Towards a GRUAN MWR product

DomeNico Cimini – CNR-IMAA, Italy

With contributions from:

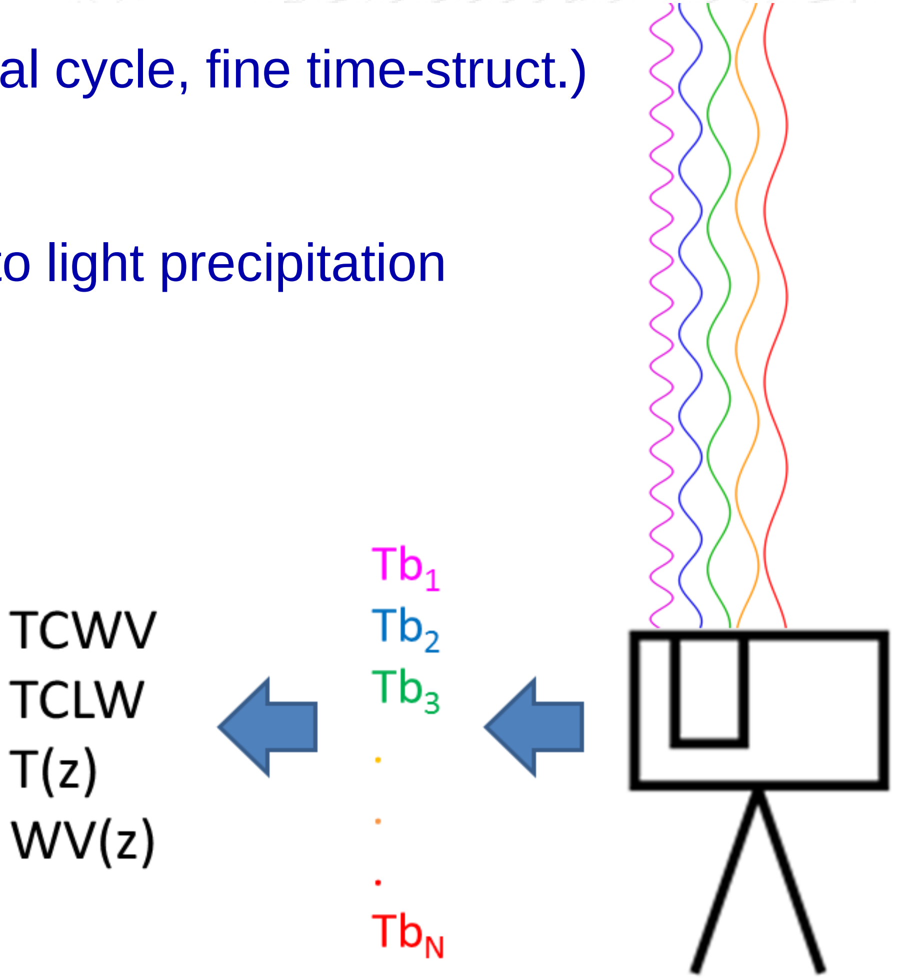
Maria Cadeddu, ARM-ANL (USA)
Stick Ware, Radiometrics (USA)
Francisco Navas, University of Bern (Switzerland)
Alexander Haefele, MeteoSwiss (Switzerland)
Niklaus Kampfer, University of Bern (Switzerland)
Jürgen Gülder, DWD (Germany)
Bernhard Pospichal, University of Lipzig (Germany)
Ulrich Löhnert, University of Köln (Germany)
Harald Czekala, RPG (Germany)

Towards a GRUAN MWR product

- What's the role of MWR in GRUAN
  - MWR Survey
- GRUAN MWR Program Guide
  - Status
    - Redundancy
    - Validation
    - Calibration & Maintainance
    - Data Quality management
    - Managing changes
    - Data Format
    - Reference Measurement
    - Uncertainty
- Research activities in Payerne/Bern

What's the value of MWR for GRUAN?

- **Redundant**
  - wrt to RS, GNSS, RL, FTIR
- **Continuos**
  - Complement sondes (diurnal cycle, fine time-struct.)
- **All-weather** (nearly)
  - Not affected by clouds, up to light precipitation
- **Supplementary**
  - TCLW (also an ECV)



GRUAN MWR instrument survey

Different instruments exists in GRUAN, providing different products

- 2/3-channel → TCWV, TCLW (e.g. Lamont)
- WV profilers → TCWV, TCLW, WV(z) (e.g. Barrow)
- T profilers → T(z) (e.g. Bern)
- T + WV profilers → TCWV, TCLW, T(z) + WV(z) (Lindenberg, Beltsville, Cabaw, NyAlesund, Payerne, Potenza, …)

GRUAN MWR instrument survey

Site	MWR	Manufacturer	Since
Barrow, USA	T-WV profiler	Radiometrics	2007
Beltsville, USA	T-WV profiler	Radiometrics	2009
Boulder, USA	??		
Cabauw, Netherlands	T-WV profiler	RPG	2006
Darwin, Australia	??		
Lamont, USA	TCWV-TCLW	Radiometrics	1990
Lauder, New Zealand	??		
La Réunion, France	??		
Lindenberg, Germany	T-WV profiler	Radiometrics	2000
Ny-Ålesund, Norway	T-WV profiler	RPG	
Paris, France	T-WV profiler	RPG	2010
Payerne, Switzerland	T-WV profiler	RPG	
Potenza, Italy	T-WV profiler	Radiometrics	2004
Sodankylä, Finland	??		
Tateno, Japan	??		
Xilin Hot, China	??		

GRUAN MWR Program Guide

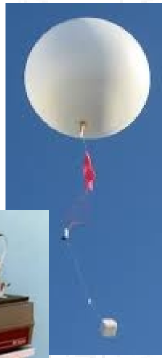
Following the GRUAN Guide (GCOS-171)

STATUS

1.	INTRODUCTION	OK
2.	INSTRUMENTATION	OK
3.	REFERENCE MEASUREMENTS	~OK
4.	MEASUREMENT UNCERTAINTY	in progress
5.	MEASUREMENT SCHEDULING	in progress
6.	DATA MANAGEMENT	NYS
7.	POST-PROCESSING ANALYSIS &FEEDBACK	in progress
8.	QUALITY MANAGEMENT	in progress
9.	SITE ASSESSMENT AND CERTIFICATION	NYS

MWR redundancy

- MWR provide redundant observations (in nearly all weather) wrt:
  - RS (T(z)+WV(z), TCWV)
  - GNSS (TCWV)
  - RL (T(z)+WV(z))
  - AERI (T(z)+WV(z), TCWV, TCLW(< 100 g/m^2))



- MWR were used to demonstrate radiosonde issues
  - RS80 “dry bias” (Turner et al., 2003)
  - VIZ-B2 / GPS Mark II “wet bias” (Mattioli et al., 2008)

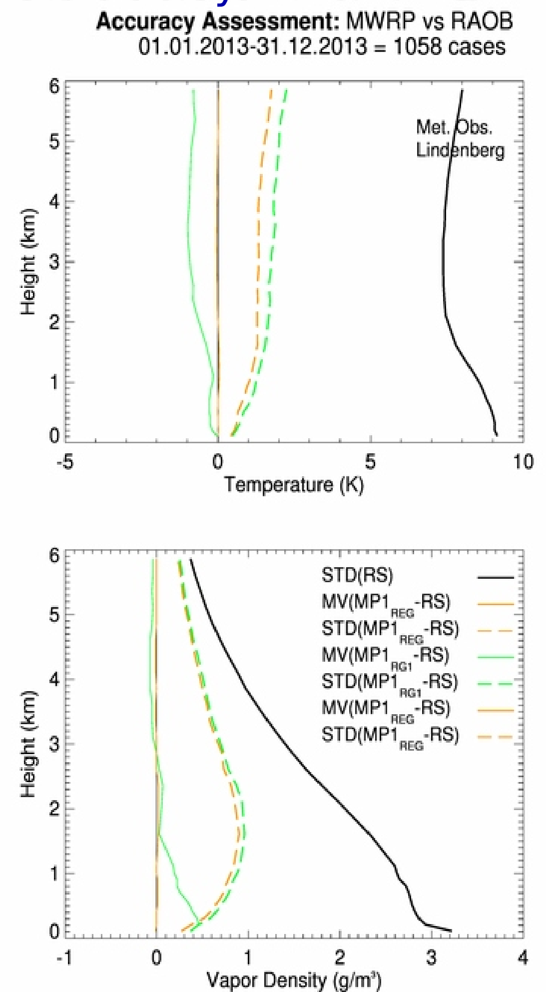
- MWR show the highest redundancy with RS TCWV
  - potential to reduce the RS random uncertainty

(Madonna et al. 2014)

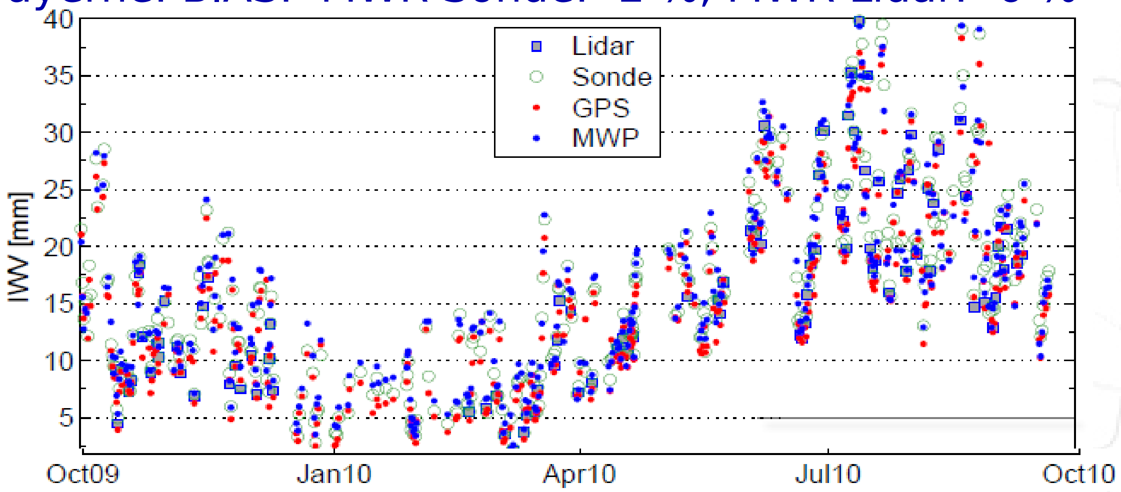
MWR validation

- Validation of MWR measurements is done routinely at some GRUAN sites (Lindenberg, Payerne, Lamont,…)
  - T(z) & WV(z) wrt to RS
  - TCWV wrt RS / GNSS / RL
  - Mean, STD, RMS differences are taken as estimates of measurement uncertainty

Lindenberg:
Yearly assessment



Payerne: BIAS: MWR-Sonde: -2 %; MWR-Lidar: -6 %



MWR calibration & maintenance

Quality measurements require proper calibration and maintenance

Good example:

- ARM (Liljegren, 1998; Cadeddu et al., 2013)
  - Automated calibration
  - Consistent throughout the network
  - Centralized processing
  - **NB:** Just for low-opacity channels

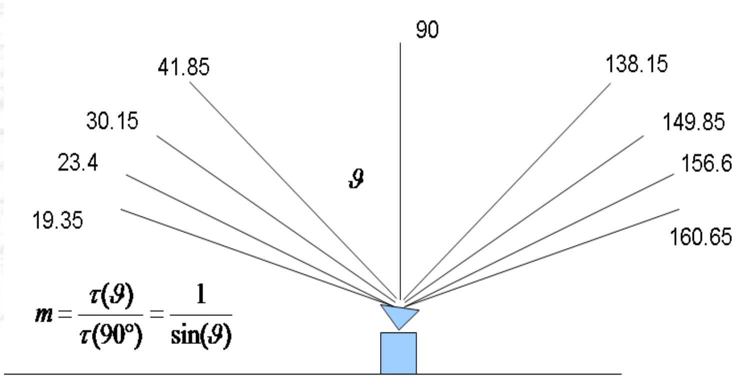
MWR calibration

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

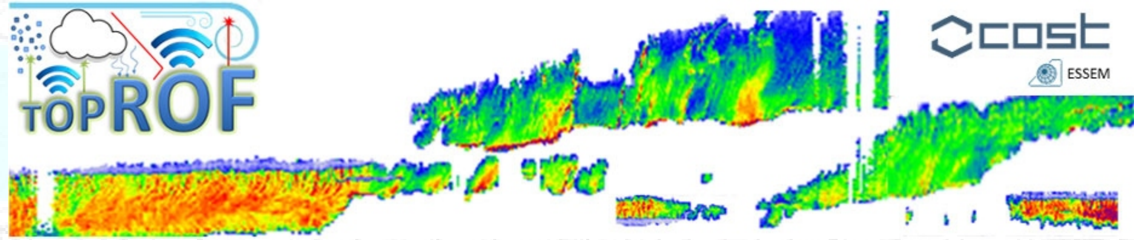
- Gain calibration (2-4 cal points)
  - very frequently (secs) with noise doide sources
- High-emissivity black-body (BB) targets (1-2 cal points)
  - 1 or 2 external BB targets at T_{hot} and T_{cold}
    - Tight temperature control
- Tipping curve (aka: sky dip) (1 cal point)
  - airmass-opacity relationship
- Cryogenic calibration (1 cal point)
  - BB target in liquid nitrogen (LN2) cryogenic bath

MWR calibration

- Calibration poses some practical difficulties
- Tipping curve
  - Applicable to low-opacity channels only (e.g. 20-30 GHz)
  - Side-views may be partially obstructed
  - Clear-sky (not always available)



- Cryogenic calibration
  - Safety and training issues
  - LN2 not easily available everywhere
  - No standard procedure



J-CAL

- Joint Calibration Experiment (J-CAL, Lindenberg 25-29 August 2014)
  - EU COST Action TOPROF (Towards Operational Profiling…)
  - Five MWR within 10 meters

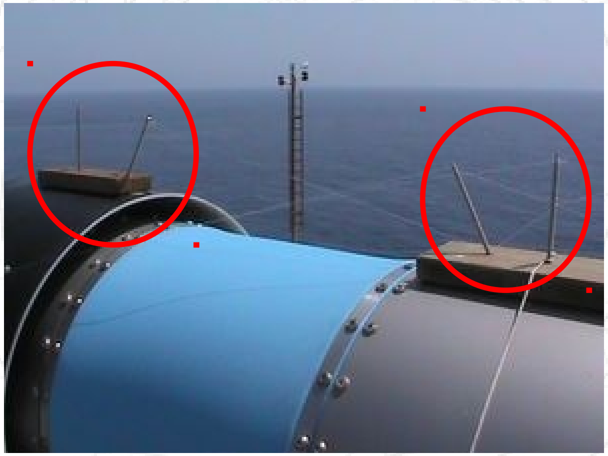
- Objectives:
  - Develop standard protocols for optimum LN2 calibration
  - Chararacterize the LN2 calibration
    - repeatability, stability, and random uncertainty

- J-CAL report is expected soon (Pospichal and Güldner)

- JCAL2 is scheduled for Summer 2015

MWR maintainance

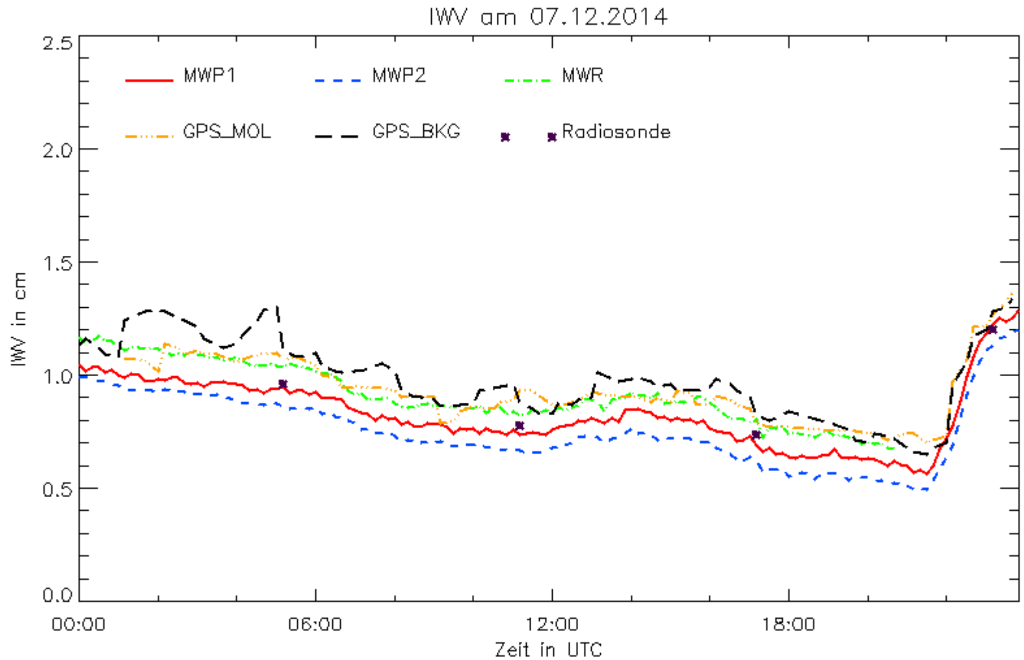
- Robust hardware, long life-time
- Need to keep liquid water off of the radome
  - Rain/dew mitigation
- Radome must be kept clean and unharmed
  - Routine services
    - depending upon environment conditi
      - dirt, sand, dust
  - Replacement every 6-12 months

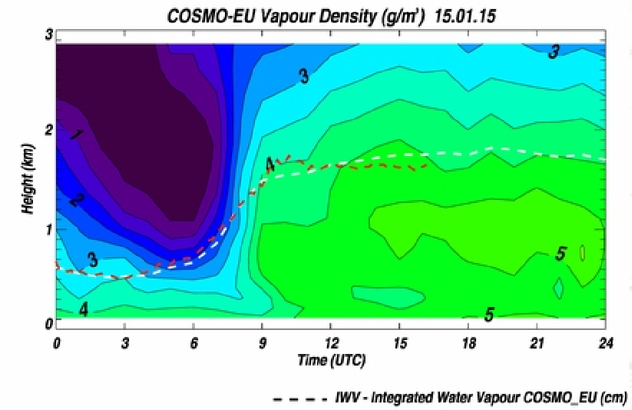


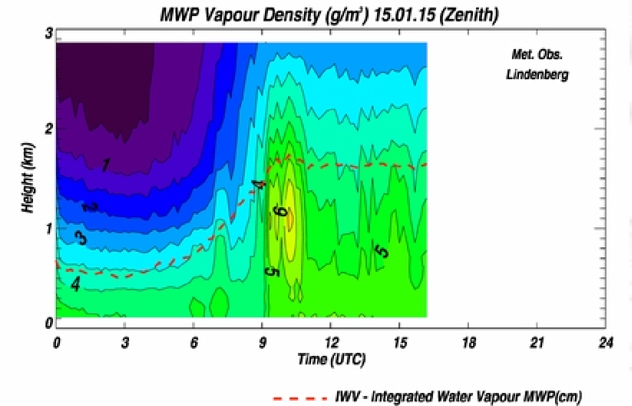
MWR data quality management

- Qualty flags are provided automatically
  - Internal sanity checks → Metadata
  - Wet/dirty radome (rain sensor) → Metadata

- Automated quality control is available at some GRUAN sites, e.g. Lindenberg wrt RS, GNSS, and model (Güldner, 2013)







Managing MWR change

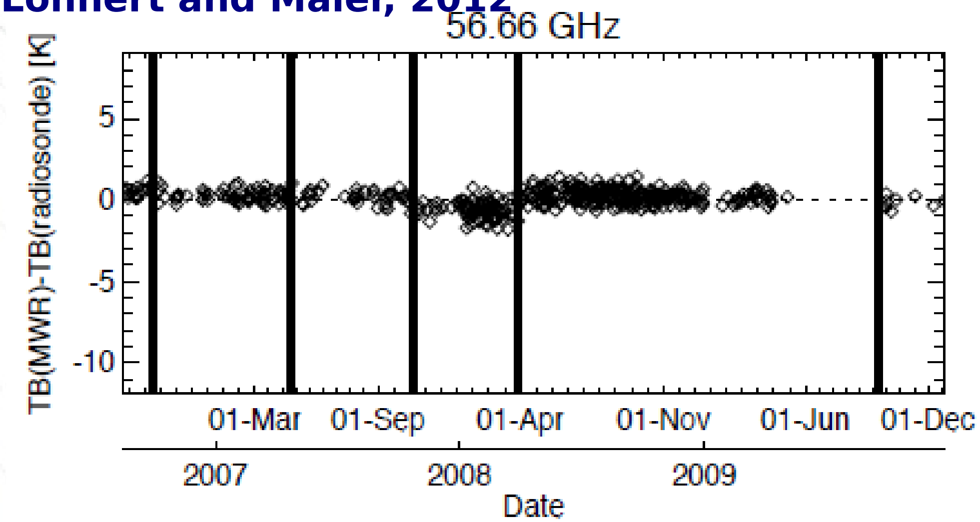
- Tb computed from RS (Turner et al., 2007; Löhnert and Maier, 2012)

- New instruments
  - Parallel operation old+new MWR
  - ~1 year

- Environment
  - side views must be clear (→pics)
  - RFI should be monitored (→SA?)

Lindenberg, courtesy of Jürgen Güldner, DWD

Löhnert and Maier, 2012



MWR data management

- Data format
  - NetCDF compliant with Climate and Forecast convention (discussed and agreed within MWRnet)
  - A suitable data format has been organized in the framework of the German HD(CP)2 Project
    - MWR data in Cabauw and Lindenberg (as well as other non-GRUAN sites) are already processed based on this
- Metadata
  - Additional metadata need be agreed and added
    - Calibration
    - Operator
    - Environment
    - …

Reference Measurements

But is MWR a “reference”?

“**Reference**” requirements for GRUAN:

- Tied to a traceable standard ??
- Determined uncertainty (including corrections) ??
- Documented and accessible procedure OK

Reference Measurements

Traceability

- Calibration relies on high-emissivity black-body (BB) targets

- Two BB targets are at Cold and Warm temperatures
  - Traceability is partly given by
    - certified temperature measurements (Warm)
    - LN2 boiling temperature (Cold)

- Currently there are no MW SI standards
  - U.S. NIST is working on this (Walker, 2011; Gu et al., 2012a)
  - NIST expects to be able to provide (next few years)
    - SI-traceable Tb calibration for BB targets
    - transfer standards in the form of calibrated BB targets

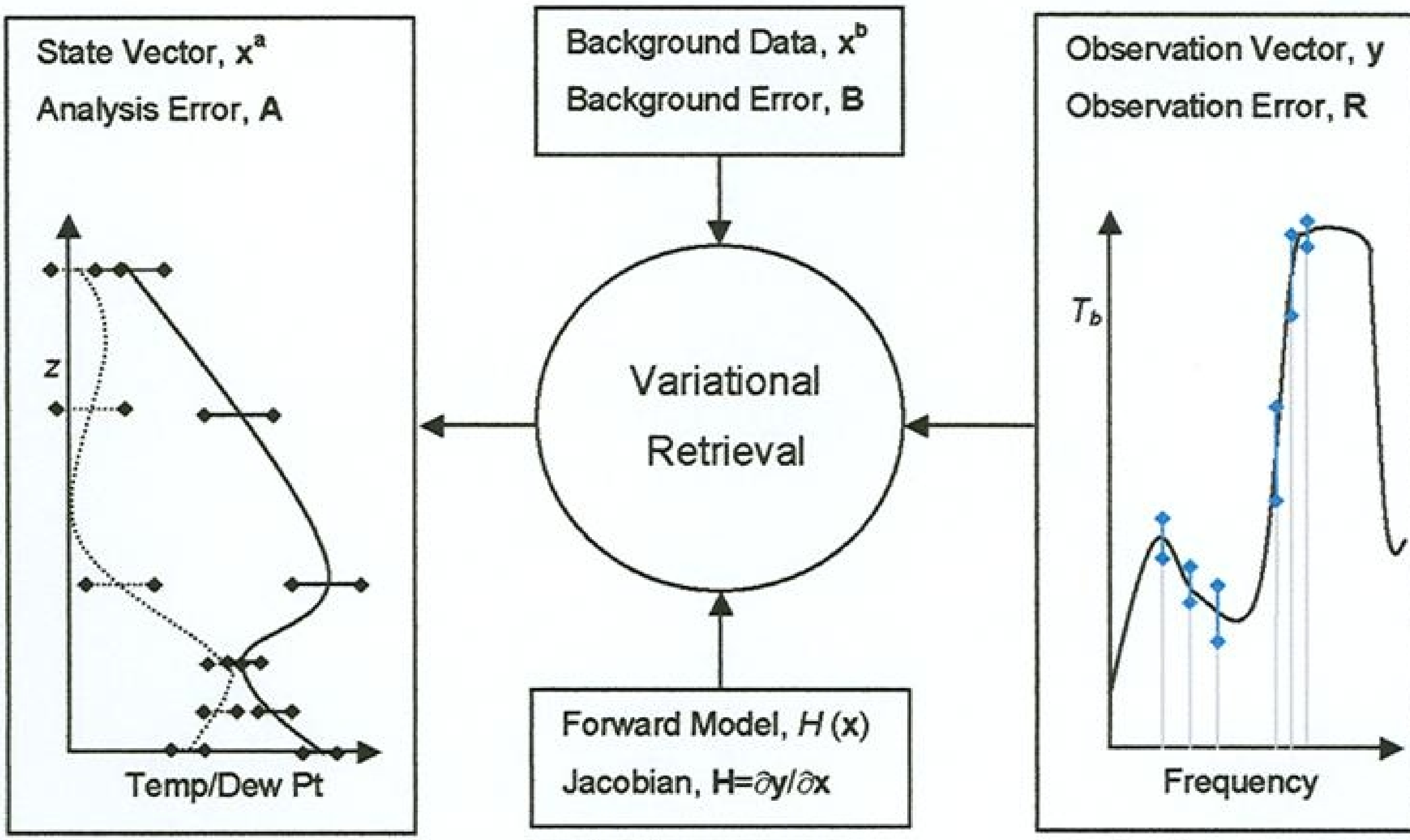
MWR measurement uncertainty

- Evaluating
  - Info are available but need to be generalized
    - e.g. Maschwitz et al., 2013
  - Calibration uncertainties
  - Retrieval uncertainties
    - *A priori*
    - Inversion method
    - Absorption model
      - WV, Oxygen, and super-cooled water
- Reporting
  - Metadata
- Validating
  - Check consistency with radiosonde

Issues to be addressed in TOPROF and GAIA-CLIM

MWR measurement uncertainty

- Optimal estimation may be used to produce retrieval uncertainty

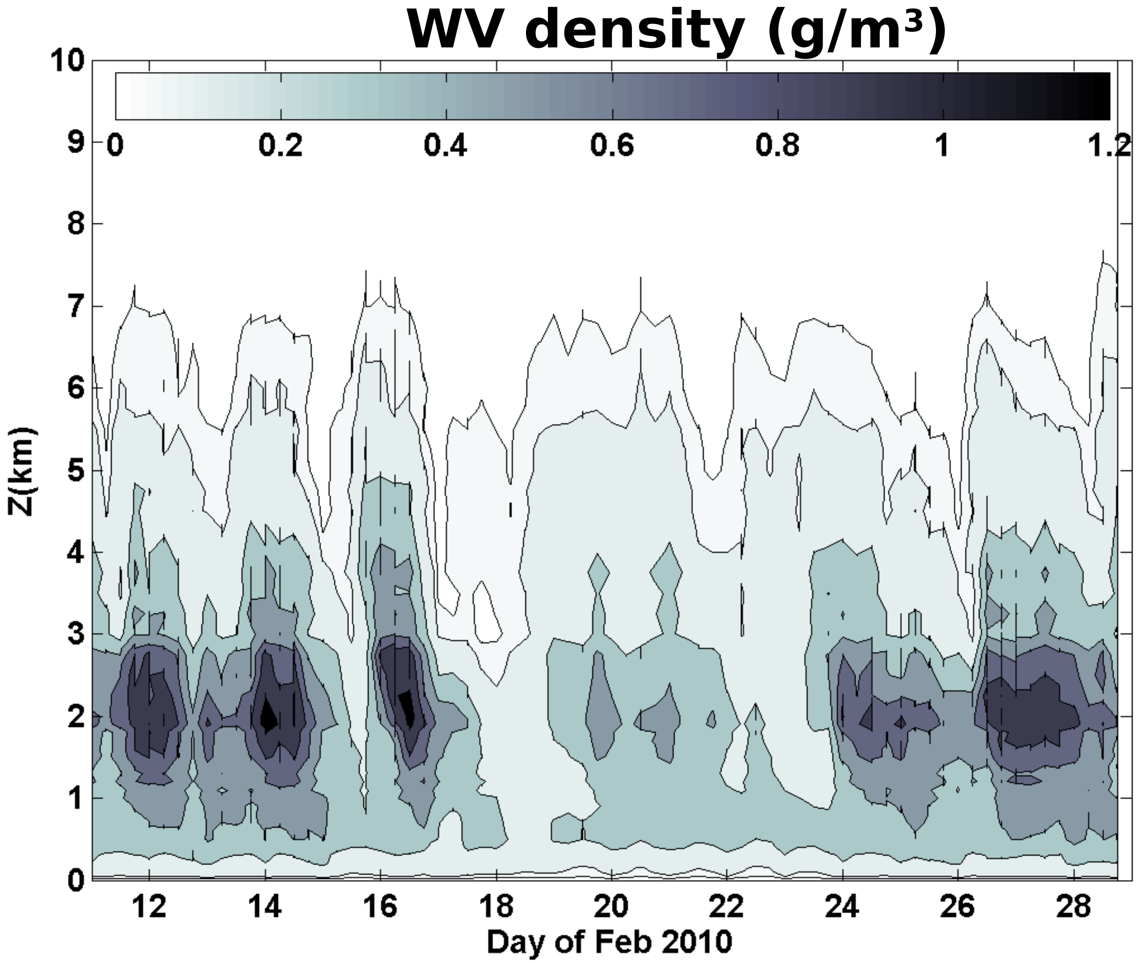


[After Hewison, 2006

MWR measurement uncertainty

Framework already available (Löhnert et al., 2009; Cimini et al., 2011)

- e.g. estimated uncertainty for WV retrievals



MWR activities in Payerne/Bern

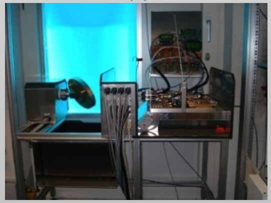
- Contribution from Nik Kämpfer, Fran Navas-Guzmán (IAP-UniBern) and Alexander Haefele (MeteoSwiss)
  - Temperature intercomparison campaign
    - RS and 2 MWR
  - Stratospheric temperature intercomparison
    - RS, GB MWR, SAT MWR

Temperature intercomparison campaign

Payerne (Switzerland)

Meteoswiss station (Payerne)

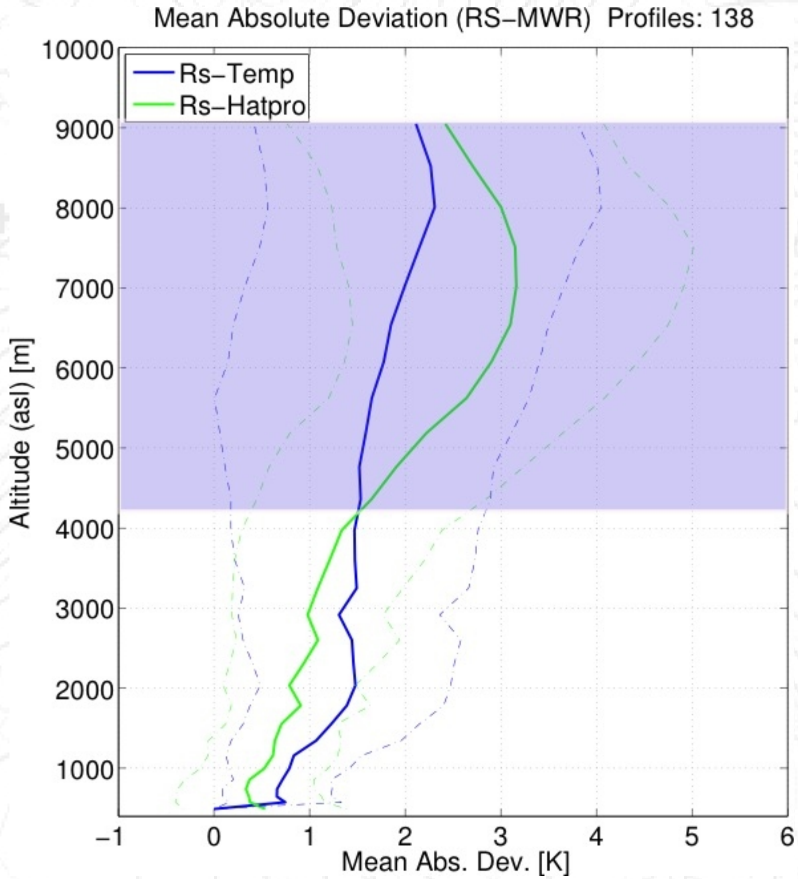
HATPRO (RPG)



TEMPERA radiometer (Univ. of Bern)

Radiosondes

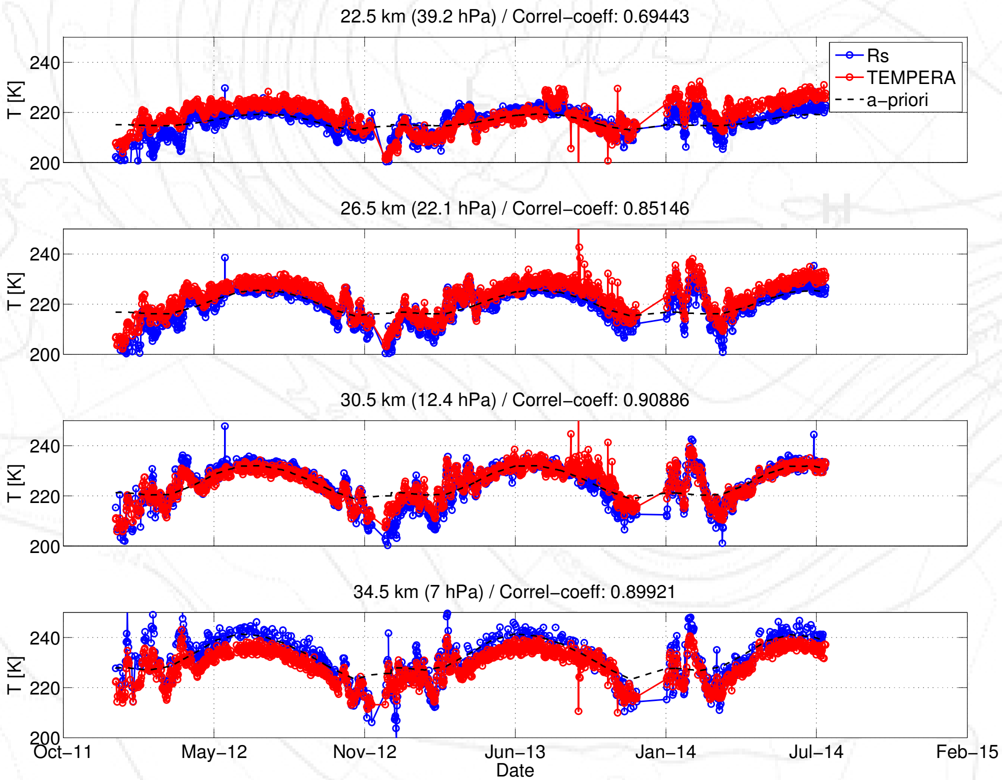
Mean Absolute Deviation (RS-MWRs)

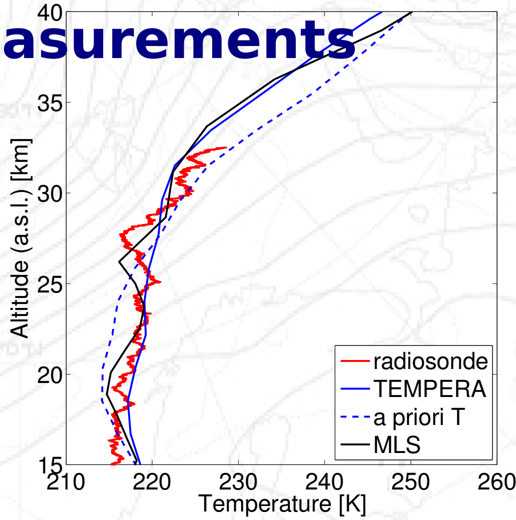


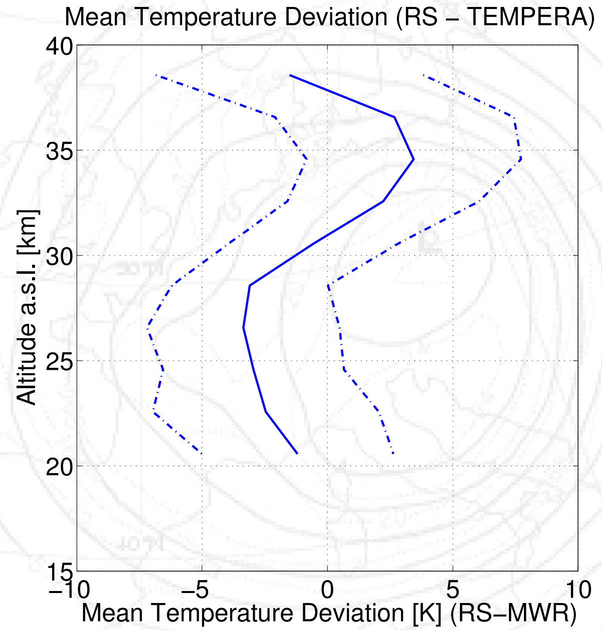
- Very good agreement in the PBL for both radiometers (< 0.7 K)
- Better results for HATPRO in the near range (< 4 km)
- TEMPERA shows a better agreement for the far range

Stratospheric temperature profiles

3 years of stratospheric temperature measurements







Good agreement is observed between RS, ground-based (TEMPERA) and satellite (MLS) MWR

Summary and conclusions

- MWR measurements are valuable for GRUAN
  - Redundant (T(z) & WV(z), TCWV)
  - Complementary (high temporal res., diurnal cycle)
  - Supplementary (TCLW)
- MWR uncertainty needs to be worked out properly
  - GAIA-CLIM & TOPROF
- MWR treaceability needs a breakthrough
  - NIST is working on that

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