Bringing MWR into GRUAN

DomeNico Cimini

Institute of Methodologies for the Environmental Analysis (IMAA)

National Research Council of Italy (CNR)

With contributions from:

Ulrich Löhnert, University of Köln, Germany

Alexander Haefele, MeteoSwiss, Switzerland

Niklaus Kampfer, University of Bern, Switzerland

MWRnet (http://cetemps.aquila.infn.it/mwrnet)

About 61 members, more than 94 MWR worldwide

MWRnet - An International Network of Ground-based Microwave Radiometers

- Home

Information

- What is MWRnet?
- News
- More information
- Picture Gallery
- Contacts

Community

- How to join
- Members
- The network
- MWRnet library
- Software

Last update: 09 Feb 2011

TV profiler; T profiler; V profiler; IWV/LWP; Other;

Designed by N.C. - Powered by HIMET

MWRnet: an international network of MWR

- **MWRnet** started under the auspice of COST Action EG-CLIMET:
  - **Aim**: Addressing the lack of coordination and increase the utilization of quality controlled MWR data
- **Goals**:
  - Establish the "**best practices**" for MWR observations and retrievals
  - Facilitate the **access** of well documented and QC MWR observations and retrievals (with uncertainties)
- **Status:**
  - EG-CLIMET ended Nov 2012
  - Waiting for the response for a new COST proposal (TOPROF)
    - MWR is one of the 3 instruments considered

MWR and GRUAN: EU FP7 Proposal

- **EMERGE**: European MicrowavE Radiometer network within GEo
  - EU FP7 Coordination action for 3 years activity
  - Area 6.4.1.1: Integration of European activities within GEO

- **Objective**:
  - Coordinating the integration of MWR observations at GRUAN sites into GEOSS (facilitating the access to a broad community).

- **Contributors**:
  1. CETEMPS, U. of L'Aquila (IT)
  2. U. of Köln (D)
  3. KNMI (NL)
  4. IMAA (IT)
  5. FMI (FI)
  6. DWD (D)
  7. Meteoswiss (CH)
  8. MetOffice (UK)

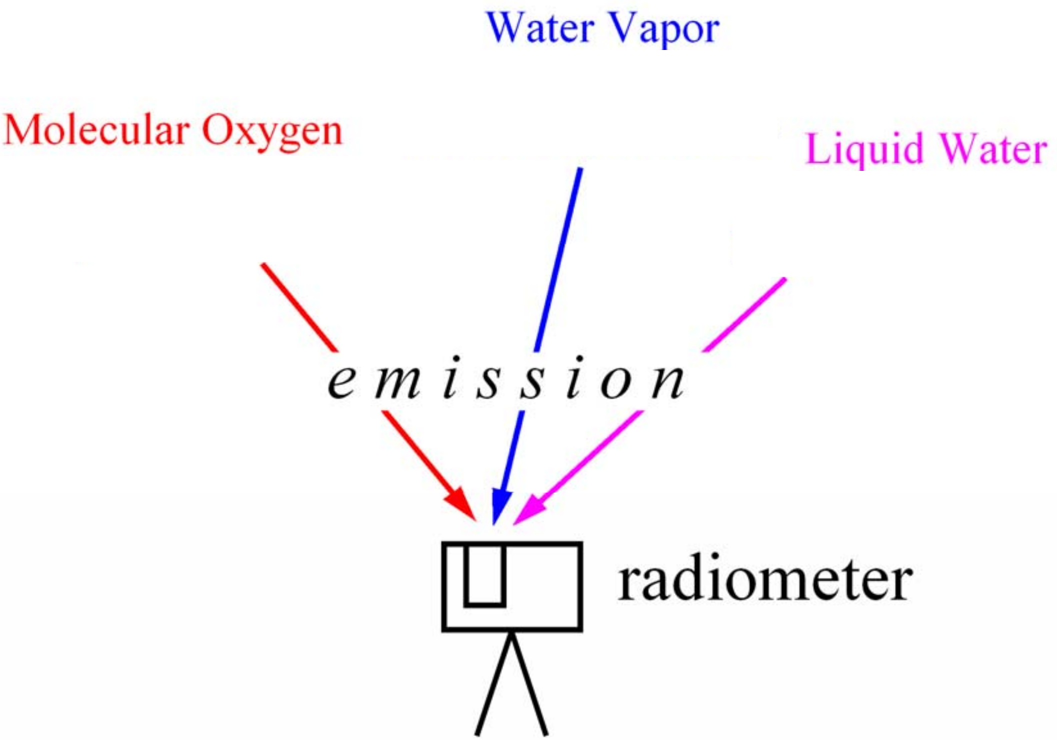
- **Evalutation**:
  - Passed all quality criteria but got not funding

Bringing MWR into GRUAN

- Introduction
  - What MWR can do for you?
  - Advantages and limitations
- Examples of MWR activities of GRUAN interest
  - Payerne
  - Lindenberg
  - Lamont
  - Non-GRUAN sites
- Summary and conclusions

What MWR can do for you?

- Passive technique: natural emission from the atmosphere
- Robust, all-weather, unattended instruments
- Real time accurate geophysical measurements



What MWR can do for you?

- **A variety of instrumentation exists, providing different products**
  - Dual-channel → IWV, LWP (e.g. Lamont, Nauru)
  - WV profilers → IWV, LWP, WV prof. (e.g. Barrow)
  - T profilers → T profiles (e.g. Bern)
  - T + WV profilers → IWV, LWP, T + WV prof. (e.g. Barrow, Lindenberg, Payerne, Potenza,…)
- The retrieval of liquid water content (LWC) **profiles** is controversial
- Retrieval accuracy depends on instrument, but also on the inverse method being used

MWR advantages and limitations

- Advantages of MWR:
  - Good (relative) accuracy (ε_{Tb} ~ 0.3-0.5 K)
  - Azimuth and elevation scanning
  - Suitable for all weather conditions
    - Clear, cloudy, (light) precipitation
  - Continuous unattended operations at ~1min temporal resol.

MWR advantages and limitations

- Limitations of MWR:
  - Proper calibration needs monitoring and maintenance
  - Low-to-moderate vertical resolution
    - Intrinsic in passive observations
      - Specially true for WV profiles
      - Higher resolution for T profiles in the BL
  - Performances degrade under precipitation
    - Mitigation solutions
      - hydrophobic coating, blowers, side-views
    - Precipitation flag
  - Uncertainties with absorption models
    - WV, Oxygen, and super-cooled water

What's the added value of MWR for GRUAN?

- **Continuos**
  - Complement sondes (fine time-structure, diurnal cycle)
- **All-weather** (nearly)
  - Supplement lidar in case of clouds
- **Redundant**
  - T and WV profiles wrt to sonde/lidar
  - IWV wrt GPS, sonde*
- **Supplementary**
  - Unique (?) information on LWP (also an ECV)
  - No other GRUAN sensor does?

*note that MWR helped in detecting RS80 dry bias

MWR calibration

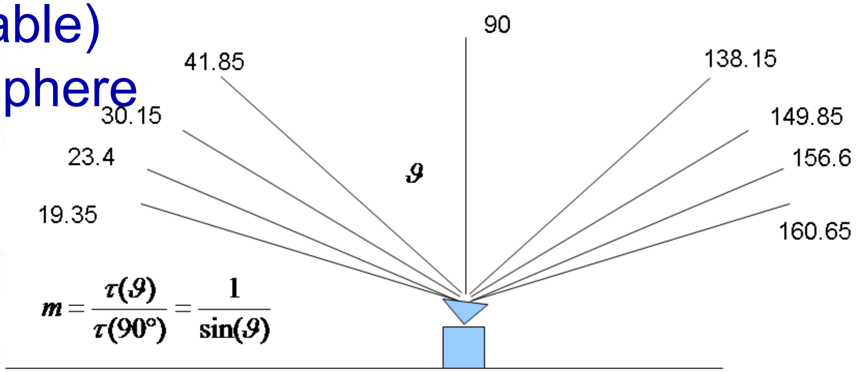
MWR calibration relies on the combination of 2-3 methods:

- External targets
  - 1 or 2 external BB targets at T_h and T_c
    - High emissivity and tight temperature control
    - T_c is usually greater than measured T_b
- Internal noise diode
  - One or two internal noise diode sources providing gain calibration
    - Low stability
- Tipping curve (or sky dip)
  - The relationship airmass-opacity is used (1 calibration point)
    - Applicable to low-opacity channels only (e.g. 20-45 GHz)
- Cryogenic target
  - BB target in cryogenic bath (liquid nitrogen) is used (1 calibration point)
    - Impractical

MWR calibration

- Current technology is such that receivers are stable over long periods (months), requiring less frequent calibration adjustments
- However, some practical difficulties remain
- Cryogenic calibration
  - Safety and training issues
  - LN2 not easily available everywhere
  - Measures to avoid condensation

- Tipping curve
  - Side-views may be partially obstructed
  - Clear-sky (not always available)
  - Horizontally stratified atmosphere



$$m = \frac{\tau(\vartheta)}{\tau(90°)} = \frac{1}{\sin(\vartheta)}$$

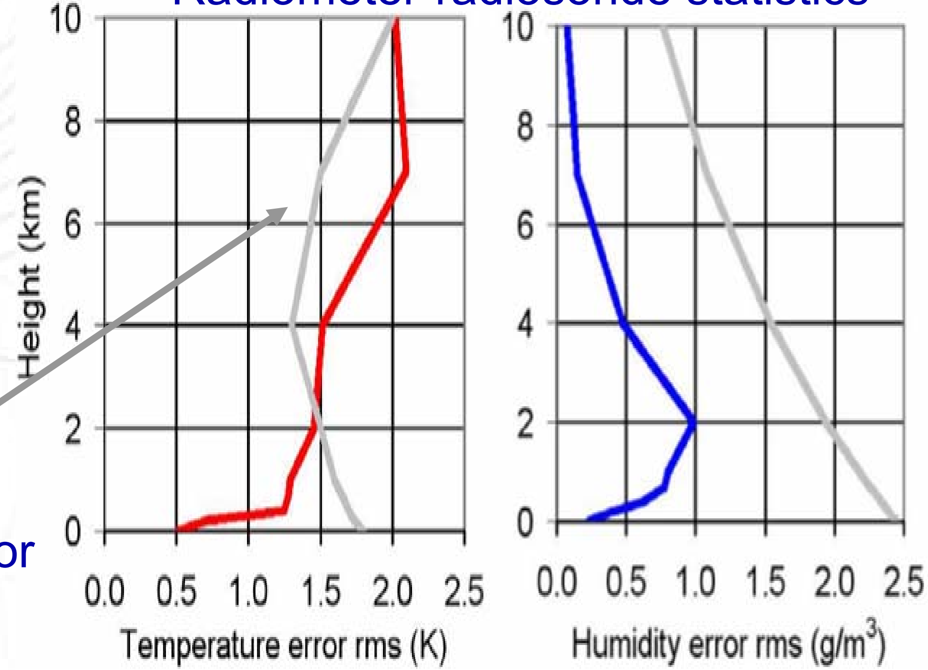
Is MWR a "reference"?

- According to GRUAN, a "reference" needs to be:
  - Traceable to SI unit or an accepted standard ??
  - Accepted by others as the best observation OK
  - Well understood OK
    - Uncertainty analysis may be provided
    - May be validated by intercomparison or redundant obs.
  - Free of biases ??
  - Well documented in accessible literature OK
    - May maintain all raw data
    - May include complete meta data description

MWR retrieval performances

- Accuracy (rms difference wrt reference)
  - Tb ~ 0.3-0.5 K
  - IWV ~ 1.0 mm (kg/m^2)
  - LWP ~ 0.02 mm
  - T(z) ~ 0.5-2.0 K
  - WV(z) ~ 0.2-1.5 g/m^3

Radiometer-radiosonde statistics



radiosonde representativeness error into NWP models

[After Güldner and Spänkuch, JAOT, 2003]

MWR and GRUAN: Site survey table (tbc)

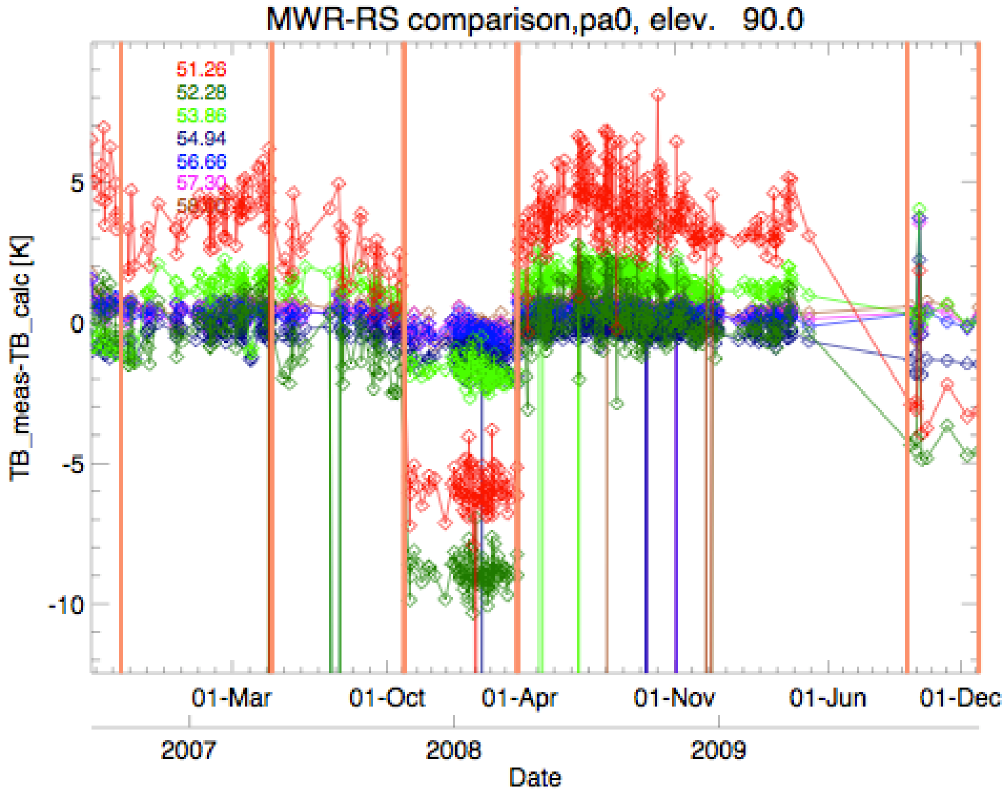
Site	MWR	Manufacturer	Since
Barrow, USA	WV profiler	Radiometrics	
Beltsville, USA	T-WV profiler	Radiometrics	
Boulder, USA	??		
Cabauw, Netherlands	T-WV profiler	RPG	
Darwin, Australia	??		
Lamont, USA	T-WV profiler	Radiometrics	
Lauder, New Zealand	??		
Lindenberg, Germany	T-WV profiler	Radiometrics	
Manus, Papua New Guinea	IWV-LWP	Radiometrics	
Nauru, Nauru	IWV-LWP	Radiometrics	
Ny-Ålesund, Norway	??		
Payerne, Switzerland	T-WV profiler	RPG	
Potenza, Italy	T-WV profiler	Radiometrics	
Sodankylä, Finland	??		
Tateno, Japan	??		
Xilin Hot, China	??		

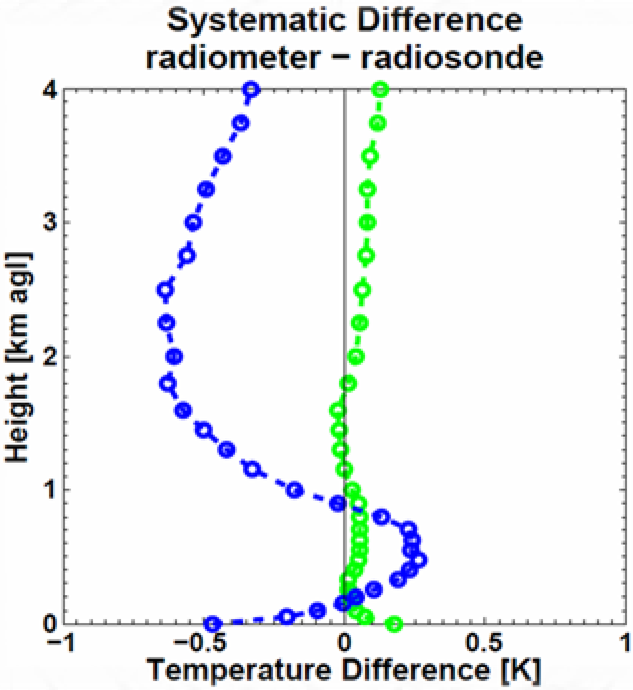
MWR activities of GRUAN interest

- MWR activities at MeteoSwiss in Payerne
- Quantifying the retrieval performances in Lindenberg
- Long term IWV and LWP monitoring at Lamont
- Prototype MWR for tropo-stratosphere temperature profiling
- Uncertainty estimate

Payerne: Tb bias monitoring and correction

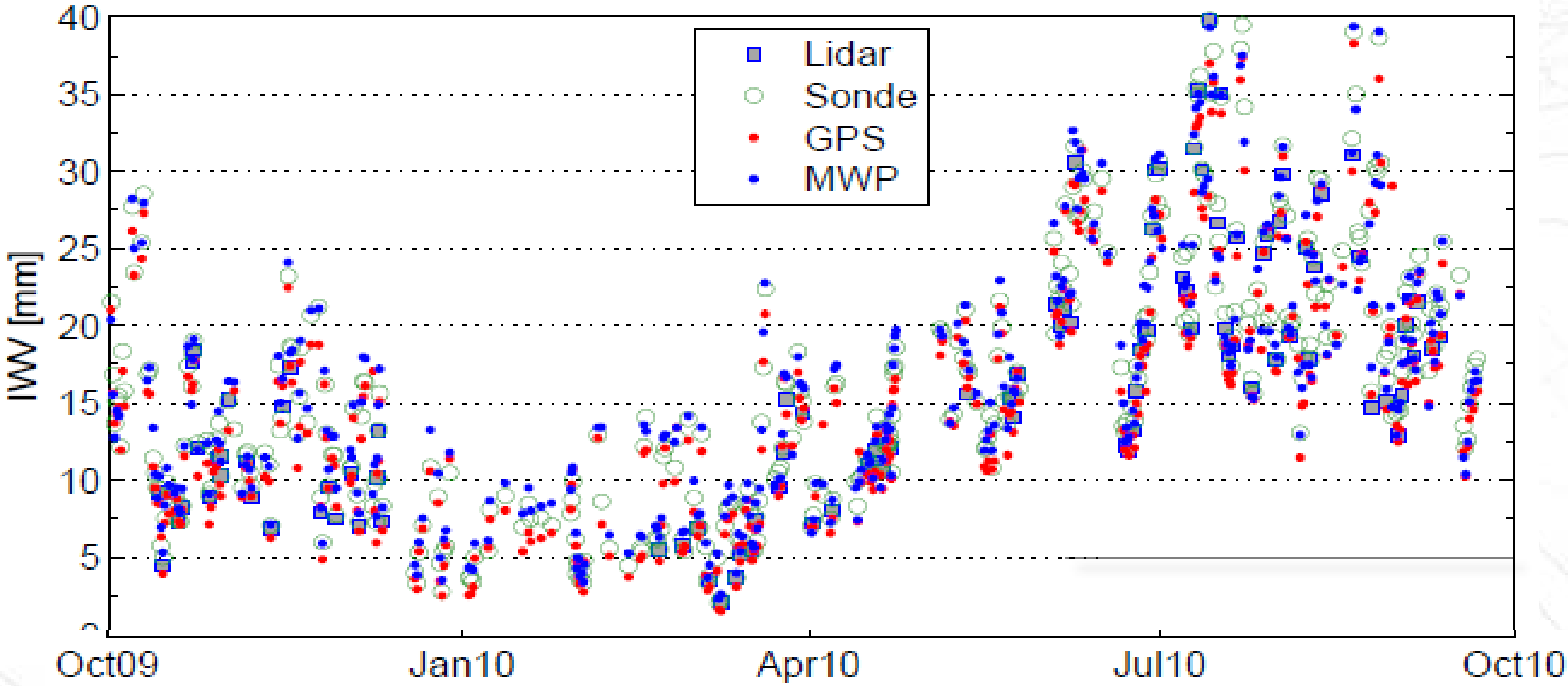
- Analysis of 3-year dataset of obs-sim Tb
- Clear-sky obs-sim Tb used to control calibration and correct biases
- Operational LN2 calibration caused significant jumps
- Correction of offset in *Tb* allows to remove bias in *T* profile





Reference: Löhnert and Maier, Atmos. Meas. Tech., 2012

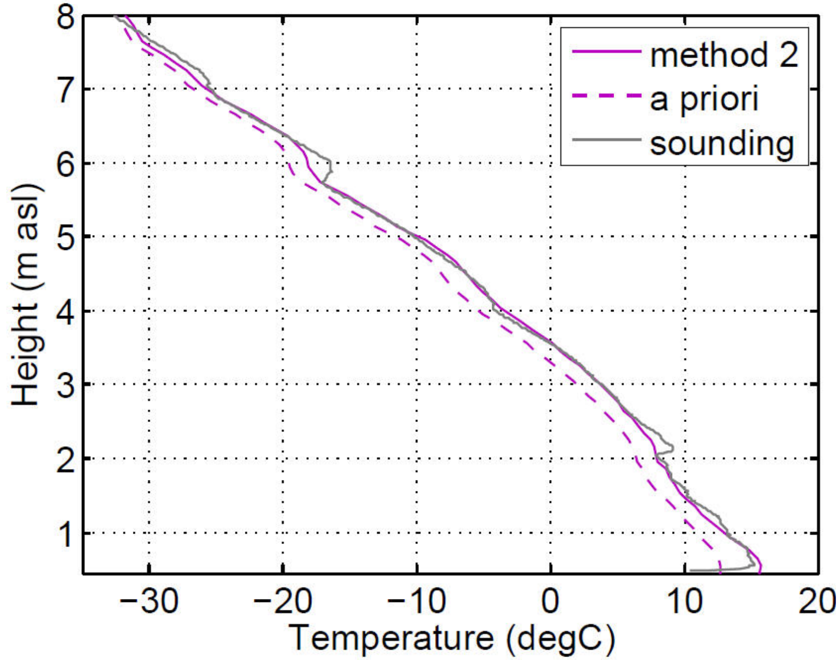
Payerne: MWR - LIDAR comparison

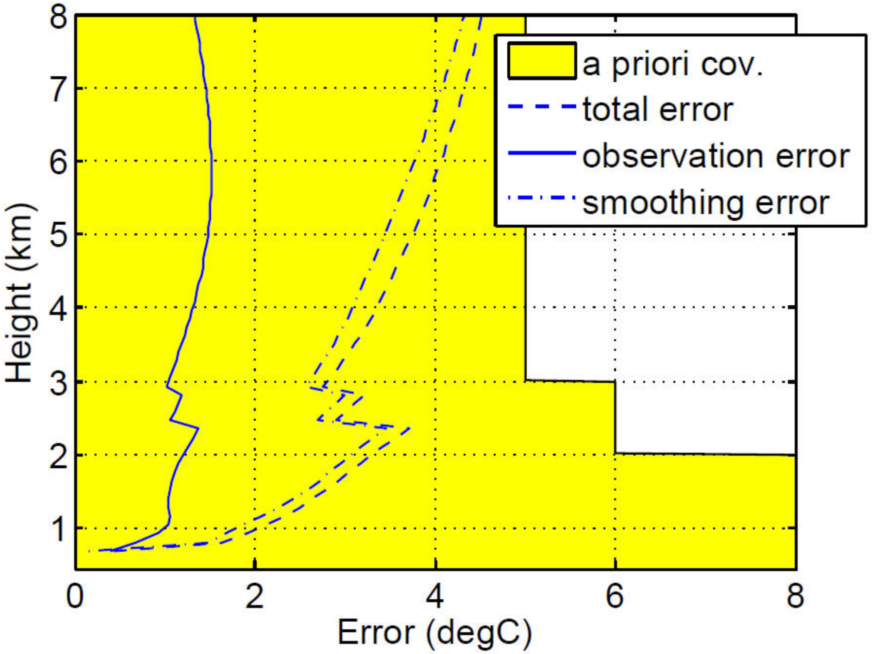


- Continuous monitoring of water vapor by MWR and lidar
- Good correlation between MWR and lidar in the whole troposphere
- IWV intercomparison
  - BIAS: MWR-Sonde: -2 %; MWR-Lidar: -6 %

Reference: Brocard et al., Atmos. Meas. Tech. Discuss., 2012

Payerne: MWR - LIDAR synergy (T profiling)





- Optimal Estimation Retrieval of T profile
- Lidar measurement is used as a priori profile
- Good characterization of error possible

Reference: Haefele et al., Proc. of ISTP, 2012

Lindenberg: MWR accuracy assessment

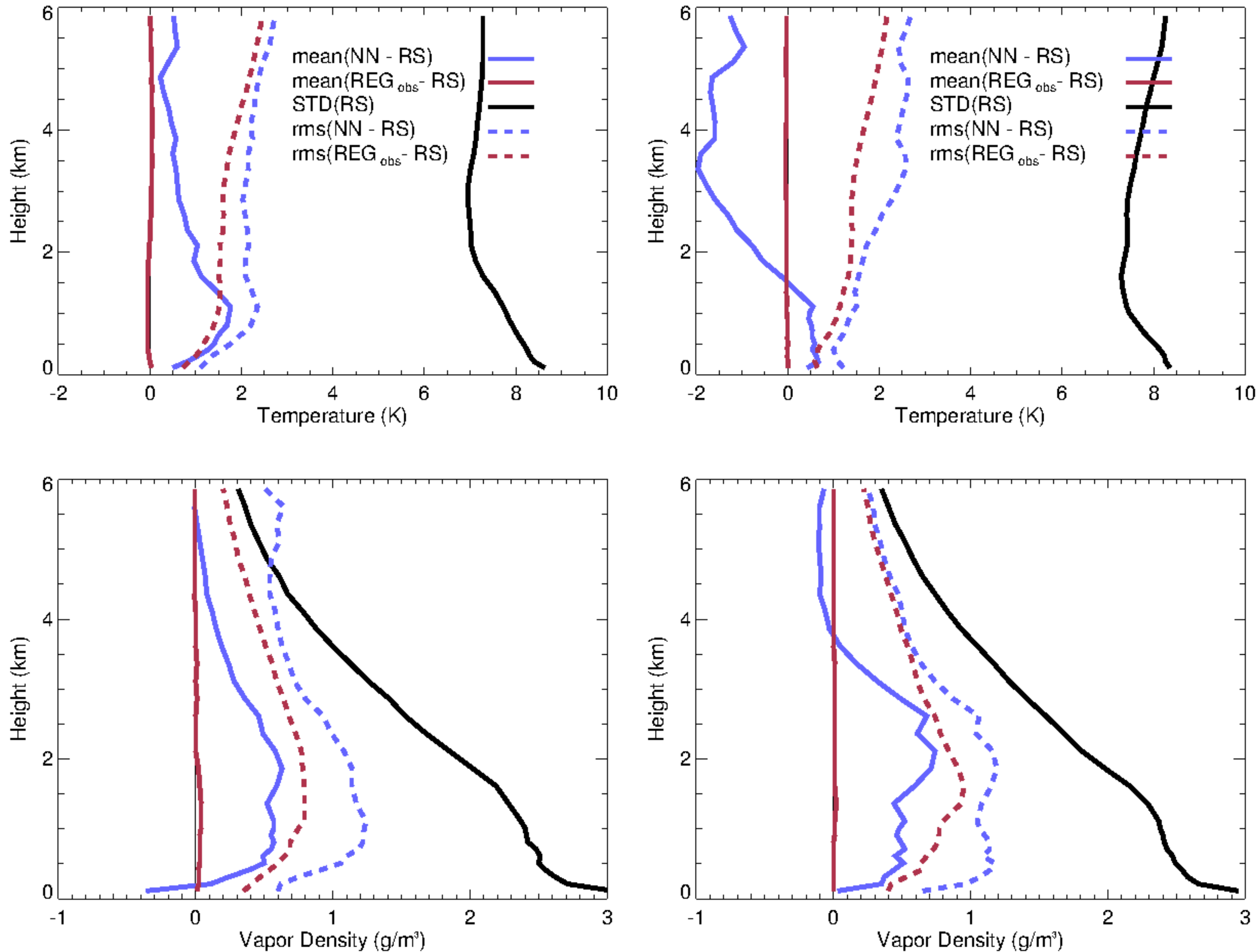
Yearly accuracy assessment at Lindenberg (using different retrieval methods)

2003-2004 **2004-2005**

T(z)

Güldner Jürgen DWD

WV(z)

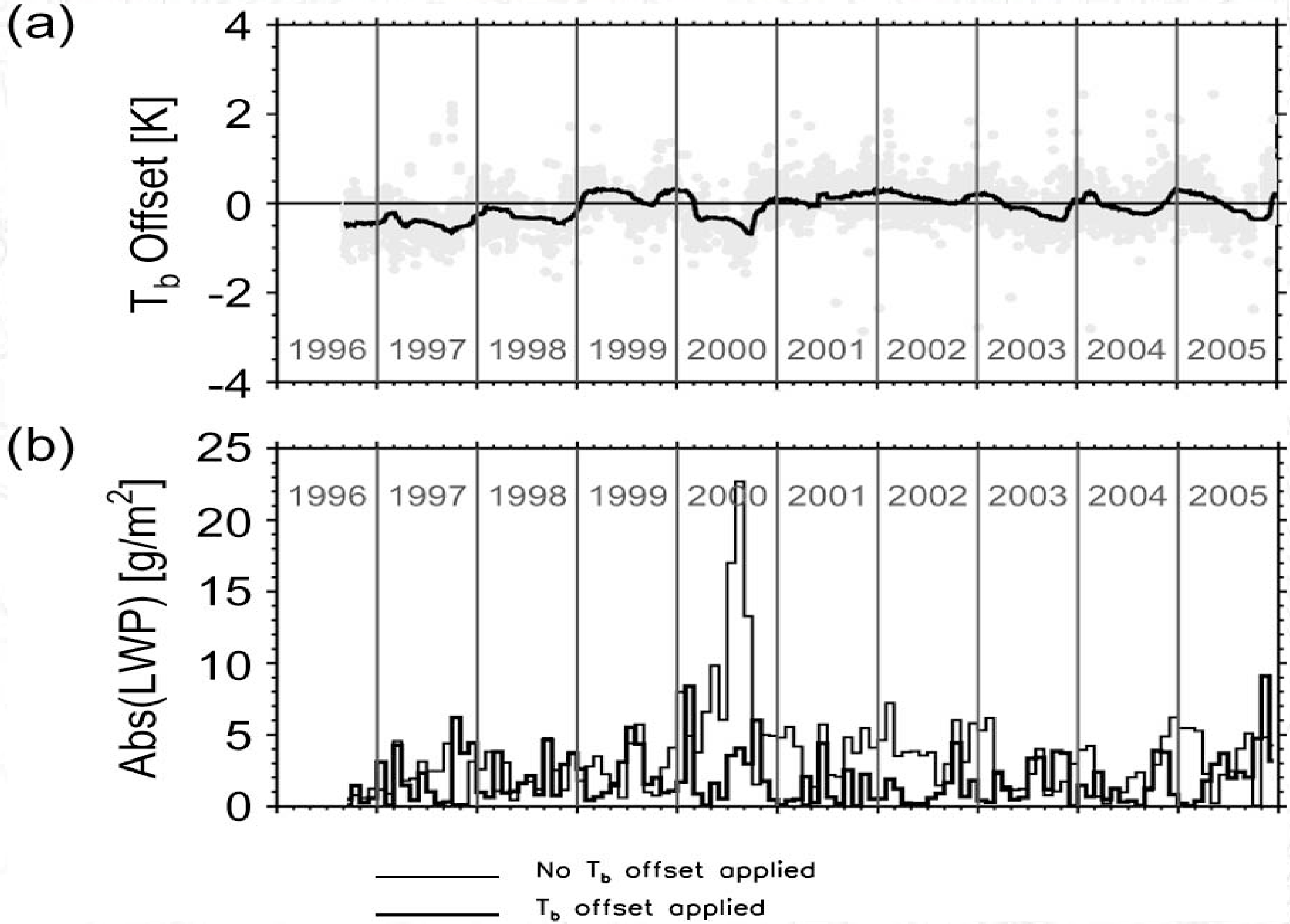


Lamont: Long-term IWV and LWP monitoring

- Some 20 years of dual channel MWR observations
- 10-year data set was analysed (wrt to clear-sky sonde)
  - Tb offsets demonstrate significant seasonal, yearly, and site-to-site variability.
  - Bias-corrected Tb provided more accurate retrievals of IWV and LWP (e.g. LWP much closer to zero in clear sky).
    - Bias ± ~ 1 K (both for 23.8 and 31.4 GHz)
      - ΔIWV ~0.7 mm
        - i.e. 7/IWV(cm)% (7% at 1 cm; 2% at 4 cm)
      - ΔLWP ~0.04 mm
        - i.e. 40% at 0.10 mm (100 g/m^2)

Reference: Turner et al., TGRS 2007

Lamont: Long-term IWV and LWP monitoring



Reference: Turner et al., TGRS 2007

Long-term monitoring (in general)

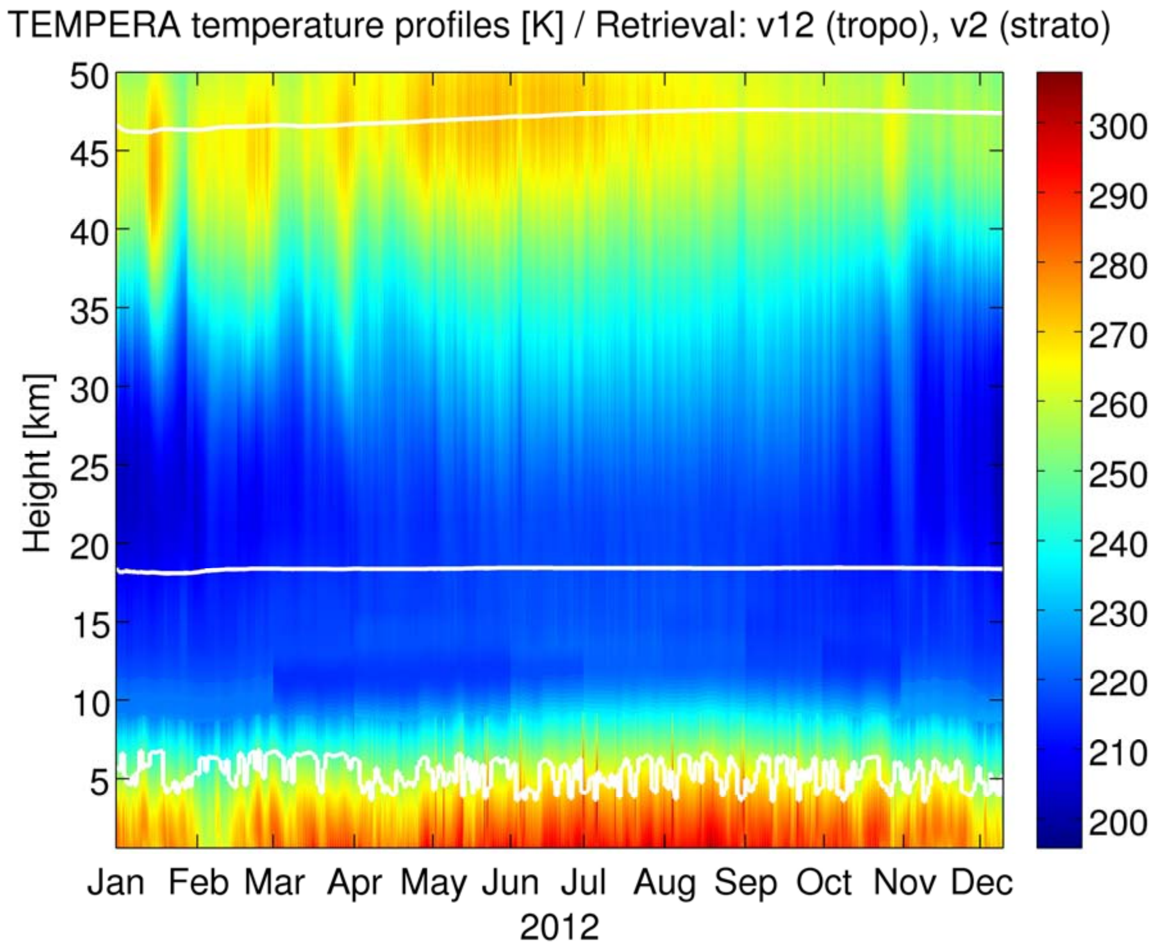
WARNING:

- Tb-bias corrections may be applied, but only for reprocessing
  - NOT in real time; original data should always be kept
- Keep the opportunity to monitor sondes independently
  - MWR to correct sondes, sondes to correct MWR

MWR for tropo-to-stratosphere T profiling

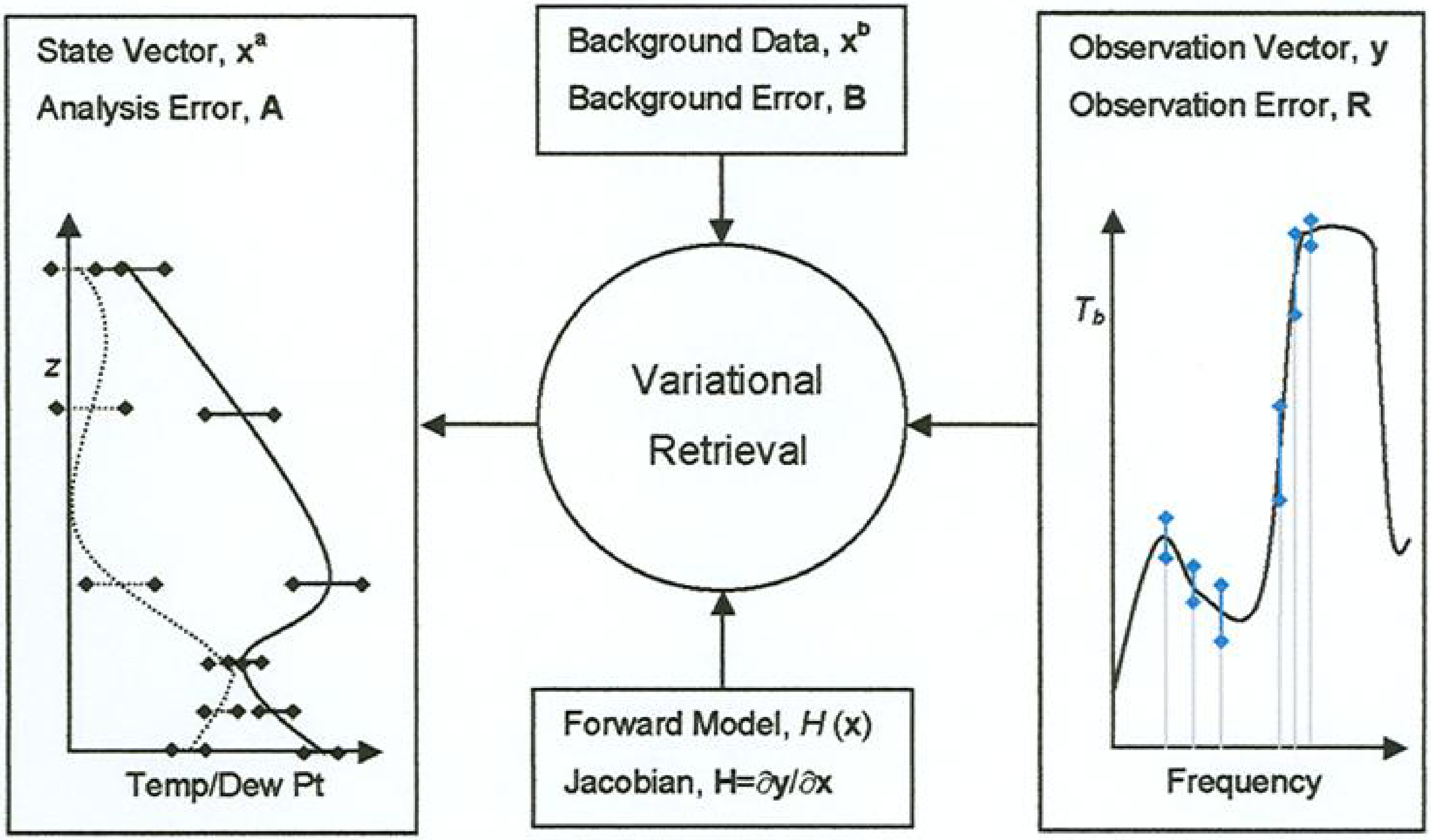
- Contribution from IAP, Uni. Bern (N. Kampfer)
- TEMPERA (TEMPErature RAdiometer): a research prototype MWR for T profiles from ground to the stratopause

Compared with radiosondes (Payerne) and satellite (MLS) measurements



Estimating the uncertainty

- Variational retrieval may be used to produce retrieval uncertainty

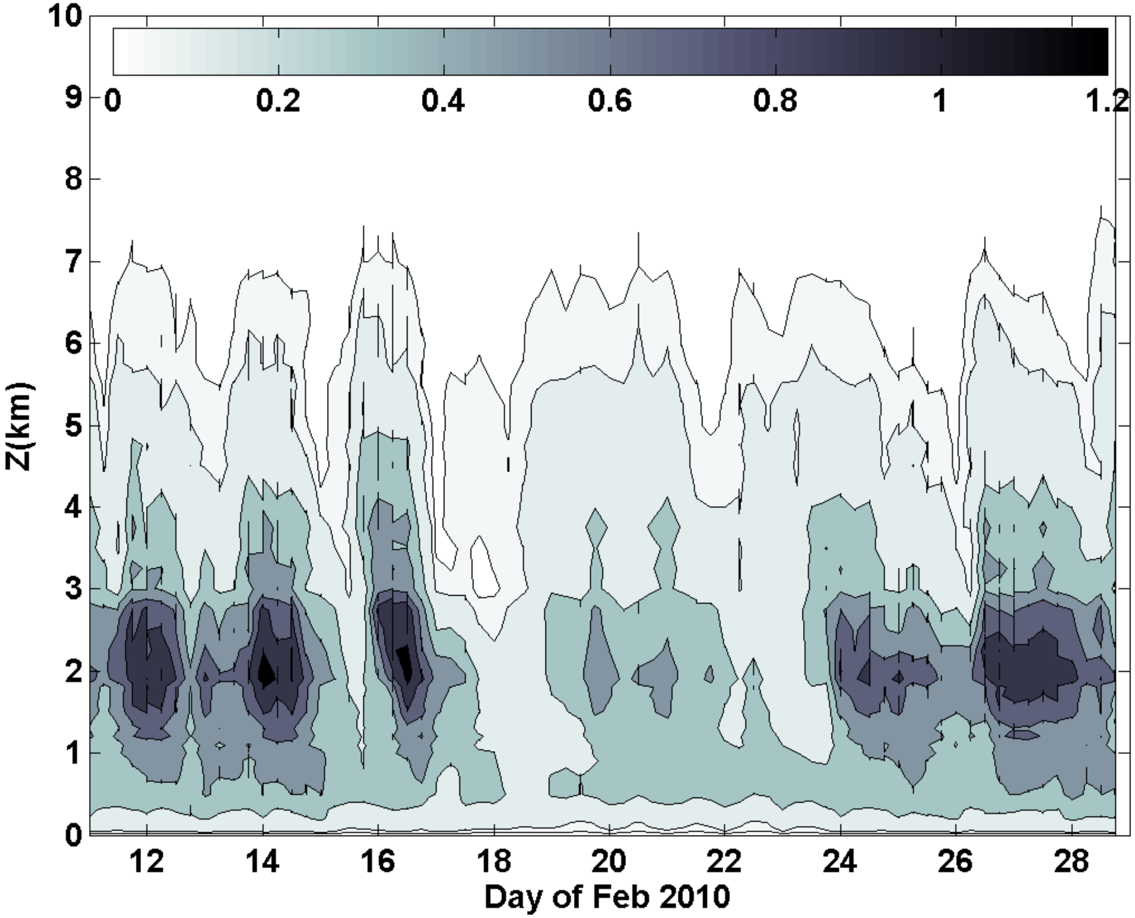


[After Hewison, 2006]

References: Lonhert et al. 2004; Hewison 2007; Cimini et al. 2006; 2009; 2011

Retrieval uncertainties

- Time-height cross section of estimated statistical error for water vapor density retrievals. Values are in g/m^3.



Summary and conclusions

- MWR measurements are valuable for GRUAN
  - Complementary (high temporal res., diurnal cycle)
  - Redundant (T, WV, IWV)
  - Supplementary (LWP)
  - Solid framework for estimating uncertainty
- MWR treaceability needs discussion/efforts
- MWR long-term bias needs maintainance and monitoring

Summary and conclusions

- First draft of GRUAN MWR guide (Jan. 2013)
  - Credits: T. Leblanc, N. Kampfer, A. Haefele, M. Cadeddu
- Far from being complete
  - Many sections are still empty
  - Specially the most «technical»: protocol, software…

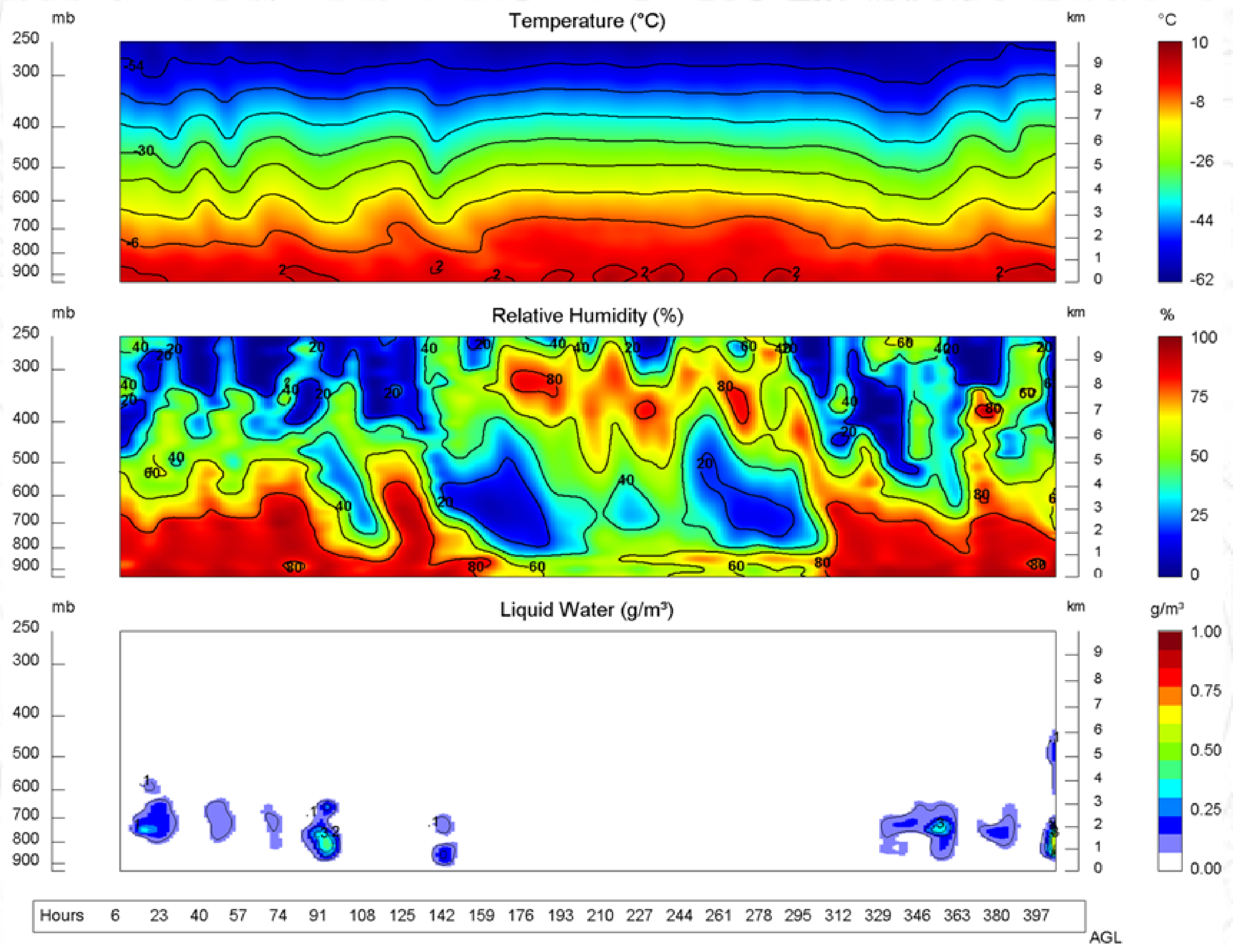
Thank you very much for your attention!

List of Acronyms

ECV	Essential Climate Variable
EUMETNET	European Meteorological Service Network
EUCOS	EUMETNET Composite Observing System
FCDR	Fundamental Climate Data Record
GCOS	Global Climate Observing System
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GEWEX	Global Energy and Water Vapor Experiment
GMES	Global Monitoring for Environment and Security
GRUAN	GCOS Reference Upper Air Network
G-VAP	GEWEX Water Vapor Assessment Project
LUAMI	Lindenberg Upper-Air Methods Intercomp. Camp.
MWR	Microwave radiometer

MWR deployment in all-weather 2010 Winter Olympics

2-week time series (12-28 Feb 2010)



MWR deployment in all-weather 2010 Winter Olympics

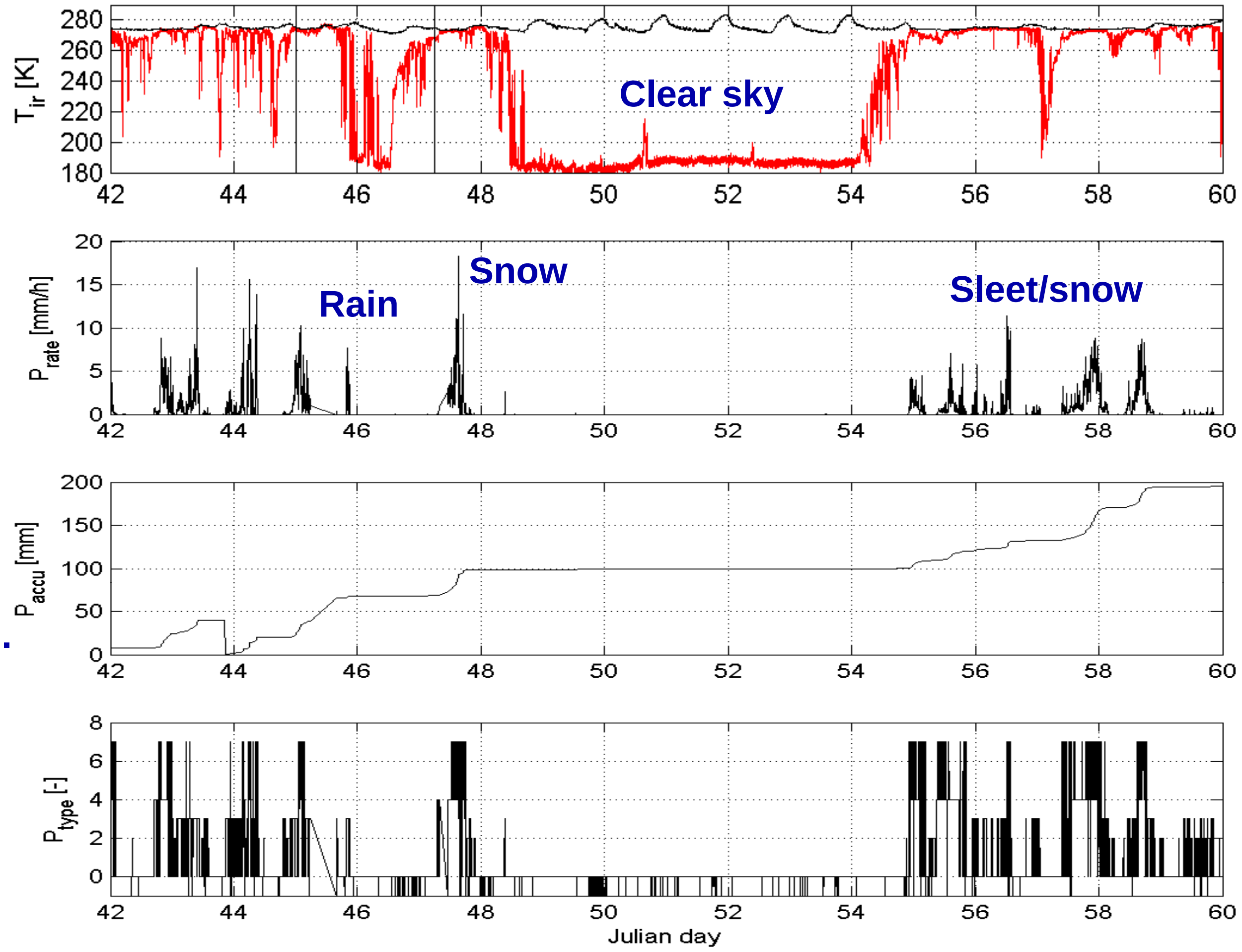
- **All-weather conditions**: clear-sky, rain, sleet, snow,...(200 mm accumulated precipitation)

Ts & Tir

Precip. Rate

Precip. Accum.

Precip. type



What MWR can do for Climate?

- IWV, LWP, Temperature and Humidity profiles are all GCOS ECV
- MWR estimates meet most of the requirements indicated by WMO for climate observations (threshold, breakthrough, goal)
  - Temperature profiles:
    - o PBL: uncertainty, observing cycle, vertical resolution
    - o Free: uncertainty, observing cycle, vertical resolution
  - Humidity profiles:
    - o uncertainty, observing cycle, vertical resol. in lower levels
- Accuracy (rms difference wrt reference) in troposphere
  - IWV ~ 1.0 mm (kg/m^2)
  - LWP ~ 0.02 mm
  - T(z) ~ 0.5-2.0 K
  - WV(z) ~ 0.2-1.5 g/m^3

Recommendations from:
WMO Statements of Guidance
WMO Observing Systems Capability Analysis and Review Tool

What MWR can do for NWP?

- The planetary boundary layer (PBL) is the single most important under-sampled part of the atmosphere
  - Poor satellite coverage
- This is particularly important and urgent in nowcasting (0-6 h range)
- The structure and variability of the PBL is not well known because vertical profiles of water vapor and temperature are not systematically observed
- MWR can provide timely and enough accurate atmospheric temperature and humidity data
  - especially good in the PBL

Recommendations from the U.S. National Research Council:
"Observing Weather and Climate from the Ground Up; A Nationwide Network of Networks " (2009)
"When Weather Matters: Science and Service to Meet Critical Societal Needs" (2010).

Small Working Group meetings

- **SWG 1: From raw data to meteorological products**
  - Measurement modes
  - Calibration control procedures
  - Quality control
  - Metadata & data formats

- **SWG 2: MWR data processing**
  - Reprocessing of MWR data from standard instruments
    - Application of data QC
    - Generation of harmonized retrieval products
  - Distribution of processing software (MWRpro)

- **SWG 3: Towards operational use of MWR data**
  - Towards on-line processing
  - Calibration control procedures
  - Common retrieval algorithms

SWG constructive communication

USER

2 identical radiometers were deployed side by side. **Systematic differences** in Tb(58GHz) of the order **of 1-2 K were noted**, while the absolute calibration should be < 1 K!

Calibration coefficient updates seem to introduce step-like discontinuity in the Tb comparison!

EXPERT/MANUFACTURER

The 1-2 K bias may be caused by deterioration of the temperature sensor measuring physical temperature of the BB target. **Inspection every 1.5-2 years is recommended**. New MWR provide a way to monitor sensor degradation

A good practices protocol should be followed to avoid erroneous cryogenic and sky dip calibration (**not more frequency than once every few months**).
Tight quality control should be adopted.

SWG Recommendations (1/3)

#	Type	Recommendation
MM1	Measurement mode	Perform zenith viewing alternating with elevation scans regularly, possibly as frequent as 5 min. Store observations at all channels. If possible, perform 2-side scans.
MM2	Measurement mode	Perform frequent observations of the calibration load. Use integration time ~1-10 sec.
MM3	Measurement mode	Ideally, all raw voltages of receivers and temperatures in the radiometer system should be recorded continuously in order to make a post-calibration possible.
CC1	Calibration control	Carefully follow instructions for cryogenic calibration. If possible check Tb after cryogenic calibration against a reference (e.g. clear sky radiosonde simulations).
CC2	Calibration control	Before each cryogenic calibration: observe the cold load for ~2min to characterize the instrument drifts since the last calibration
CC2	Calibration control	Be careful when using calibration coefficients obtained by a single sky dip (tipping curve). Make sure the threshold for a horizontally homogeneous sky are set very tight, Averaged time series of sky dip calibration coefficients may be used to avoid jumps in the data.
CC3	Calibration control	Inspection by manufacturer every 1.5-2 years is recommended
CC4	Calibration control	Re-processing of MWR observations and retrievals may be possible if a comparable set of collocated radiosonde profiles is available. Alternatively model analyses could be used.
QC1	Quality control	Use sanity checks to monitor the reliability of observed Tb. Use flags provided by manufacturers as well as developed by users.
QC2	Quality control	Use quality control checks to estimate the value of retrievals. Use flags provided by manufacturers as well as developed by users.
QC3	Quality control	Rain flag is necessary, especially for humidity, but is may overkill acceptable retrievals. Check the quality of retrievals during rain flagged periods.

SWG Recommendations (2/3)

#	Type	Recommendation
RA1	Retrieval algorithm	Uniform multi-linear regression (or NN) retrievals based on radiative transfer calculations should be implemented. These are robust to handle and their accuracy is mostly optimized. Alternatively, direct regression retrievals based on the relation between measurements and model output should be considered.
RA2	Retrieval algorithm	Ideally, a variational approach should be adopted for all the MWR. However, future testing is required – specifically concerning the handling of liquid clouds
RA3	Retrieval algorithm	The estimate of the retrieval error should be provided.
RA4	Retrieval algorithm	The estimate of in-depth retrieval characteristics should be provided (averaging kernels, degrees of freedom)
DF1	Data format	Produce data in a easy-to-share format with metadata.
DF2	Data format	netCDF format is preferable.
DF3	Data format	Common data and metadata format will be decided building on the experience of ARM, LUAMI, COPS.
DF3	Data format	If the proper funding will be available, data should be processed and stored in a reliable and centralized server.

SWG Recommendations (3/3)

#	Type	Recommendation
OP1	Operation and processing	Level 0 data should always be stored
OP2	Operation and processing	MWRP climate application should rely on careful calibration monitoring (including RT comparison and close maintenance)
OP3	Operation and processing	Gain calibration should be performed once every 3-5 minutes for some 5-10 sec integration time.
OP4	Operation and processing	Always store data even if quality flags (e.g. rain flag) are on. Never delete data!
OP5	Operation and processing	Avoid RH profiles computed from T and WV retrieved profiles.

MWRnet achievements within EG-CLIMET

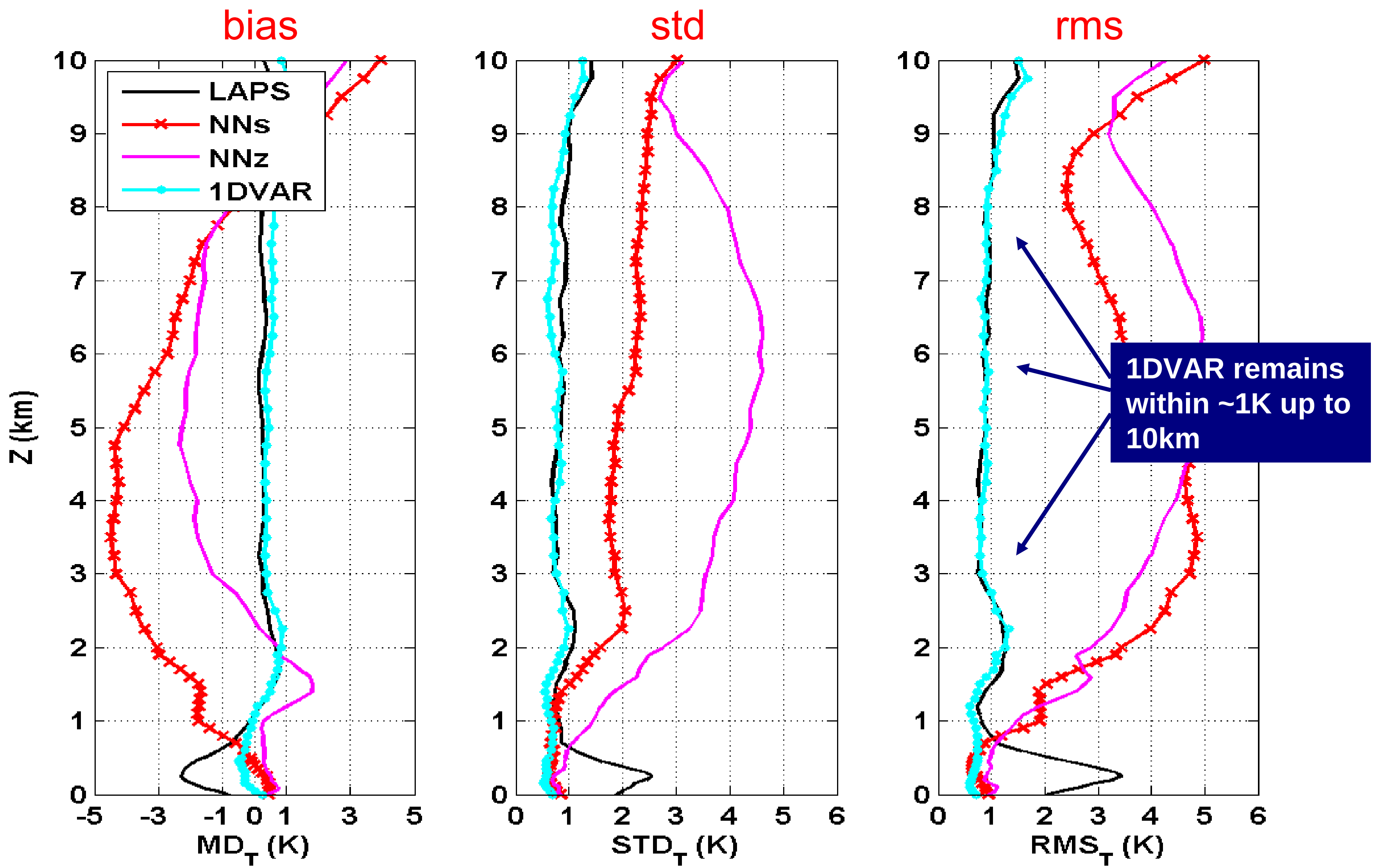
- Development of calibration control methods
- Advances in retrieval algorithm development
  - One-Dimentional Variational Retrieval
  - Model-based regression
  - Mixing layer height retrievals
- MWR Data Assimilation experiment
  - O-B statistics
  - Development of a ground-based MWR Forward Model suited for NWP

Advances in retrieval techniques

- One-Dimentional Variational Retrieval (1DVAR)
- Model-based regression
- Mixing Layer Height retrievals

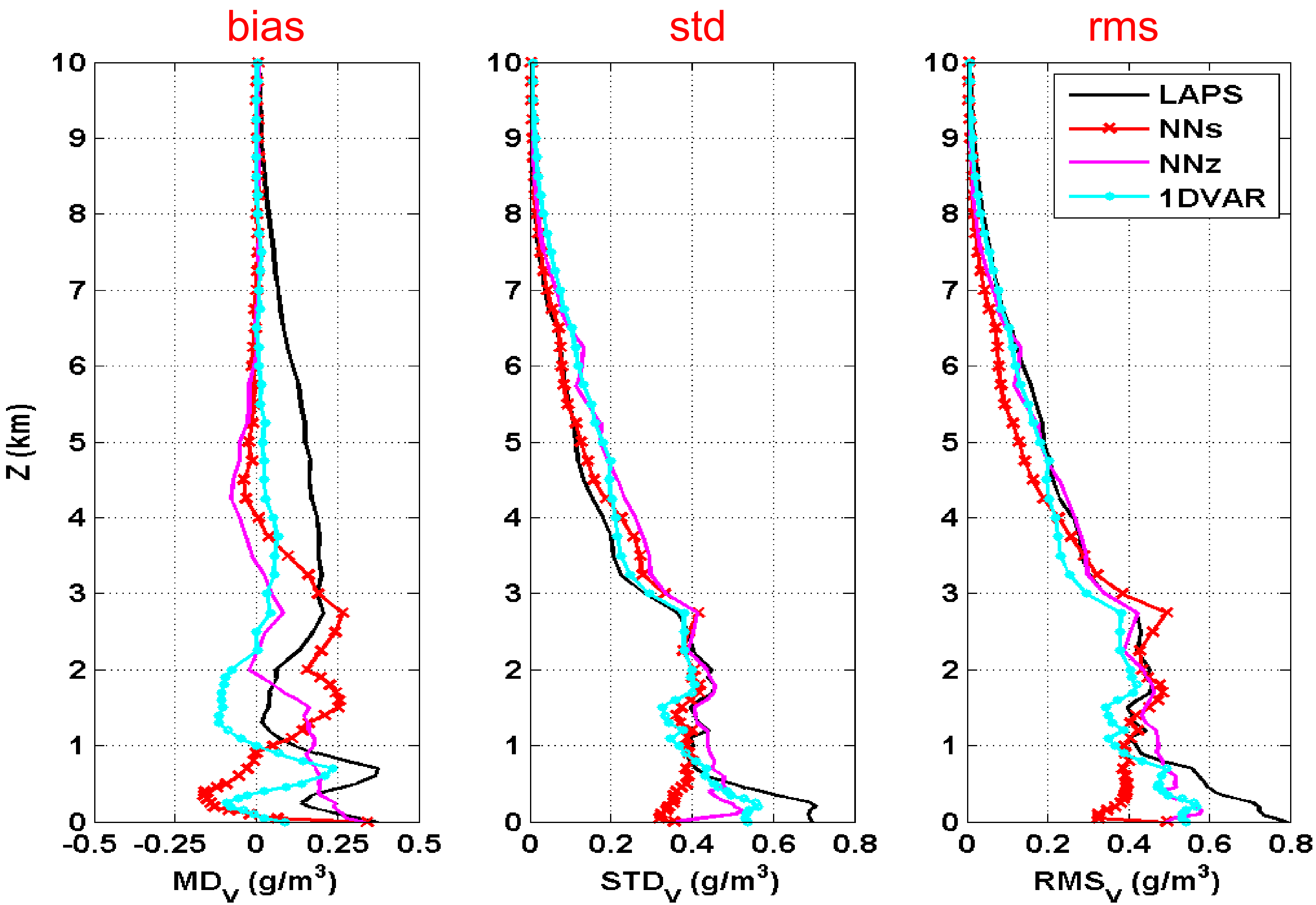
1DVAR deployment in all-weather (2010 Winter Olympics)

All-weather stats wrt radiosonde: Temperature profiles



1DVAR deployment in all-weather (2010 Winter Olympics)

All-weather stats wrt radiosonde: Humidity profiles



MWRnet future plans

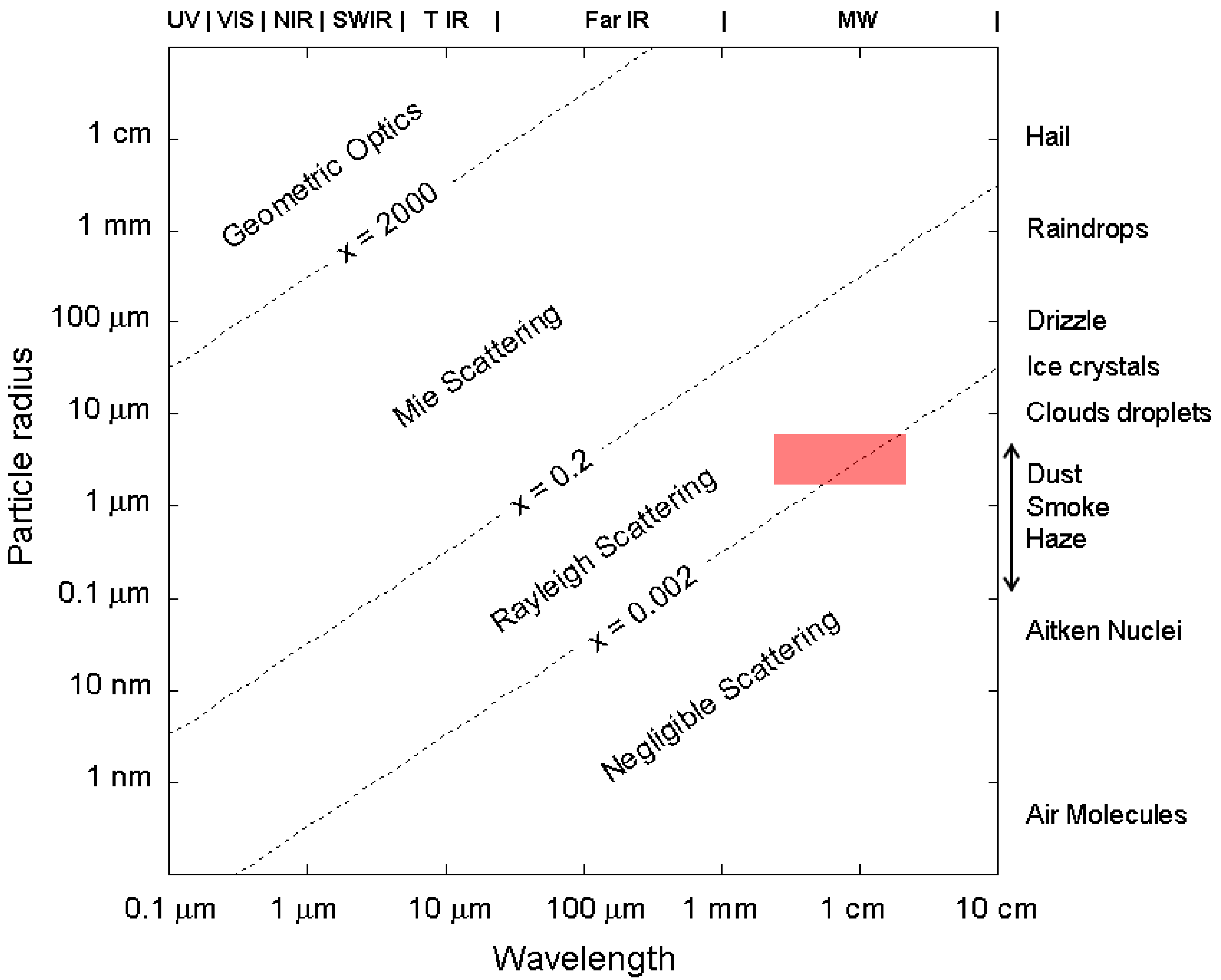
- Implement common data life-cycle
  - Common data format
    - First initiative: "**MWRnet day**" (11/11/11)
    - 24h data trasferred in a central server (48 MWR units; 63%)
  - Common retrieval
    - Testing MWRpro (developed at U. of Cologne)
    - Making 1DVAR and MODreg sharable

- A new COST proposal has been submitted:
  - **TOPROF**: Towards Operational ground based PROFiling with ceilometers, microwave radiometers, and doppler lidars

  - TOPROF is under evaluation
    - Rated as 'Excellent', but got some criticism

Scattering of EM radiation

- Scattering regimes



Basic concepts
Rain Mitigation

- Hydrophobic film (no blower)