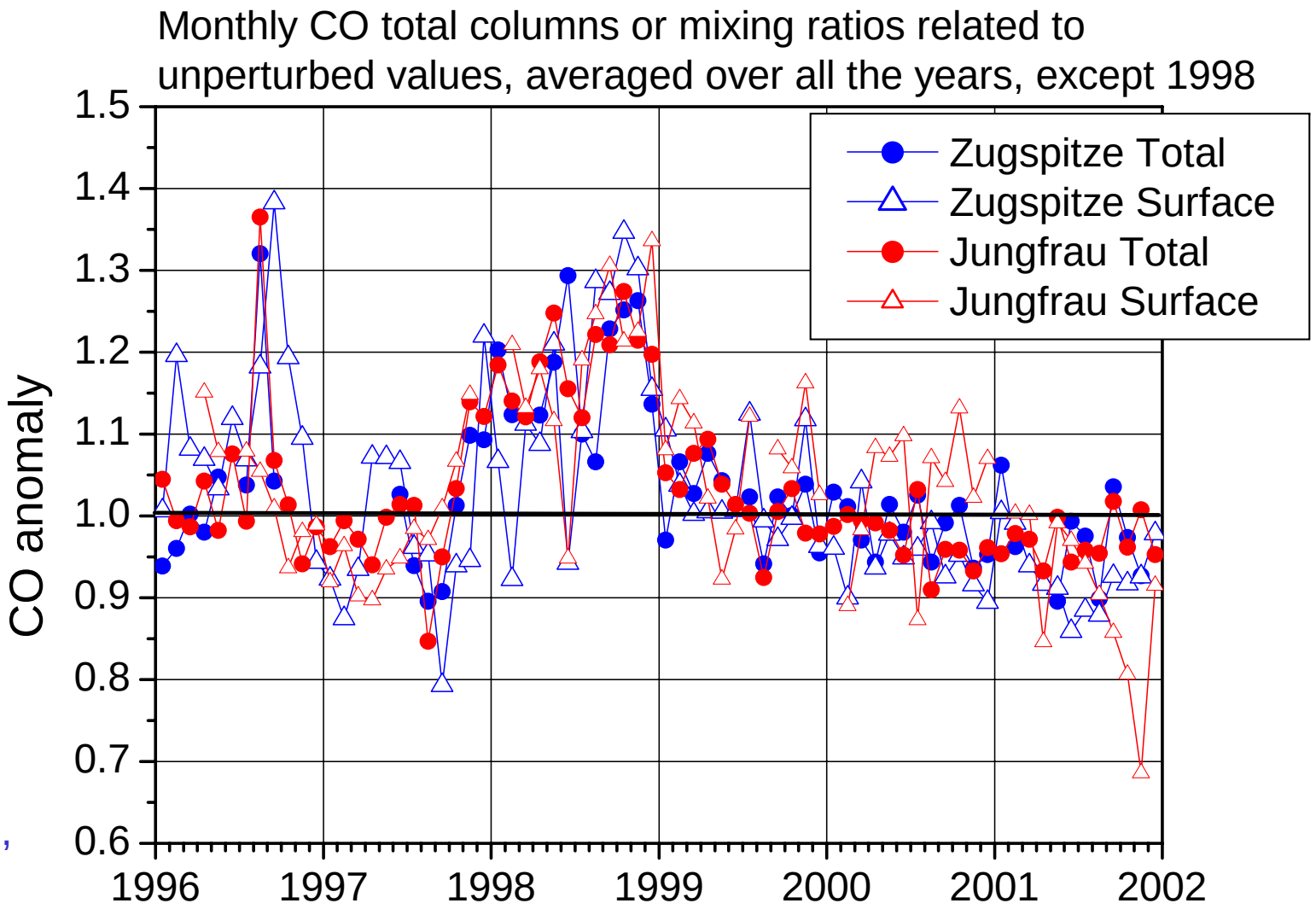
IASI validation at Permanent Ground-Truthing Facility Zugspitze/Garmisch

CO profiles Zugspitze+Garmisch FTIR: retrieval

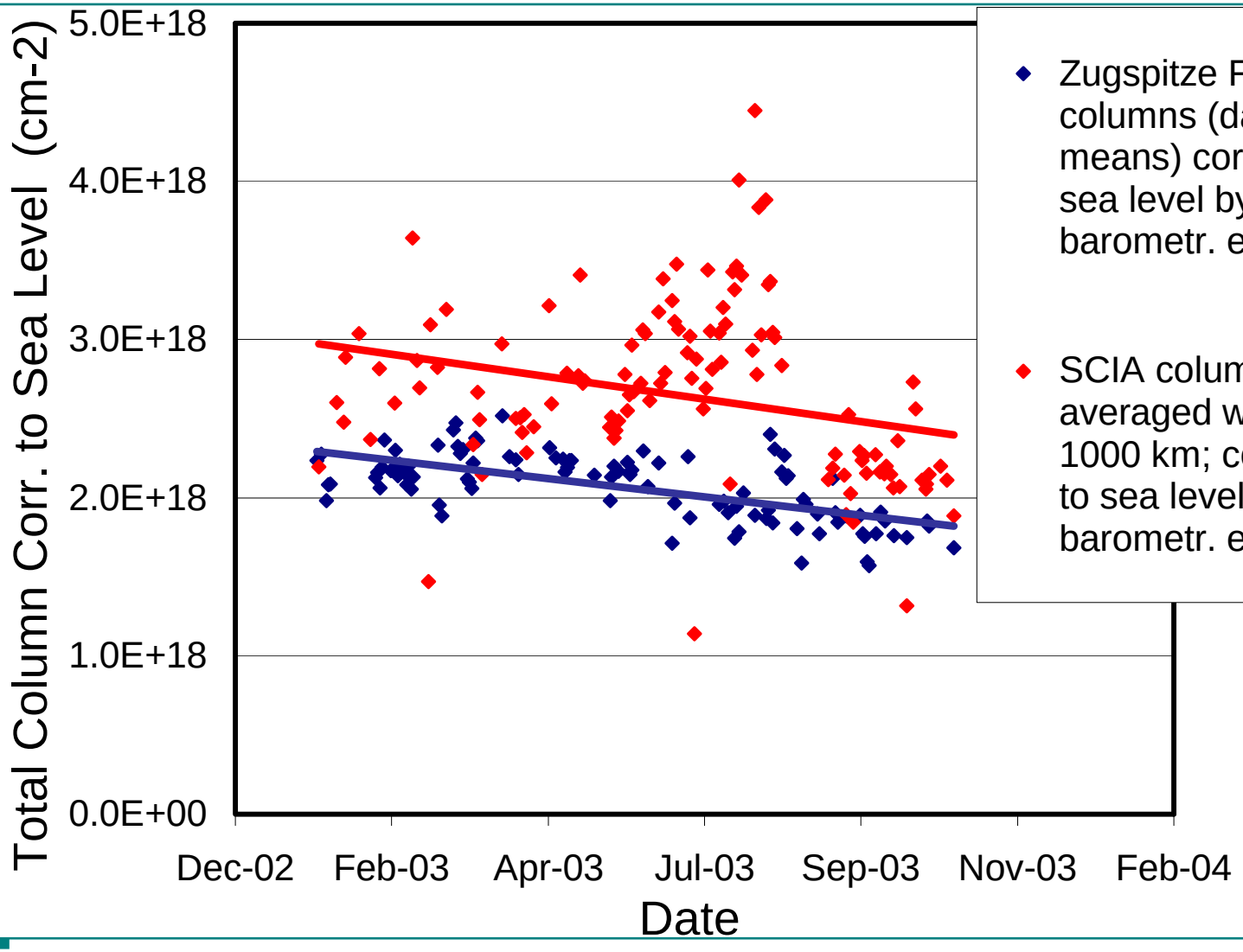


CO columns Zugspitze: Validation versus in situ and Jungfraujoch



Yurganov, Sussmann, et al., Atmos. Chem. Phys., 5, 563–573, 2005.

CO SCIAMACHY validation: Zugspitze FTIR = SCIA WFMD v0.4 * 0.78(± 0.06)



Sussmann and Buchwitz, Atmos. Chem. Phys., 5, 1497-1503, 2005.

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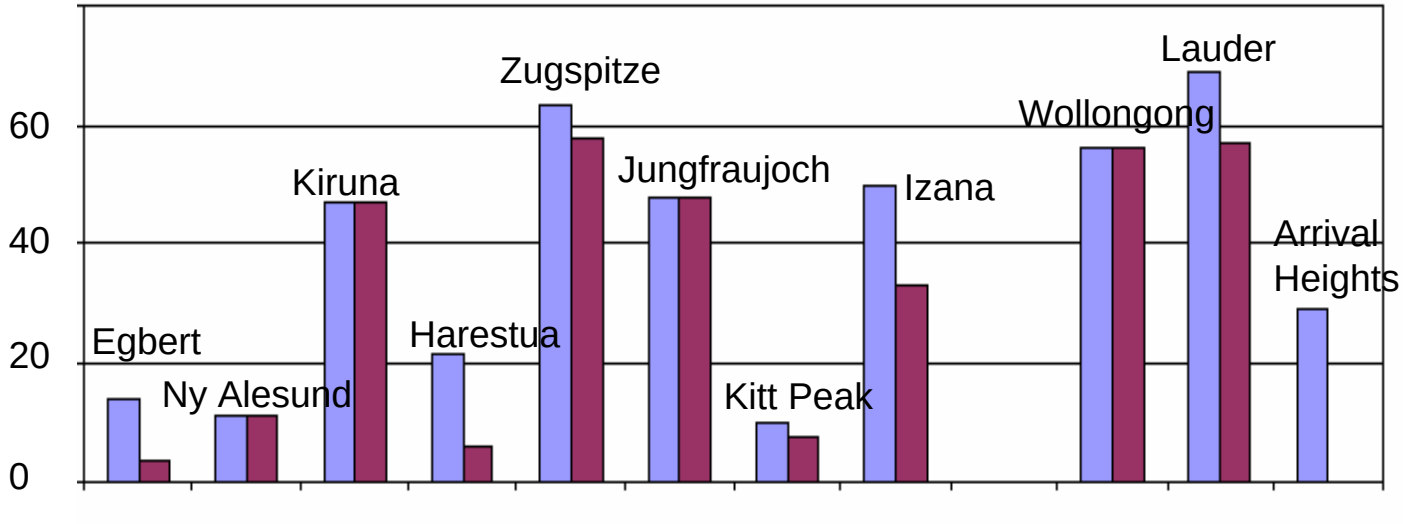
IASI validation at Permanent Ground-Truthing Facility Zugspitze/Garmisch

SCIAMACHY validation by Zugspitze FTIR: - DLR contract 9/2000 – 12/2004

- Measurement Days 15 Jul – 1 Dec 02
- Data submitted to the Cal/Val data base 15 Jul – 1 Dec 02

- part of esa TASTE project



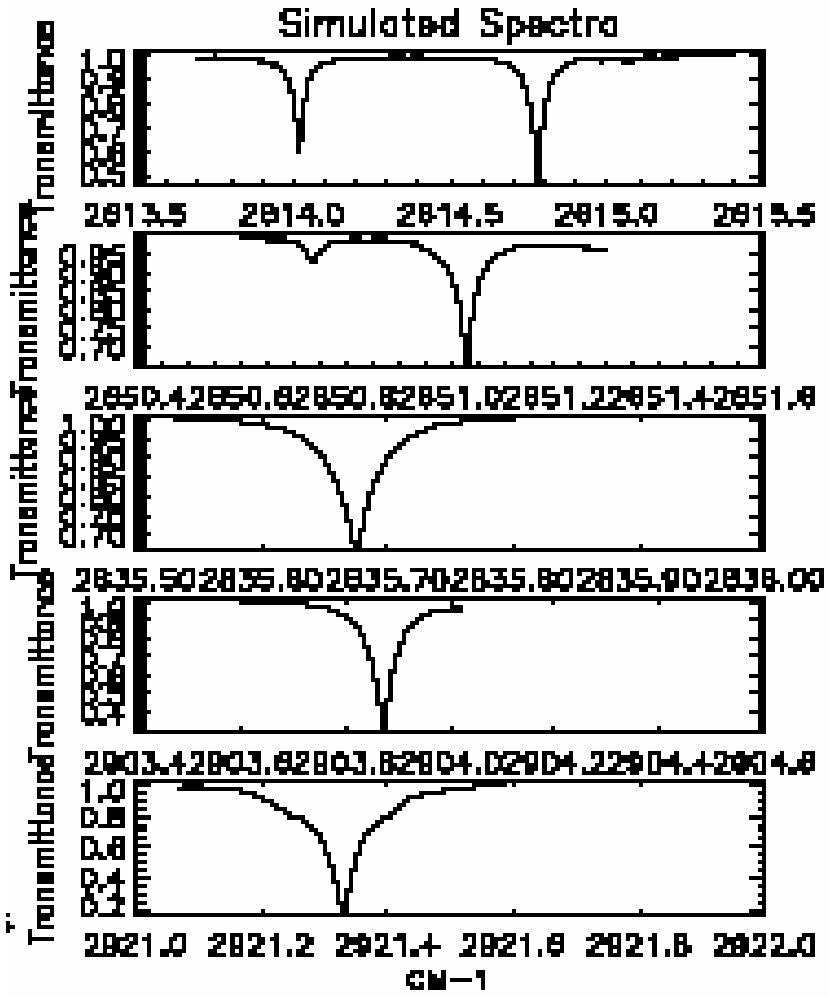
Proc. ESA-ACVE1 Meeting, Dec 2002

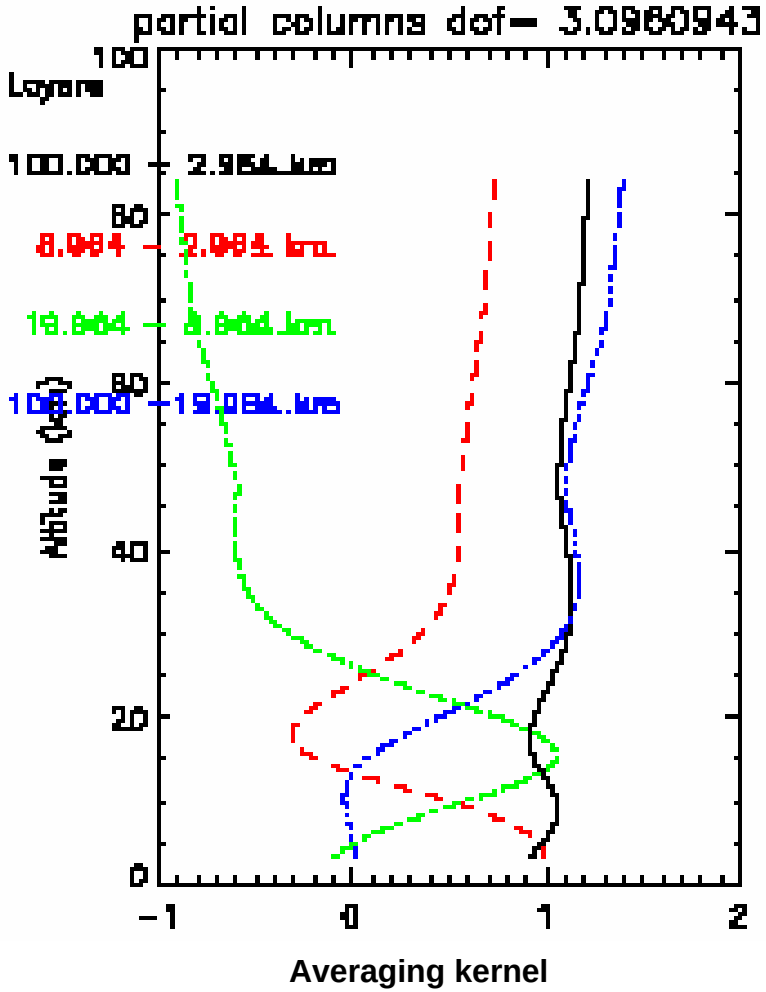
Sussmann, R. and Buchwitz, M.:
Initial validation of ENVISAT/SCIAMACHY columnar CO by FTIR profile retrievals at the Ground-Truthing Station Zugspitze, Atmos. Chem. Phys., 5, 1497–1503, 2005.

Sussmann, R., Stremme, W. Buchwitz, M., and de Beek, R.:
Validation of ENVISAT/SCIAMACHY columnar methane by solar FTIR spectrometry at the Ground-Truthing Station Zugspitze, Atmos. Chem. Phys., 5, 2419–2429, 2005.

Sussmann, R., Stremme, W., Burrows, J.P., Richter, A., Seiler, W., and Rettinger, M.:
Stratospheric and tropospheric NO_2 variability on the diurnal and annual scale: a combined retrieval from ENVISAT/SCIAMACHY and solar FTIR at the Permanent Ground-Truthing Facility Zugspitze/Garmisch, Atmos. Chem. Phys., 5, 2657–2677, 2005.

CH_4 profiles Zugspitze+Garmisch FTIR: retrieval





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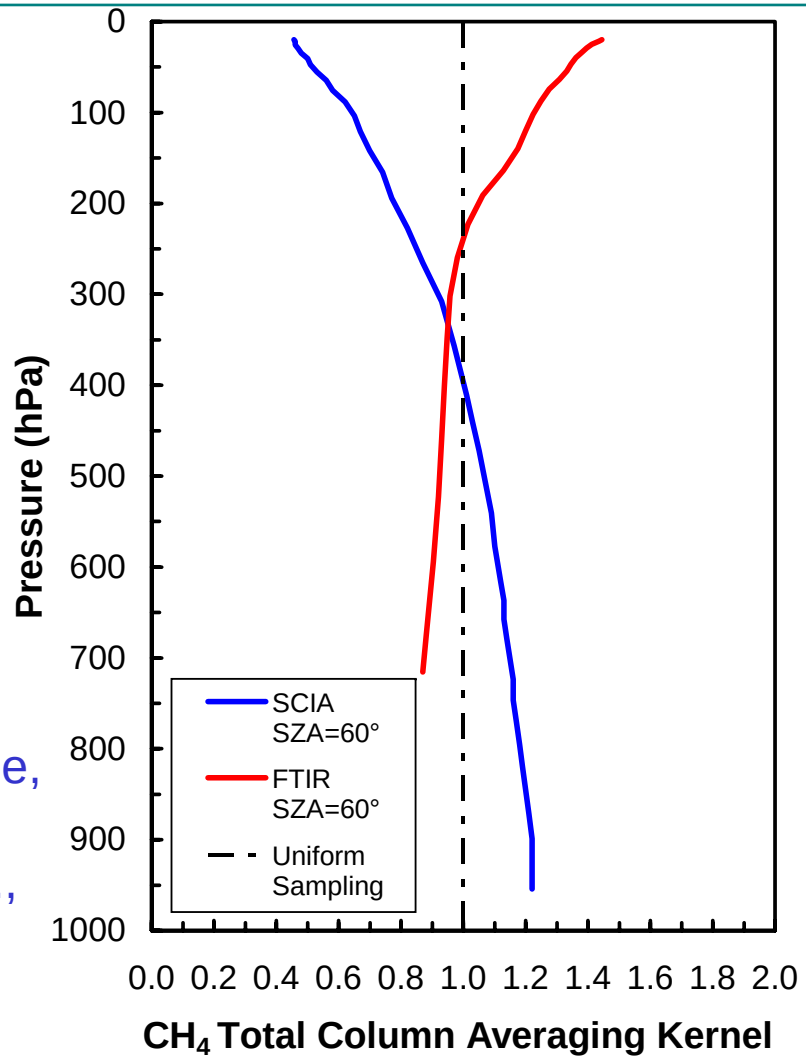
IASI validation at Permanent Ground-Truthing Facility Zugspitze/Garmisch

Validation of SCIAMACHY methane by FTIR: Averaging kernels



Sussmann, Stremme, Buchwitz, de Beek, Atmos. Chem. Phys., 5, 2419-2429, 2005.

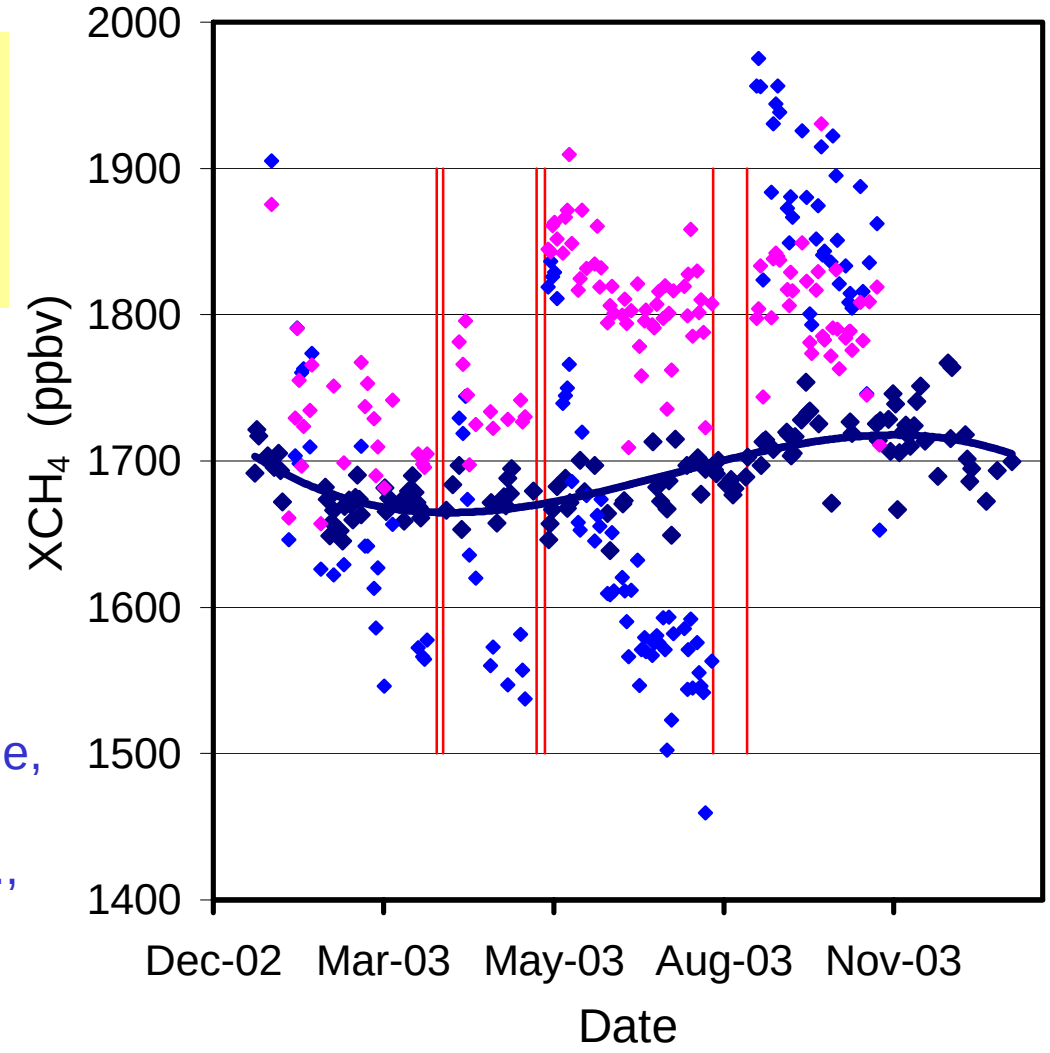
Rodgers, Connor, 2003: ***Intercomparison of two different remote sounding instruments***

FTIR is underestimating the true variability by a factor of 0.92 / 0.94 = 0.98, and WFMD by a factor of 0.93 / 0.94 = 0.99 due to the smoothing effect.

⇒ **can directly compare columns**

Ground truthing: SCIAMACHY XCH_4 versus Zugspitze FTIR

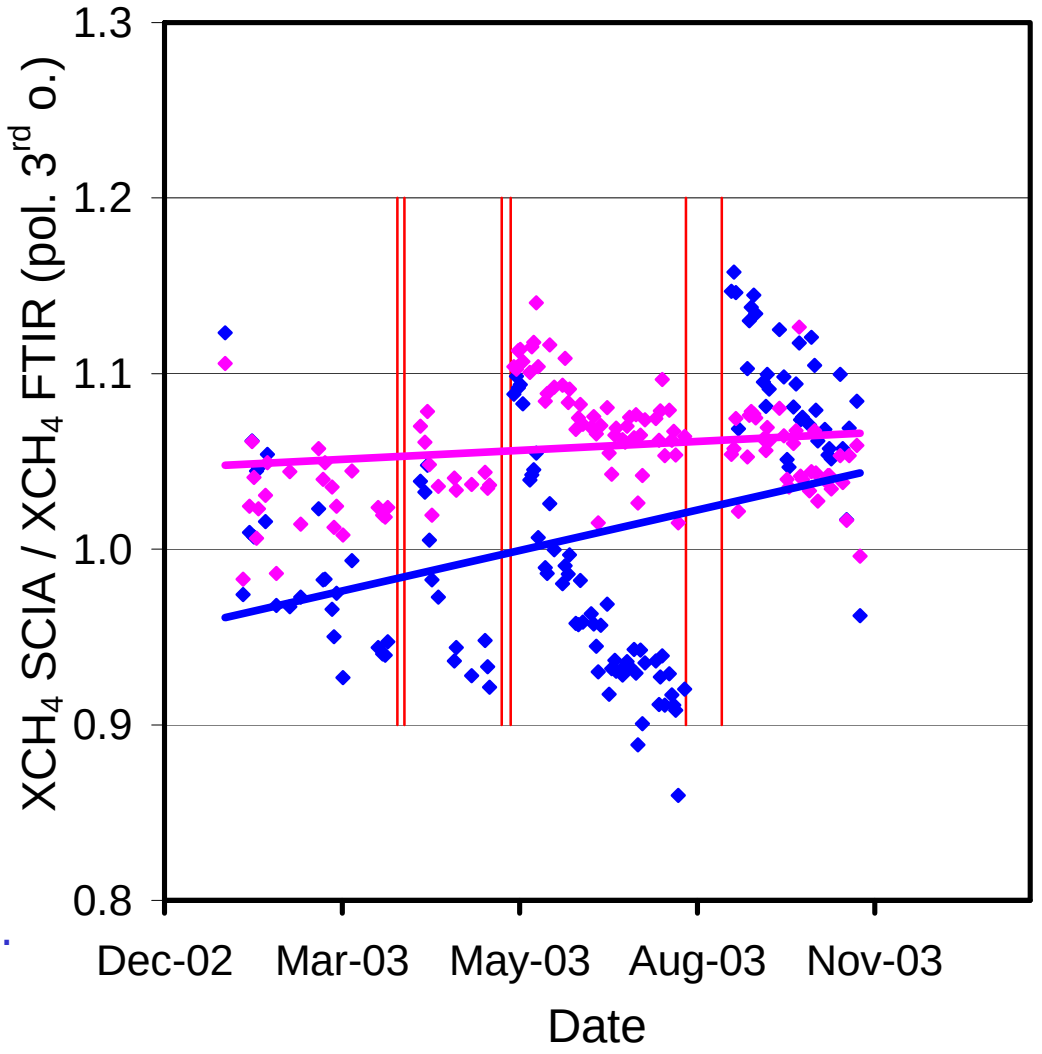
XCH_4 WFMD scientific data product (Uni Bremen)



WFMD v0.4, 2000 km
WFMD v0.41, 2000 km
FTIR daily means

Sussmann, Stremme, Buchwitz, de Beek, Atmos. Chem. Phys., 5, 2419-2429, 2005.

Validation of SCIAMACHY XCH_4: Bias relative to polynomial fitted to FTIR data

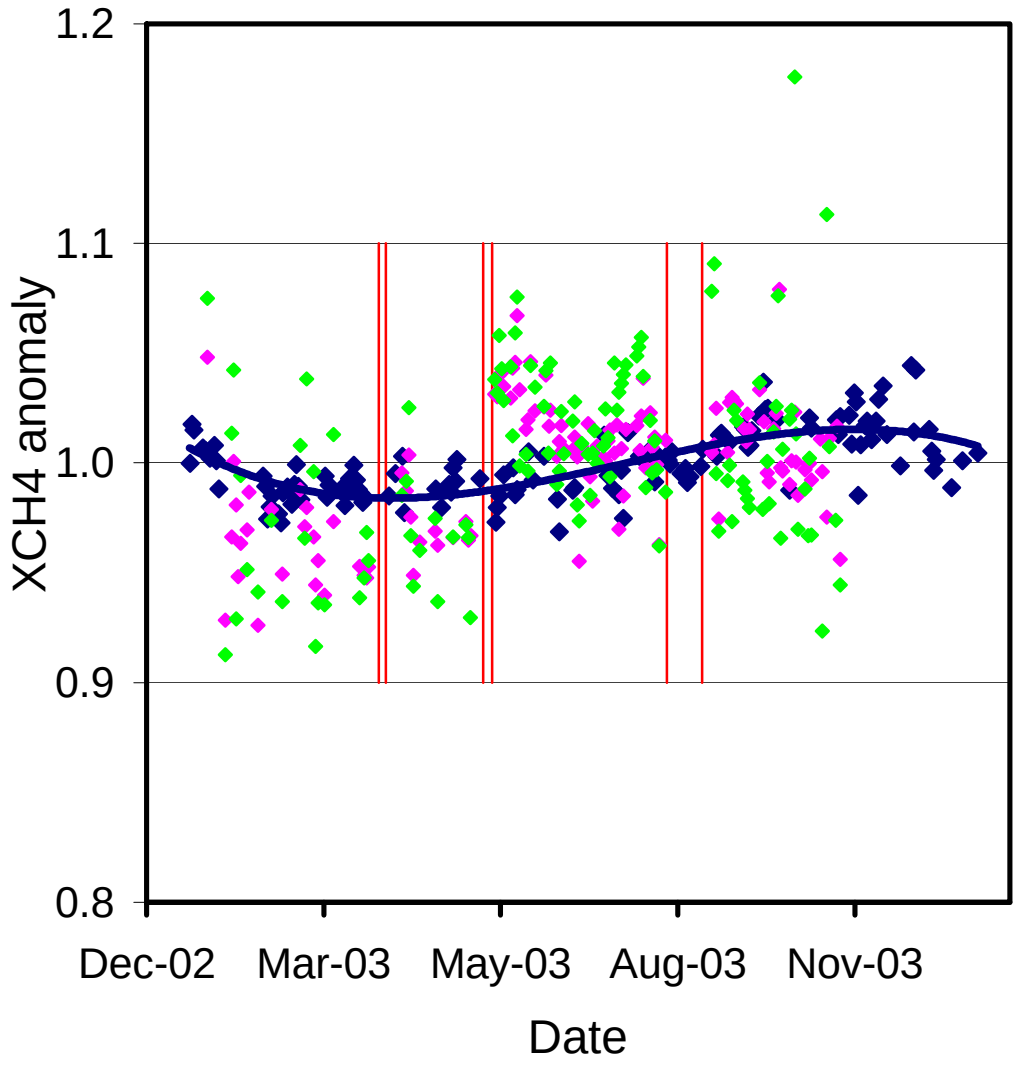


WFMD v0.4, 2000 km

WFMD v0.41, 2000 km

Sussmann, Stremme, Buchwitz, de Beek, Atmos. Chem. Phys. Discuss., 5, 2005

Validation of SCIAMACHY XCH_4: Investigation of time-dependent bias v0.41



WFMD v0.41, 2000 km
WFMD v0.41, 1000 km
Zug. FTIR daily means

Sussmann, Stremme, Buchwitz, de Beek, Atmos. Chem. Phys., 5, 2419-2429, 2005.

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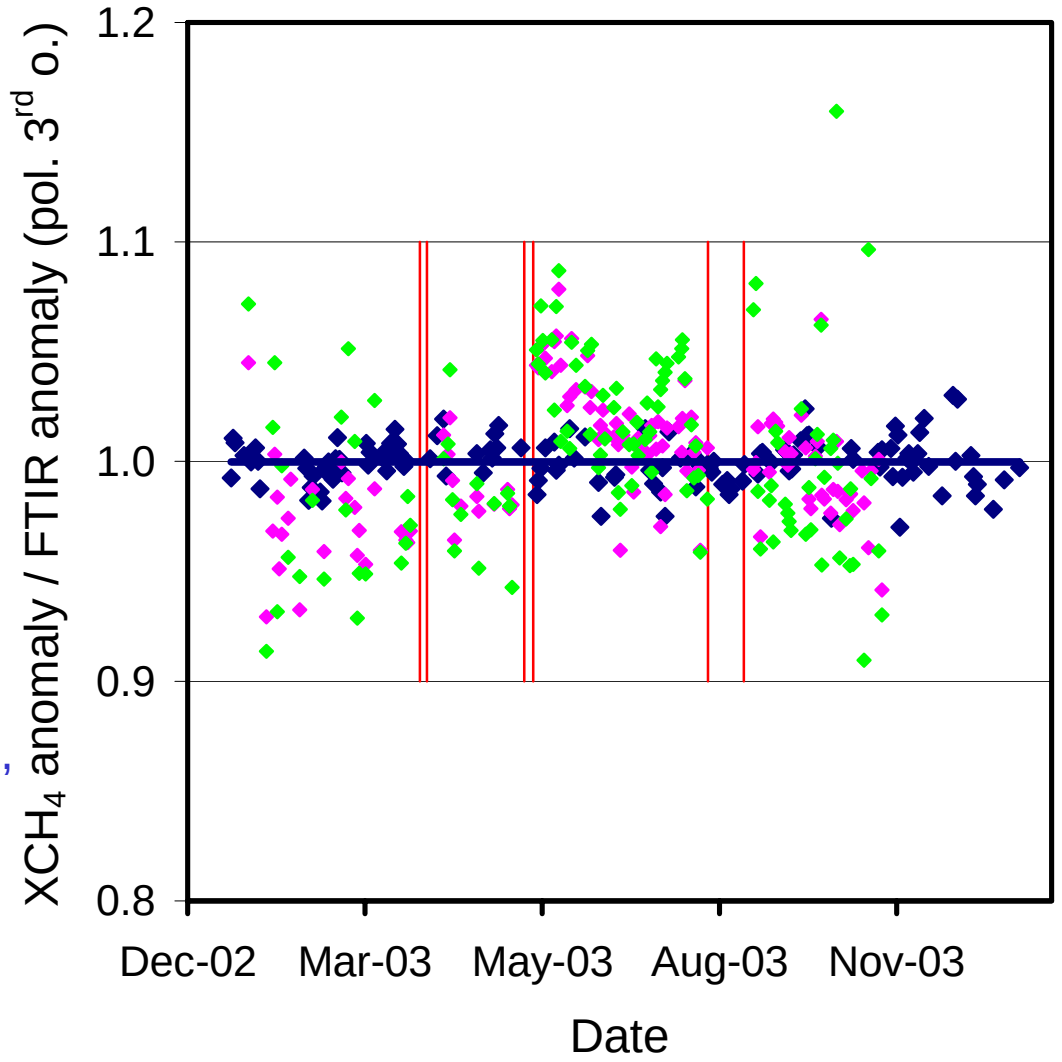
IASI validation at Permanent Ground-Truthing Facility Zugspitze/Garmisch

Validation of SCIAMACHY XCH_4: Investigation of time-dependent bias v0.41



WFMD v0.41, 2000 km
WFMD v0.41, 1000 km
Zug. FTIR daily means

Sussmann, Stremme, Buchwitz, de Beek, Atmos. Chem. Phys., 5, 2419-2429, 2005.

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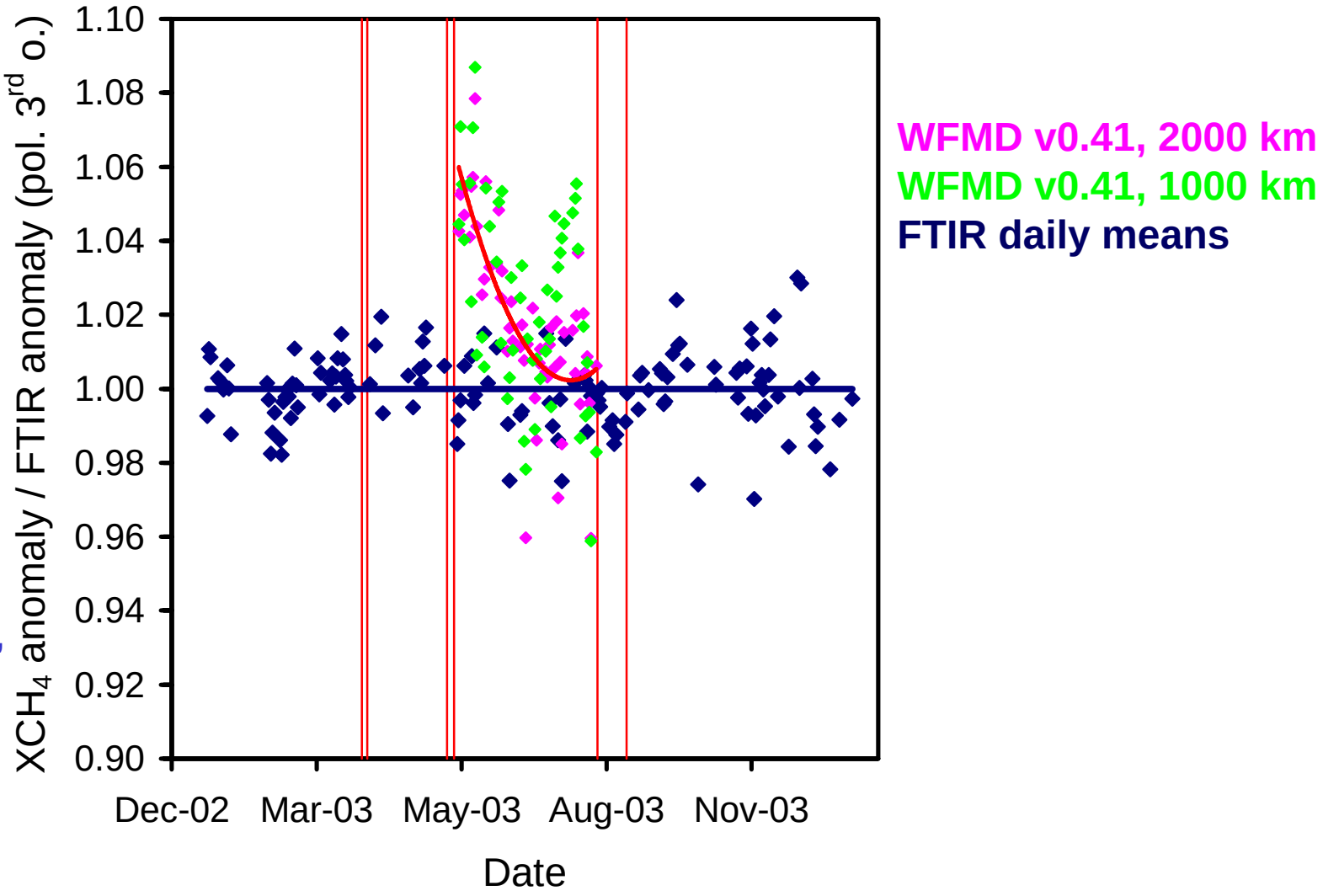
IASI validation at Permanent Ground-Truthing Facility Zugspitze/Garmisch

XCH_4 precisions FTIR versus SCIAMACHY: Single measurements, daily mean data

	$AV_i(n_i)$	$AV_i(\sigma_i)$	$AV_i(\sigma_i/sqrt(n_i))$	σ of daily means corrected for ann. cycle
Zugspitze FTIR	12.3	1.3 %	0.4 %	1.0 %
SCIA 2000	249	5.2 %	0.3 %	2.4 %
SCIA 1000	85	5.4 %	0.6 %	2.7 %

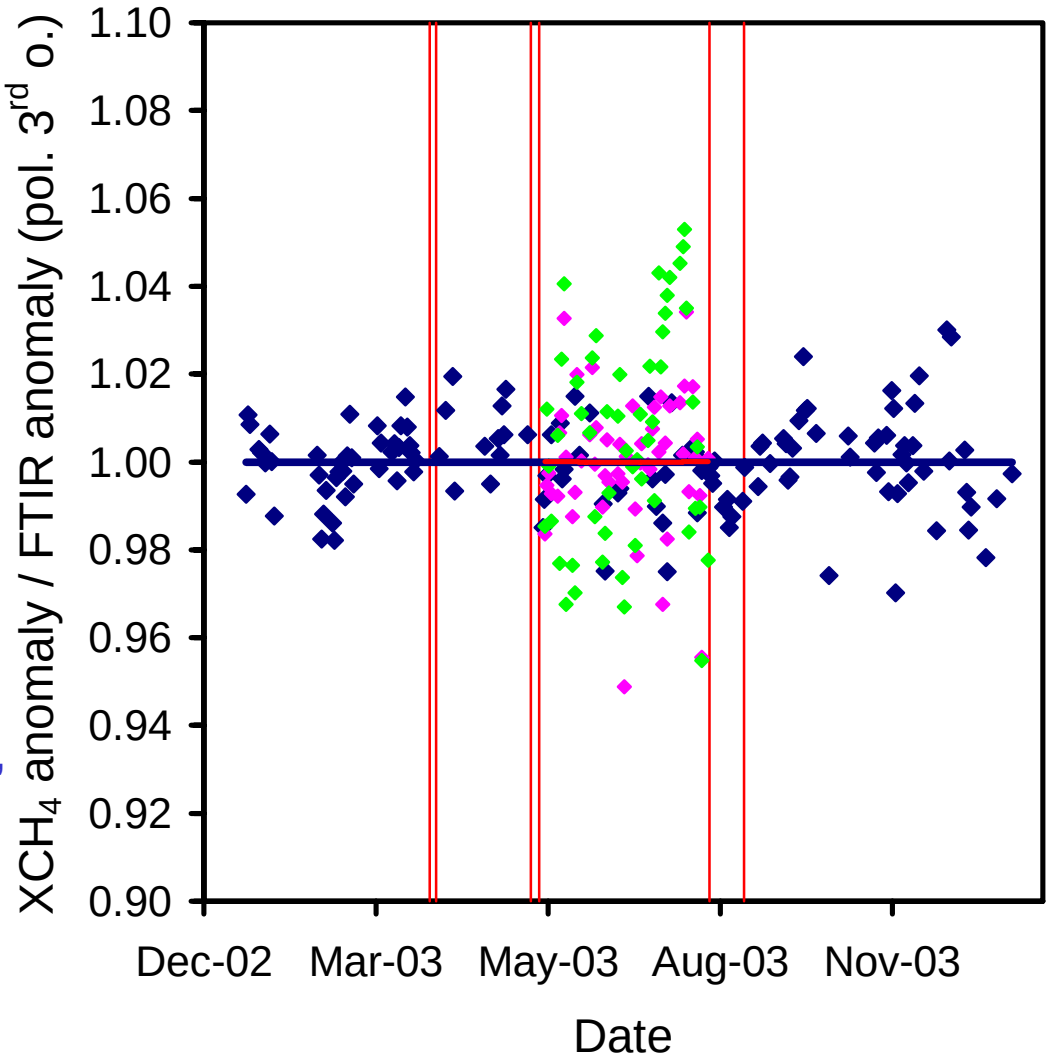
Sussmann, Stremme, Buchwitz, de Beek,
Atmos. Chem. Phys., 5, 2419-2429, 2005.

Validation of SCIAMACHY XCH_4: Additional empirical correction for time-dep. bias



Sussmann, Stremme, Buchwitz, de Beek, Atmos. Chem. Phys., 5, 2419-2429, 2005.

Validation of SCIAMACHY XCH_4: Additional empirical correction for time-dep. bias



WFMD v0.41, 2000 km
WFMD v0.41, 1000 km
FTIR daily means

Sussmann, Stremme, Buchwitz, de Beek, Atmos. Chem. Phys., 5, 2419-2429, 2005.

Summary/Outlook: IASI validation at Zugspitze/Garmisch

Profiles + columns

H_2O, O_3, N_2O, CO, CH_4

Special options

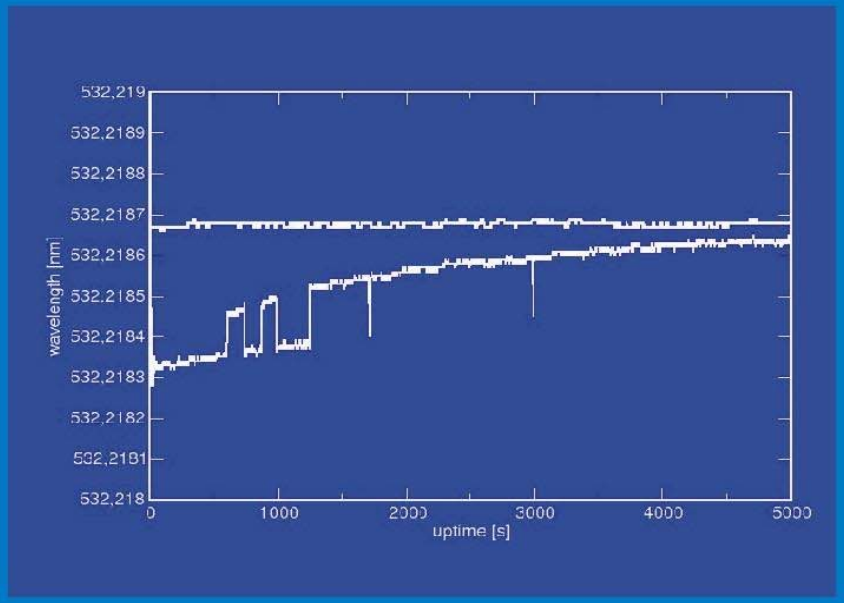
- „higher order“ products for H_2O, O_3: both optimum profile+column information *via* coincident lidar+FTIR
- Garmisch - Zugspitze „differential FTIR“
- new Garmisch-FTIR thermal emission measurements

Planned IASI validation activities

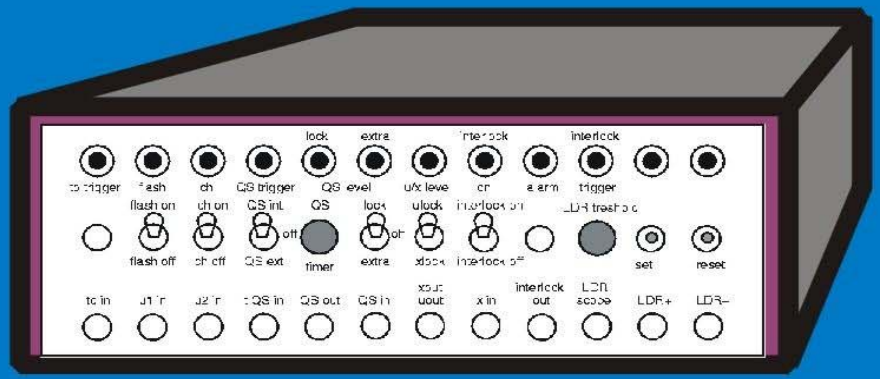
- dedicated correlative measurements (overpass ± 2h)
- provide formatted correlative ground data
- systematic validation studies for varied satellite-pixel selection criteria and diff. meteorological situations

Nd:YAG Pumplaser

Continuum 8020 Powerlite



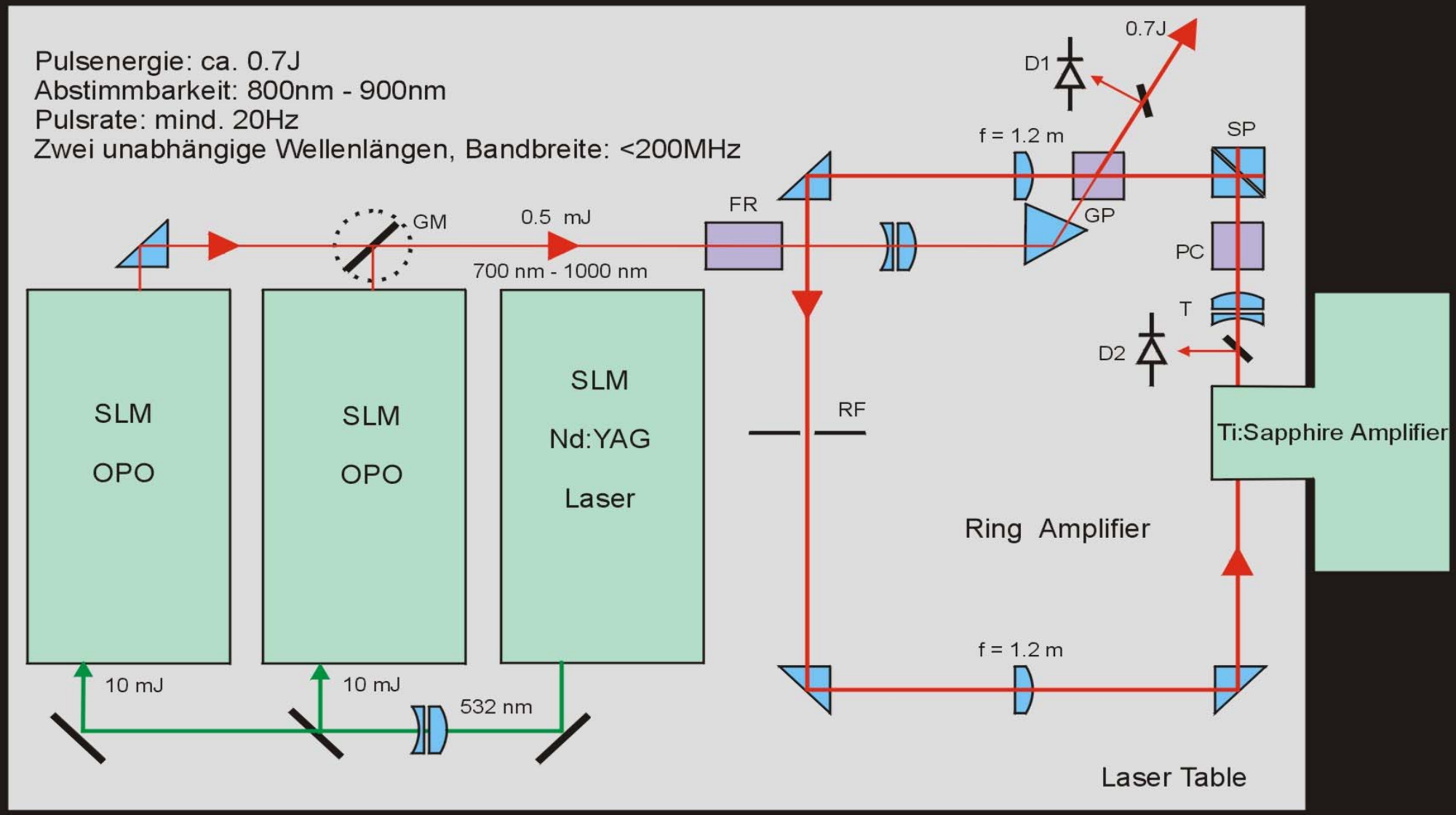
Spezifikationen:
Pulsenergie: max. 0.5J
Wellenlänge: 532nm
Bandbreite: 90MHz
Richtungsstabilität: 25µrad
Passive Frequenzstabilität:4E-8



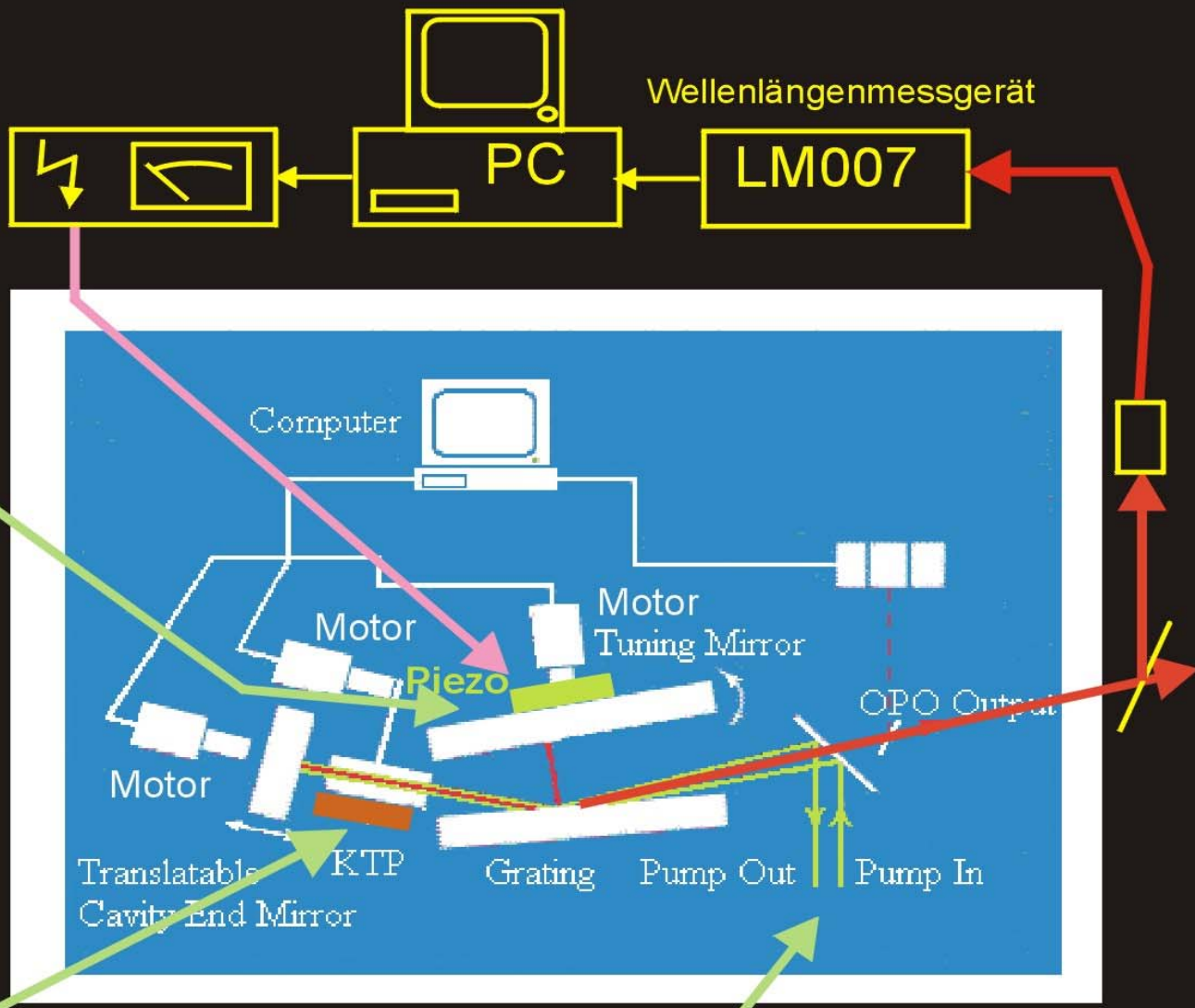
Eigene Nachbesserungen:
Umfangreiche Steuerelektronik mit:
- automatischer Schnellabschaltung bei Ausfall des Seeders.
- zusätzlichen Ein- und Ausgängen für externe Synchronisation mit gemeinsamer Zeitbasis für das ganze LIDAR-System.

Verbesserte Abschirmung gegen HF-Einstreungen durch den TiSA

LASER-SYSTEM



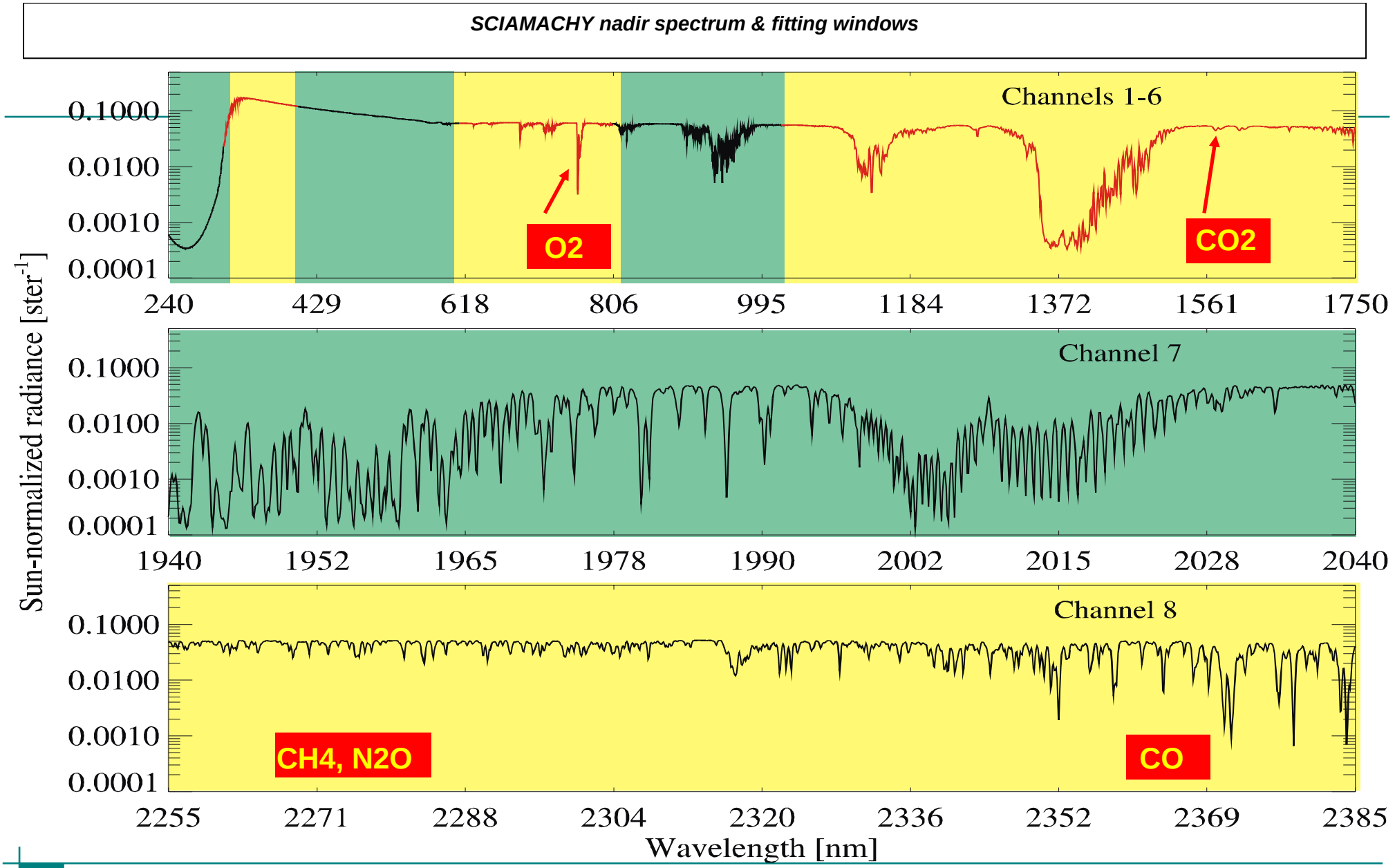
Weiterentwicklung der OPOs



Feinabstimmung
mit Piezokristall

Beheizte
Kristallaufnahme

elliptischer Pumpstrahl



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IASI validation at Permanent Ground-Truthing Facility Zugspitze/Garmisch

Smoothing errror/columns variability: Derive a realistic etimate

We write the variance of daily-mean total columns col_{FTIR} observed by FTIR as

$\sigma^2(col_{FTIR}) = \mathbf{a}^T_{FTIR}\, \mathbf{S_a}\, \mathbf{a}_{FTIR} + \sigma^2(\varepsilon_{FTIR})$,

where vector $\mathbf{a}_{FTIR}$ is the total-column averaging kernel, and $\mathbf{S_a}$ is a starting assumption for the a priori covariance matrix. $\sigma^2(\varepsilon_{FTIR})$ denotes all random-type measurement errors.

Using $\sigma(col_{FTIR})$ = 1 % (Table), and using for the error term $\sigma(\varepsilon_{FTIR}) = AV_i(\sigma_i/sqrt(n_i))$ = 0.4 % (Table), we obtain

$\mathbf{a}^T_{FTIR}\, \mathbf{S_a}\, \mathbf{a}_{FTIR}$ = 0.92 %.

We use $\mathbf{a}_{FTIR}$ and scale $\mathbf{S_a}$ to fulfil this relation. Using the resulting best-estimate $\mathbf{S_a}$ we calculate for WFMD analogously

$\mathbf{a}^T_{WFMD}\, \mathbf{S_a}\, \mathbf{a}_{WFMD}$ = 0.93 %.

For an ideal observing system with $\mathbf{a}_{ideal}$ = (111…1) we would obtain

$\mathbf{a}^T_{ideal}\, \mathbf{S_a}\, \mathbf{a}_{ideal}$ = 0.94 %.

⇒ FTIR is underestimating the true variability by a factor of 0.92 / 0.94 = 0.98, and WFMD by a factor of 0.93 / 0.94 = 0.99 due to the smoothing effect.