CO observations above Kiruna and their applications

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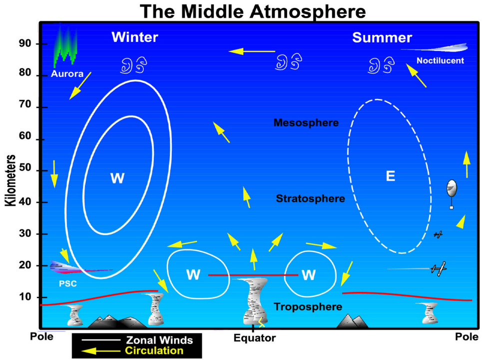
Outline of results to be presented today

1. Introduction
2. Retrieval of CO time series from microwave observations
3. Comparison to satellite observations
4. Validation of Arctic dynamics in the model SD-WACCM
5. Modeling study on the interpretation of descent rates derived from CO

Winter circulation: the ideal zonal mean picture



[M.R. Schoeberl, edited by B.-M. Sinnhuber]

[www.awi.de]

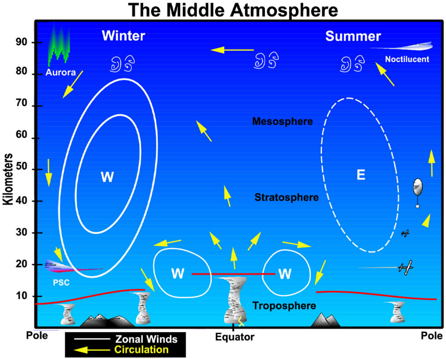
Zonal:

- Strong westerly jet
- Polar vortex
- Transport barrier
- Precondition for polar ozone depletion

Meridional:

- Directed towards winter pole
- Descent of air above high latitudes

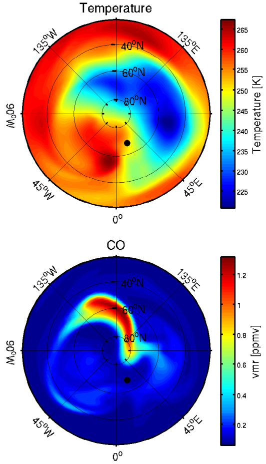
The impact of the descent of mesospheric air



[M.R. Schoeberl, edited by B.-M. Sinnhuber]

- Mesosphere is influenced by energetic particles
- Production of NO_x
- NO_x is catalyst for ozone destruction in stratosphere
- Natural contribution to ozone variability

The more realistic Arctic picture: high variability



SD-WACCM, 2 February 2010, 50 km

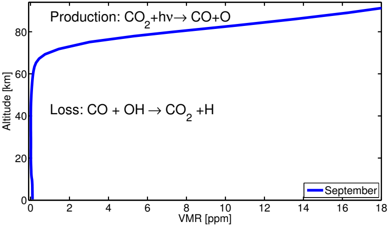
- Vortex shape, position, and extent
- Barrier strength (partly permeable)
- Temporal variability (daily to interannual)
  - Seasonal: buildup and breakup of vortex
  - Sudden stratospheric warmings (SSW)

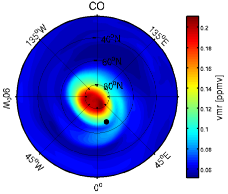
Relevance of dynamical variability

- Processes not fully understood.
- Separation and prediction of anthropogenic influences
  - Ozone loss and recovery
  - Interactions with climate change

(Natural) dynamical variability has to be captured.

CO as tracer for dynamics





SD-WACCM, 17 October 2009, 50 km altitude

- No chemistry during polar night
- Continuity equation:

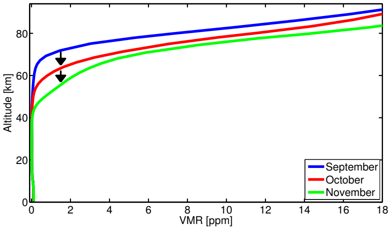
$$\underbrace{\frac{\partial CO}{\partial t}}_{temporal} = \underbrace{-u\frac{\partial CO}{\partial x} - v\frac{\partial CO}{\partial y}}_{horizontal} \underbrace{-w\frac{\partial CO}{\partial z}}_{vertical}$$

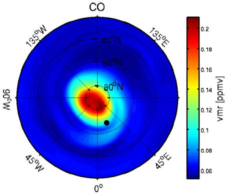
- Vertical and horizontal gradients

Derivation of descent rates:

- Assumption: vertical term dominates
- Descent shifts CO profile
- $w_{CO} = \frac{\Delta z}{\Delta t}$
- But assumption questionable

CO as tracer for dynamics





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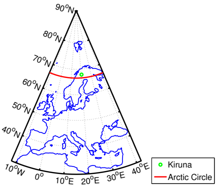
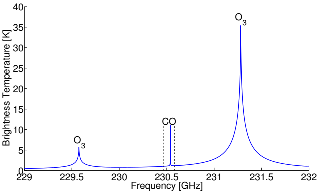
Instrument and dataset



Measurement site

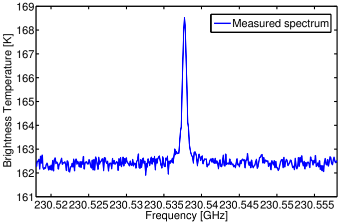
- Swedish Institute of Space Physics (IRF)
- Kiruna, Sweden, $68^\circ N$
- Kiruna Microwave Radiometer (KIMRA)
  - CO at 230 GHz and O_3 at 231 GHz.
  - 1800 K noise temperature (SSB)
  - FFTS (BW 110MHz, 1024 channels)
  - AOS (BW 1.2GHz, 2048 Channels)

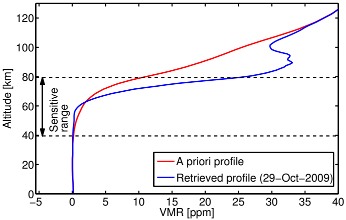


Set of spectra

Period	Dec. 2008–Apr. 2009
	Sep. 2009–Apr. 2010
Days covered	309 of 393
Total number of spectra	1497
Mean integration time	59 ± 20min
Mean noise on spectra	0.20 ± 0.04K

Retrieval Setup





Retrieval and setup

- Optimal estimation
- ARTS/QPack
- CO, O_3, continuum H_2O, O_2, HITRAN.
- Pressure grid at fixed altitudes 1-130km, 1km spacing
- p,T from SABER, ECMWF
- A priori profiles: CO, O_3, O_2, H_2O winter mean of SD-WACCM
- A priori and covariance constant

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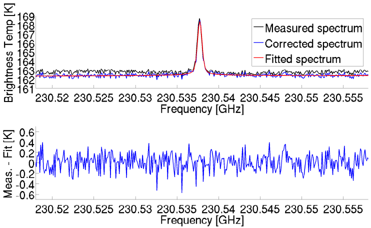

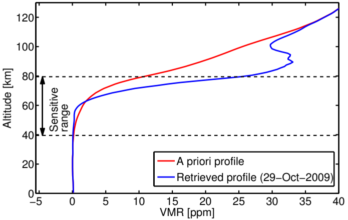

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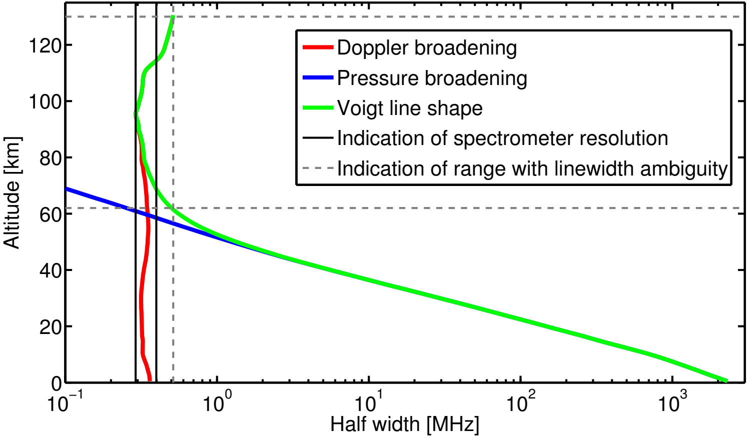
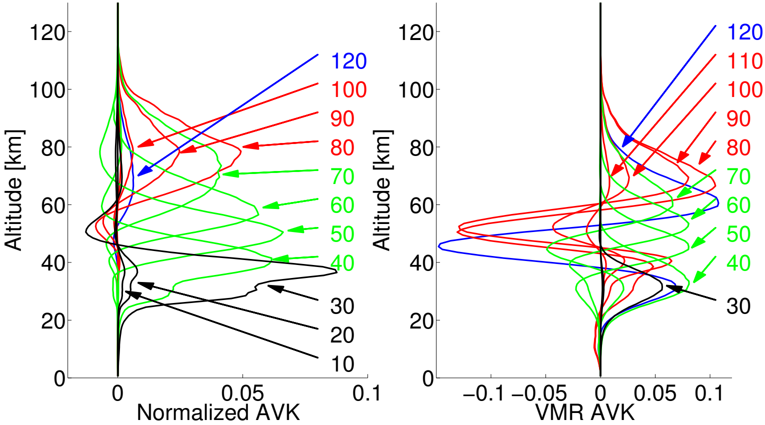
Broadening of Emission lines: 230GHz CO line

Increase of linewidth above 100 km altitude

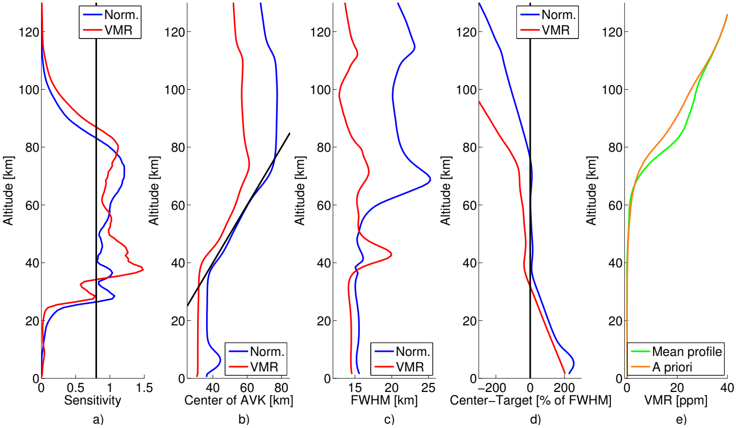


Retrieval Performance



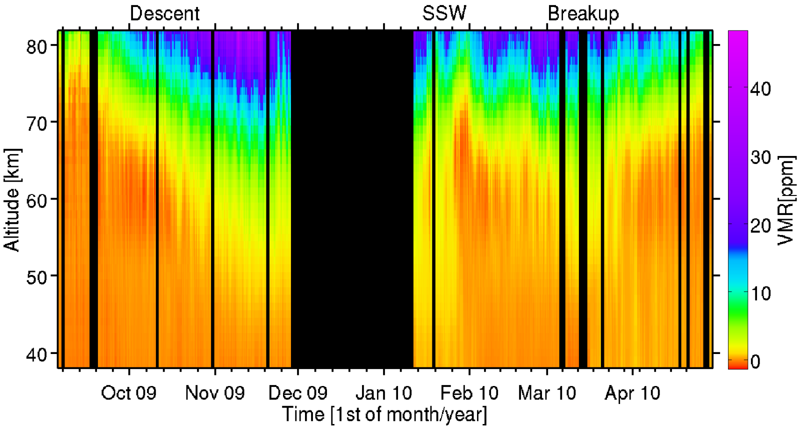
AVK of 29 October 2009, 120km kernel multiplied by 50 [adapted from Hoffmann et al., 2011, AMT]

Average retrieval performance



[Hoffmann et al., 2011, AMT]

KIMRA CO time series 2009/2010



Descent rate (mid Sept. to mid Nov., yellow contour) $\approx 300\,\mathrm{m/day}$.

Hoffmann et al. (2011), AMT

Comparison of time-mean profiles: overview

Motivation:

- Consistency check with reduced noise: time-mean
- Validation of KIMRA
- No ground-based vs. satellite comparison published so far
- Interesting for new satellite generations

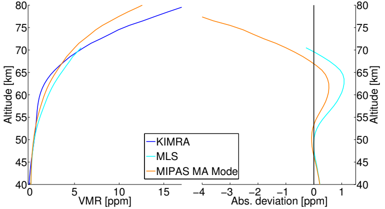
Difficulties:

- Different vertical coverage
- Sparse collocations
- Strong horizontal CO gradient

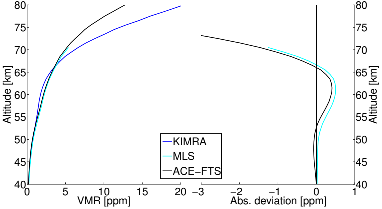
Approach:

- All available satellite data: MLS, ACE-FTS, MIPAS NOM, MIPAS MA
- Collocation criteria: radius, PV, same day
- Equalization of time coverage
- Convolution with KIMRA AVK
- Different setups tested, robust results extracted

Comparison of time-mean profiles



(9 days with collocations)



(22 days with collocations)

Generalized findings:

- Agreement ok below 65 km
- Profile shape deviation of KIMRA
- KIMRA too high above 70 km
- Connection to thermospheric emission?

Outcome

- KIMRA vmr not ideal
- First published comparison
- Basis for further intercomparisons
- General problem ob ground-based MW?
- Variability of CO ok

Whole Atmosphere Community Climate Model (WACCM)

WACCM:

- Developed by NCAR, USA
- Part of Community Earth System Model (CESM)
- Troposphere to thermosphere (140km)
- Horizontal resolution $\approx 2^\circ$.
- Fully interactive chemistry climate model
- Free-running:
  - Only simulated climate comparable to real world.
  - Arbitrary conditions on shorter time scales.

SD-WACCM:

- Specified Dynamics (SD)
- WACCM nudged with analyzed meteorological data
- Nudging: 1% of value of each meteorological variable replaced
- Applied below 50 km altitude
- Sufficient to couple model to real world evolution?
- Model evaluated locally.

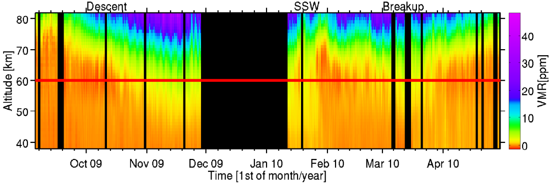
CO time series during winter 09/10

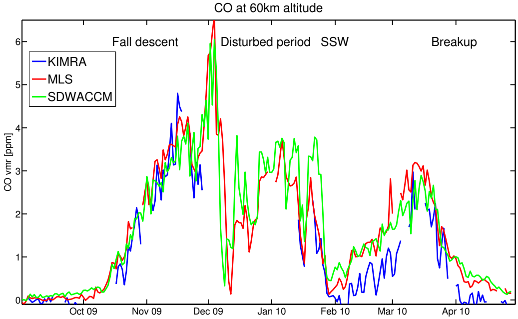
Approach:

- Comparison of CO evolution
- Indirect test of dynamics
- Observations: KIMRA, MLS

Quantification:

- Correlation coefficients
- All altitudes
- High and low frequency parts (T=20d)





Correlation: KIMRA-SDWACCM and KIMRA-MLS

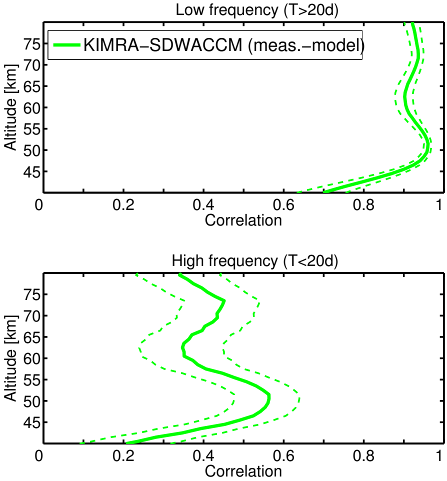
What is a good correlation coefficient?

Low frequency (T>20d):

- Close to optimal
- Vertical variation connected to KIMRA sensitivity

High frequency (T<20d):

- Not optimal
- Connected to gravity wave representation
- Still surprisingly good



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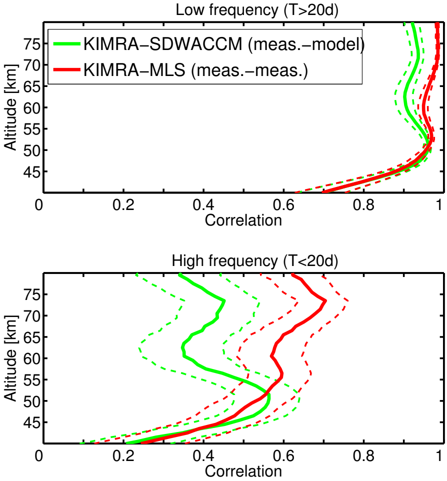


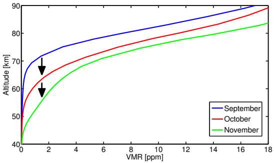
SD-WACCM validation results

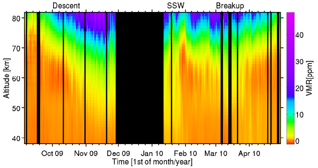
- Overall representation of polar dynamics is very good.
- SD-WACCM is a powerful tool to study the polar middle atmosphere on short time scales (intraseasonal, T>20d)

- Only slight nudging (1%), free-running above 50 km
- (Winter-) Mesosphere indeed largely controlled from below.

Hoffmann et al. (2012), ACP

Current work: Derivation of vertical wind possible?



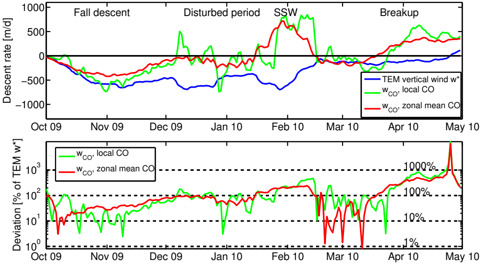


$$\underbrace{\frac{\partial CO}{\partial t}}_{temporal} = \underbrace{-u\frac{\partial CO}{\partial x} - v\frac{\partial CO}{\partial y}}_{horizontal} \underbrace{-w\frac{\partial CO}{\partial z}}_{vertical}$$

1. Horizontal influence?
   - Has to be neglectable
   - Commonly assumed:
     Allen et al. (2000), Forkman et al. (2005), Funke et al. (2009), Di Biagio et al. (2010)
   - Highly questionable
2. Zonal mean vs. local data
   - Vertical transport, zonal mean: $\overline{w}^{\star}$
   - Zonal mean $\overline{CO}$ (from satellites)
   - Ground-based: local CO
   - Ground-based: local wind w? $w \neq \overline{w}^{\star}$!

Consolidation of descent rate interpretation necessary.

SD-WACCM study: Descent rates w_{CO} vs. TEM wind $\overline{w}^*$



Descent rates w_{CO} from SD-WACCM local and zonal mean CO and $\overline{w}^*$ on constant CO VMR level (0.8ppmv)

- Deviation between w_{CO} and $\overline{w}^*$ in the order of 100%
- Exceptions: October and after SSW
- This is the best agreement (on particular CO level)
- Comparison to local wind w much worse (not shown)

Sketch of findings

Local vs. zonal mean picture:

- (local) ground-based and satellite observations (zonal mean) result in same descent quantity (not explicitely shown)
- (weak) relation to zonal mean picture, $\overline{w}^\star$

Horizontal influence:

- Horizontal influence on CO is significant throughout the winter
  - w_{CO} at best reflects order of magnitude of $\overline{w}^\star$
  - but w_{CO} might be effective velocity of mesospheric composition

w_{CO} should be called 'descent rate' and not 'vertical velocity'.

Paper with more details in preparation

Summary

- Retrieval of the KIMRA CO profile time series
  - Winter 2008/2009 and 2009/2010
  - Vertical range 40-80 km, 2 to 3 independent layers.
- First comparison of time averaged profiles of ground-based microwave to satellites
  - Agreement below 65 km altitude
  - Profile shape deviation and high bias of KIMRA above 70 km. Reason?
- Validation of polar winter dynamics in the model SD-WACCM
- Only weak relation between descent rates derived from CO and TEM vertical wind found in modeling study. (work in progress)

Publications

Retrieval, dataset and satellite comparison
C. G. Hoffmann, U. Raffalski, M. Palm, B. Funke, S. H. W. Golchert, G. Hochschild, and J. Notholt. Observation of strato-mesospheric CO above Kiruna with ground-based microwave radiometry — retrieval and satellite comparison. **Atmos. Meas. Tech., 4:2389-2408, 2011**.

Validation of SD-WACCM4
C. G. Hoffmann, D. E. Kinnison, R. R. Garcia, M. Palm, J. Notholt, U. Raffalski, and G. Hochschild. CO at 40-80 km above Kiruna observed by the ground-based microwave radiometer KIMRA and simulated by the Whole Atmosphere Community Climate Model. **Atmos. Chem. Phys., 12:3261-3271**.

Update of satellite comparison (plots shown here)
C. G. Hoffmann. Application of CO as a tracer for dynamics in the polar winter middle atmosphere: A study based on ground-based microwave observations in Kiruna. PhD thesis, University of Bremen, 2012.
Online-Resource: http://nbn-resolving.de/urn:nbn:de:gbv:46-00102610-19

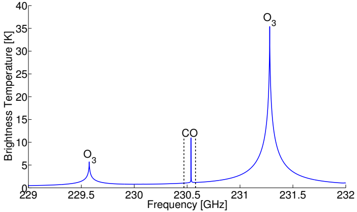
Outlook

- Modeling study about the interpretation of descent rates is work in progress
- Observations in Ny Ålesund, Spitsbergen
  - New radiometer proposed
  - 230 GHs, 500 K noise temp
  - Installation in 2014/2015
- New focus: Possible gap of satellite observations in the coming years
  - CO vmr itself is of interest
  - Deeper understanding of profile shape deviation (common problem?)
  - Optimization of retrieval.
  - Extension of comparison to more stations?
  - Other species?

Thank you for your attention

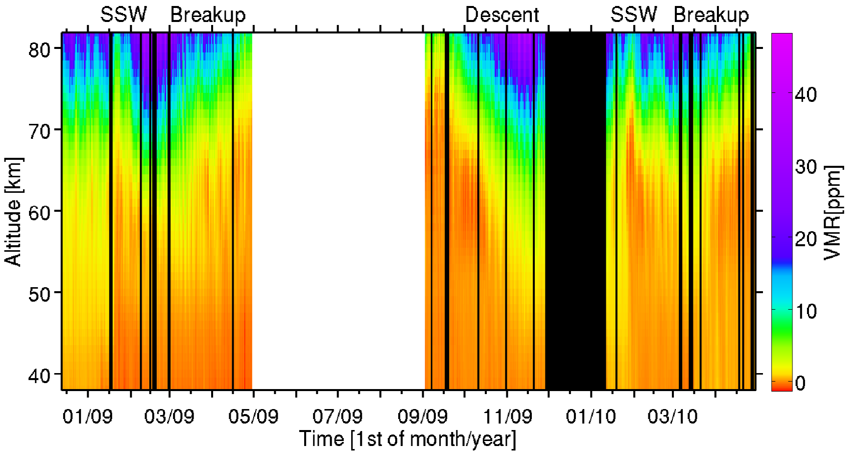
KIMRA Instrument

- CO at 230 GHz and O_3 at 231 GHz.
- Cooled Schottky diode mixer
- 1800 K noise temperature (SSB)
- FFTS (BW 110MHz, 1024 channels, Res 107 kHz)
- AOS (BW 1.2GHz, 2048 Channels)
- Balanced calibration, internal reference load



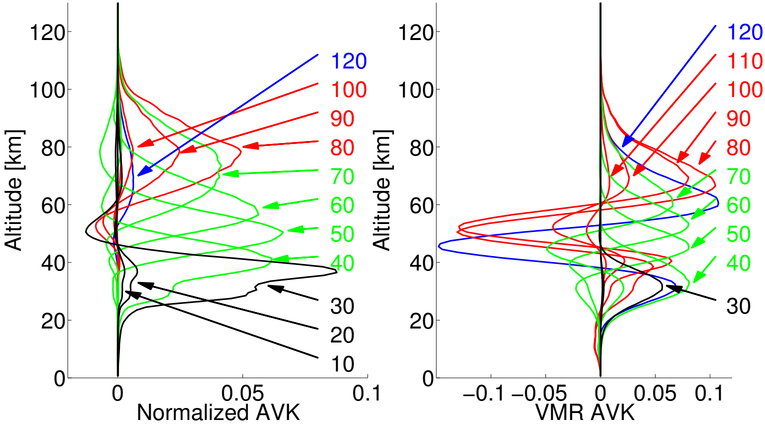
[Hoffmann et al., 2011, AMT]

Complete KIMRA CO time series



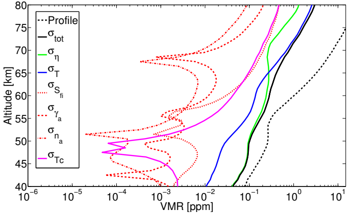
[Hoffmann et al., 2011, AMT]

Retrieval Performance

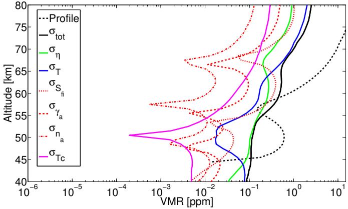


AVK of 29 October 2009, 120km kernel multiplied by 50 [adapted from Hoffmann et al., 2011, AMT]

Error contributions



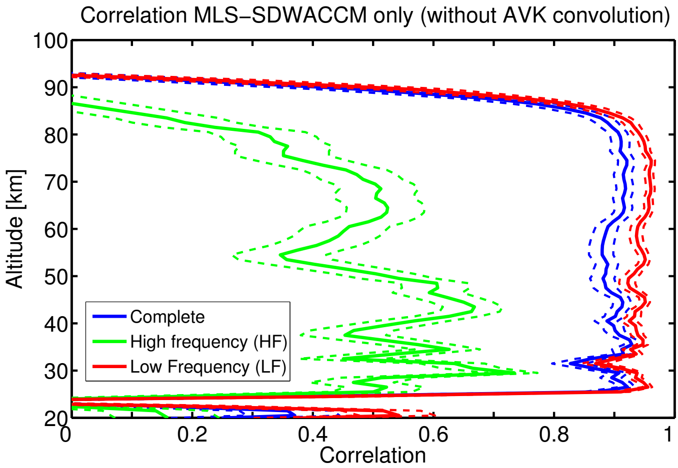
29 October 2009
[Hoffmann et al., 2011, AMT]



4 February 2009
[Hoffmann et al., 2011, AMT]

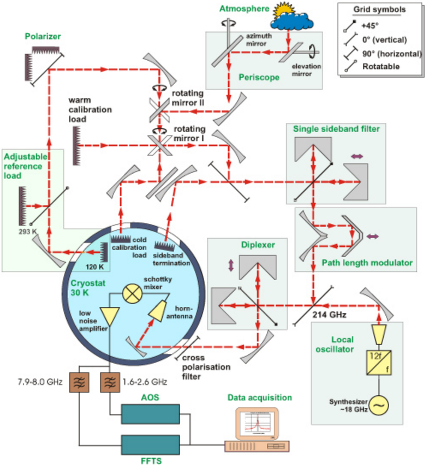
- σ_{tot}: Total error
- σ_η: Noise on spectrum
- σ_T: Error of used temperature profiles
- $\sigma_{S_{fi}}$, σ_{γ_a}, σ_{n_a}: Spectroscopic parameters
- σ_{T_c}:Calibration error

Correlations: MLS-SDWACCM



[Hoffmann et al., 2012, ACP]

Sketch of the KIMRA instrument



[Uwe Raffalski]