# GATNDOR: Topic 3

**Title: Quantifying the Value of Complementary Observations**

**Research Question:** How much is measurement uncertainty reduced by having redundant or complementary measurements of a given variable?

***"..... reducing uncertainty does not necessarily mean to have smaller errors, but also to improve the knowledge of these uncertainties......."***

The quantification of the value added by complementary observations will be assessed with respect to the following issues:

1. Sensor calibration/inter-calibration (here the ARM Value Added Products could be considered as a model)
2. Identification of possible biases
3. Representativeness of measurements
4. Quality control/assurance with a focus on instrument performance in different meteorological conditions.

**Team Lead:** Fabio Madonna

**Collaborators:** Nico Cimini (Potenza), CIAO scientific staff, Seth Gutman (NOAA), Rigel Kivi (FMI),

**Project start:** July 2010

# GATNDOR: Topic 3

Before March 2011 (ICM-3) the following items will be provided:

- summary of the detailed review of the relevant literature for the topic
- statistics from intercomparison of co-located measurements
- preliminary frame of the sensor calibration/inter-calibration procedure for reducing uncertainty

# Outline

- MW profiler and lidar
- Uncertainty: representativeness error
- Sensor intercalibration (preliminary)
- Remarks
- Towards ICM-4

# GATNDOR: Topic 3

Start sites for the analysis: Potenza, Lindenberg, Boulder

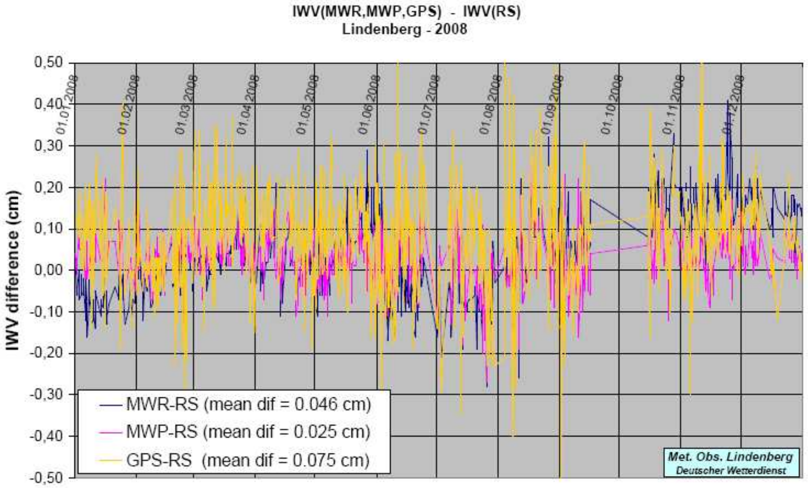
Instruments:

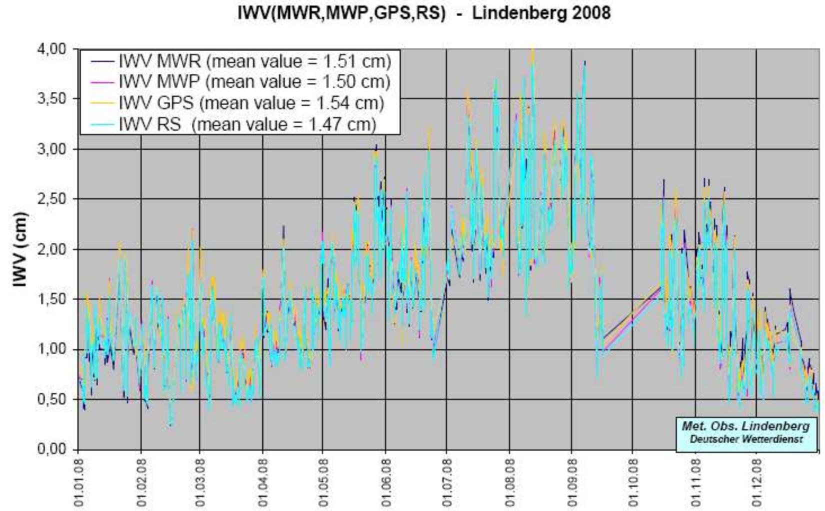
•Temperature (T): Radiosonde (RS), Microwave radiometer (MWR)

To be considered in the future Radio acoustic sounding system (RASS) and/or Meteorological Tower, only if low-level information could help also the provision of high-resolution T profiles in the upper troposphere.

•Humidity: RS, MWR, Raman lidar, GPS (same thing as for Meteorological Tower)

# Lindenberg records

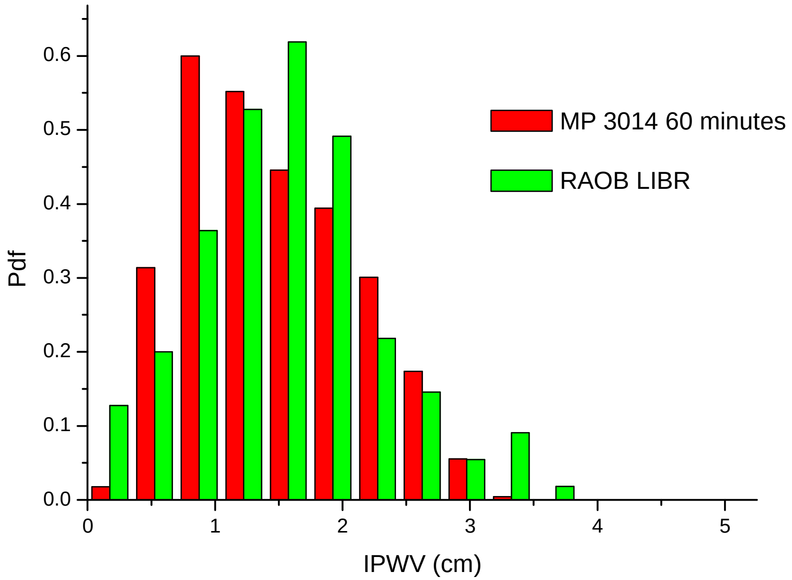


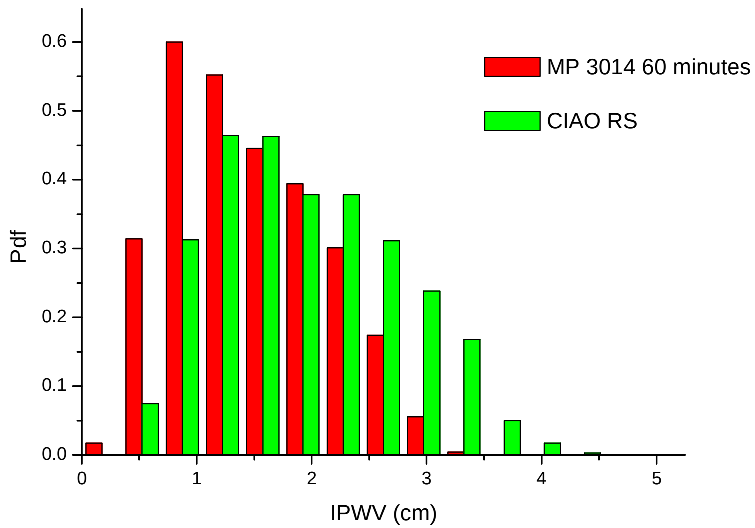




Courtesy of Juergen Gueldner (DWD MOL-RAO)

- Main focus of MWP is directed to look at potentials for weather forecast in a network.
- More important to measure with best estimate and possibly biasfree.
- Retrieval operators fitted or trained to other observations (radiosondes or a model).
- MWP reflects the climate trends of the radiosondes.
- Physical model based on Radiative transfer model (RAOB independent)
- Further issues: meteorological conditions
- Redundancy: OK

# Statistics IPWV



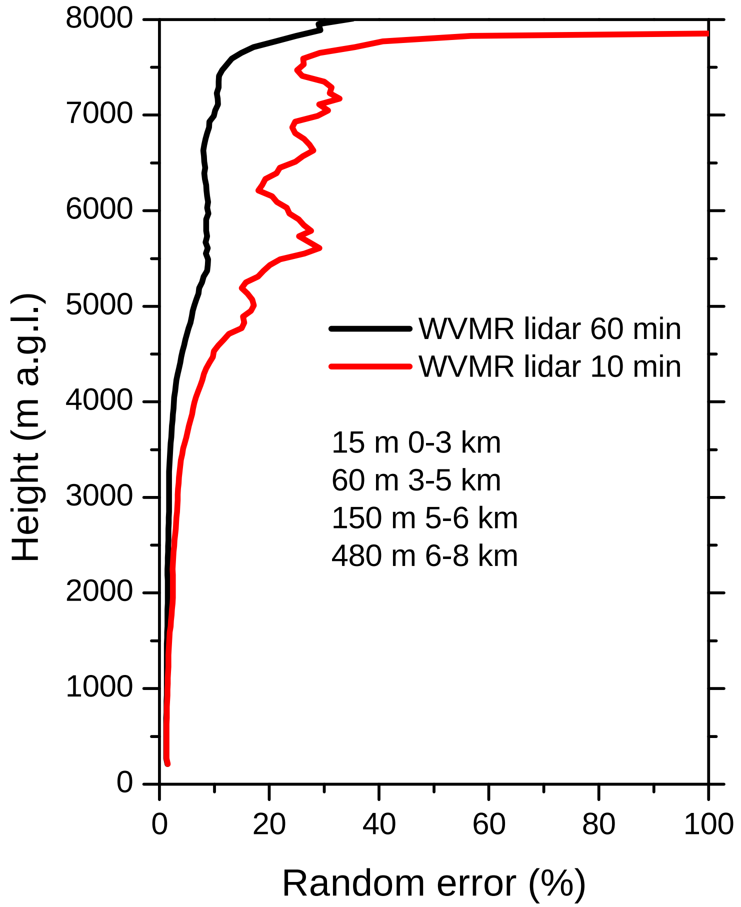




| Sensor | Center | Width |
|---|---|---|
| MP3014 | 1.3779 | 1.2993 |
| RAOB LIBR | 1.8385 | 1.8907 |
| CIAO RS | 1.4968 | 1.1936 |

# Accuracy of complementary measurements vs GRUAN

• Water vapour mixing ratio profile for GRUAN (2% along the whole profile)

- Random errors
- Calibration errors
- Others (aerosol, instrumental effects …)




• MW IWV for GRUAN (1% for colum content)

Example:
Cadeddu et al., 2007
Hewison, PhD, 2007
Crewell et al., 2003
……..

Accuracy (RMS deviation)
No random and calibration errors

Cadeddu et al., 2007 < 10% for neural retrievals (including random, calibration, other erorr sources)

In MWRnet the provision of error will be mandatory

# Uncertainty

As a whole the total uncertainty of a remote-sensing or in situ observation could be figure out as follows (Kitchen, 1989):

$$\Delta E = \sqrt{\Delta r^2 + \Delta s^2 + \Delta t^2 + \Delta i^2}$$

where the first term indicates the observation error, including all the error contributions due to statistical noise, sensor response functions, rounding errors; the second and the third term are related to the observation representativeness due to space and time co-location, respectively. The last term indicates the error related to the model used for comparison with observations.

In case of temperature and humidity the main error sources are related to:

a. statistical (noise)

b. calibration (systematic)

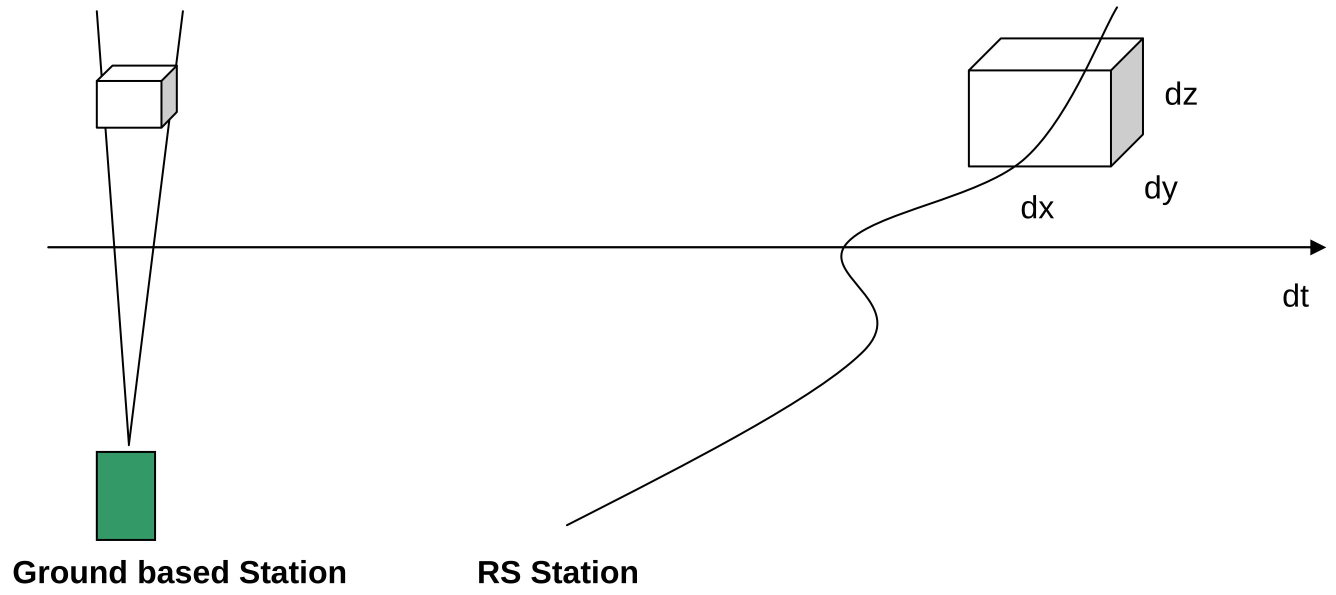
c. representativeness or sampling error

d. model

e. further (RS: solar heating, strong gradients; lidar: extinction, overlap, fluorescence,…..)

# Representativeness (sampling) error - RE

The representativeness is related to the mismatch in the investigated atmospheric volume among different sensors.




**ΔVRS = ΔxRS ΔyRS ΔzRS= ΔzRemoteSensing ΔtRemoteSensing = ΔVRemoteSensing**

If **ΔzRS** = **ΔzRemoteSensing** then:

**ΔVRS = ΔxRS ΔyRS = ΔtRemoteSensing = ΔVRemoteSensing**

**ΔxRS ΔyRS - ΔtRemoteSensing** represents RE of RS respect to the considered remote sensing technique.

# Representativeness (sampling) error - RE

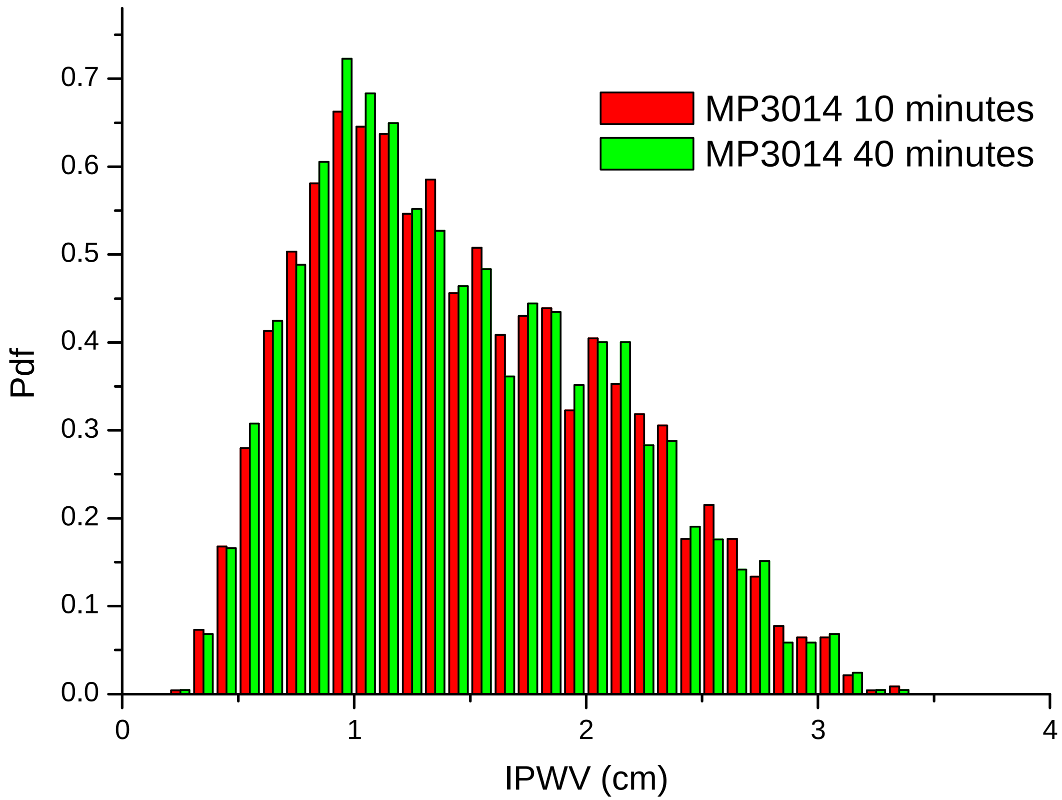
- RE contribution to error budget to be quantified and considered when coupling two remote sensing observers with different instrumental features, e.g. field-of-view, pointing angle, etc.

- Its contribution can largely exceed the contribution related to the observation error, inducing misinterpretation of data resulting from the comparison or combination of different sensors (Kitchen 1989).

- To compare, combine, integrate RS and ground-based remote sensing data, the latter should be spatially and temporally averaged over a domain that minimizes such systematic error sources.

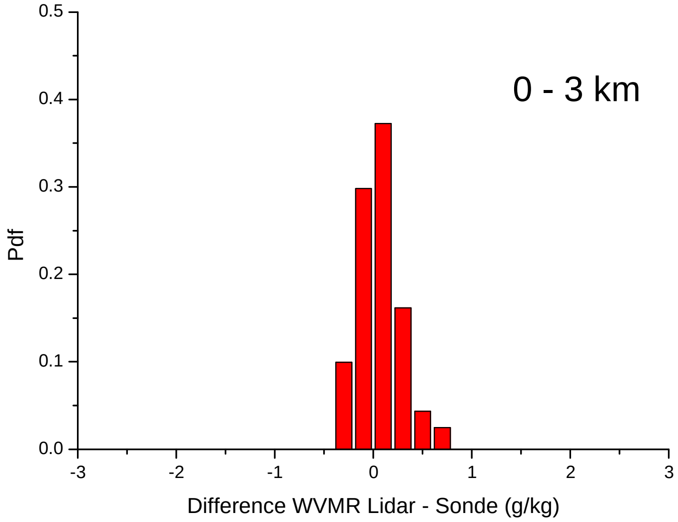
- Two measurements should be representative (in approximation) of the same atmospheric volume

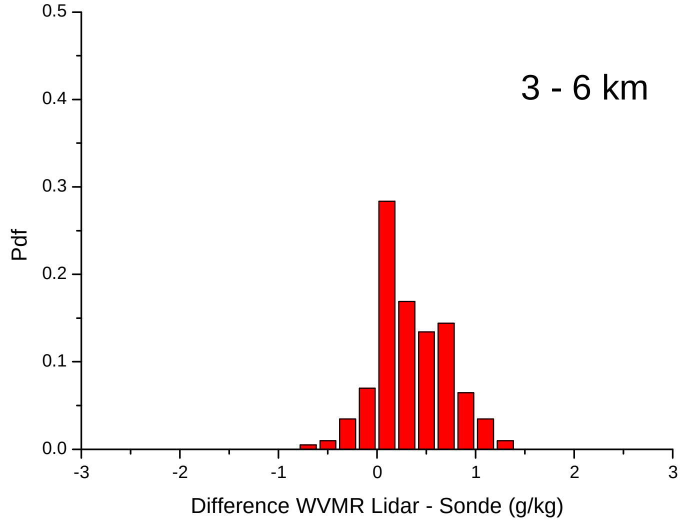
# Statistics IPWV 2004-2005

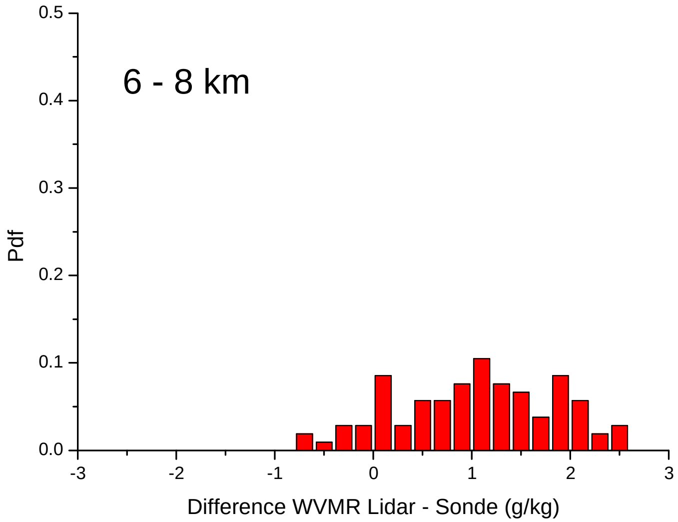



| Sensor | Center | Width |
| --- | --- | --- |
| MWP 10 | 1.3628 | 1.4264 |
| MWP 40 | 1.3437 | 1.4144 |
| RS | 1.5193 | 1.1650 |

# Statistics - LIDAR (2004-2005)




Dt = 10 minutes

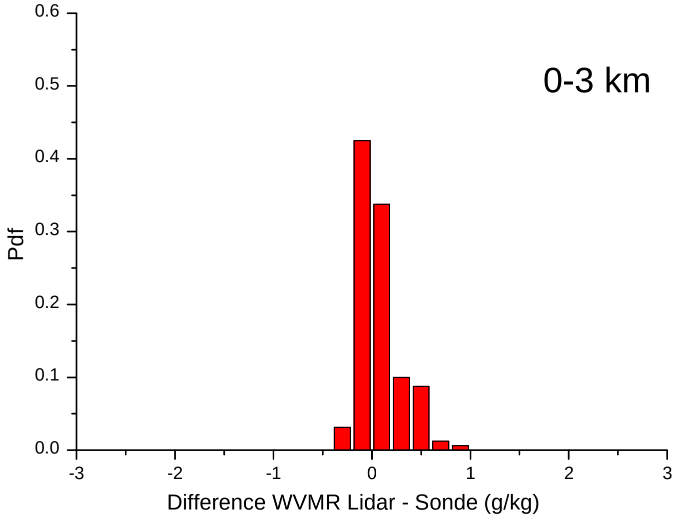
Dz = 15 m 0-3 km

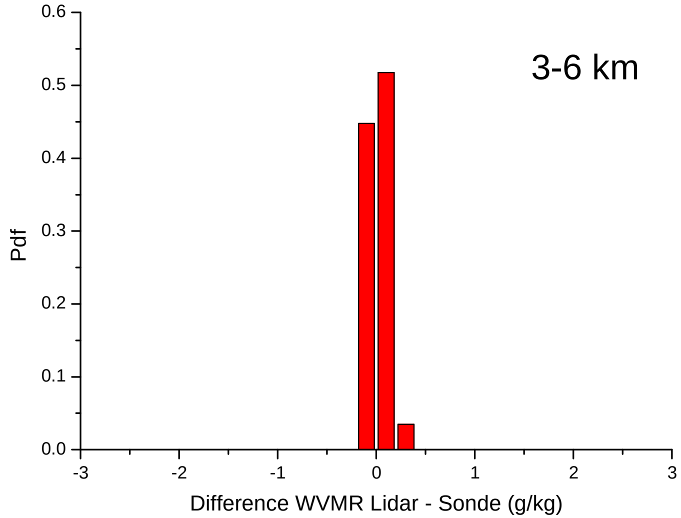
60 m 3-5 km

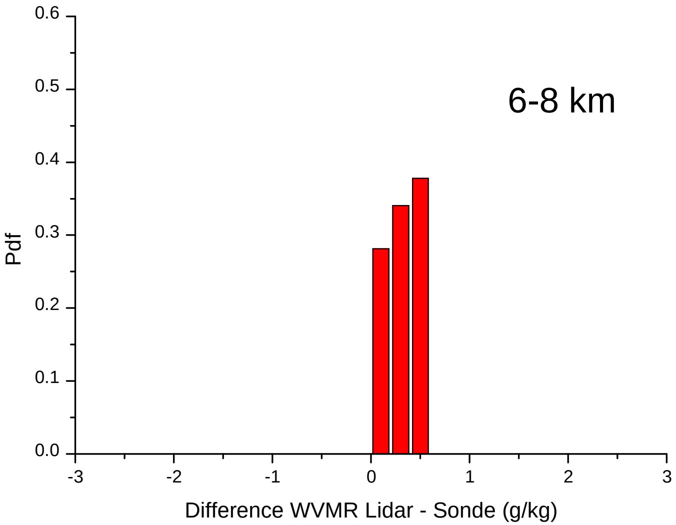
150 m 5-6 km

330 m 6-8 km

# Statistics - LIDAR (2004-2005)




Dt = 40 minutes

Dz = 15 m 0-3 km

60 m 3-5 km

150 m 5-6 km

330 m 6-8 km

# Statistics – LIDAR (2004-2005)

## Gaussian fit Parameters

**40 minutes**

| Range (km) | Center | Width | Offset |
|---|---|---|---|
| 0 - 3 | -0.01362 | 0.24275 | 0.47609 |
| 3 - 6 | 0.013204 | 0.22619 | -0.0941 |
| 6 - 8 | 0.33787 | 0.32503 | -0.1631 |

**10 minutes**

| Range (km) | Center | Width | Offset |
|---|---|---|---|
| 0 - 3 | 0.046341 | 0.38319 | 0.07423 |
| 3 - 6 | 0.28763 | 0.73132 | 0.18708 |
| 6 - 8 | 1.1747 | 1.6293 | -0.0525 |

# Calculating RE

PCA scheme for noise filtering?

- 1° scheme: difference of variabilities assuming zero bias

$$\sqrt{\left(\frac{1}{N-1}\sum_{i=1}^{N}\left(x_i^A-\mu^A\right)^2\right)}-\sqrt{\left(\frac{1}{N-1}\sum_{i=1}^{N}\left(x_i^B-\mu^B\right)^2\right)} \qquad \mu^A=\mu^B$$

- 2° scheme: average over an ensemble (Frehlich and Sharman - 2004) assuming zero bias

$$\sqrt{\left(\frac{1}{N}\sum_{i=1}^{N}\left(x_i^B-x_i^A\right)^2\right)} \qquad x_i^A \approx \mu$$

- 3° scheme: Eurelian and Langrangian

$$\frac{Dq}{Dt}=\frac{dq}{dt}+V*Ax$$

# Calculating RE

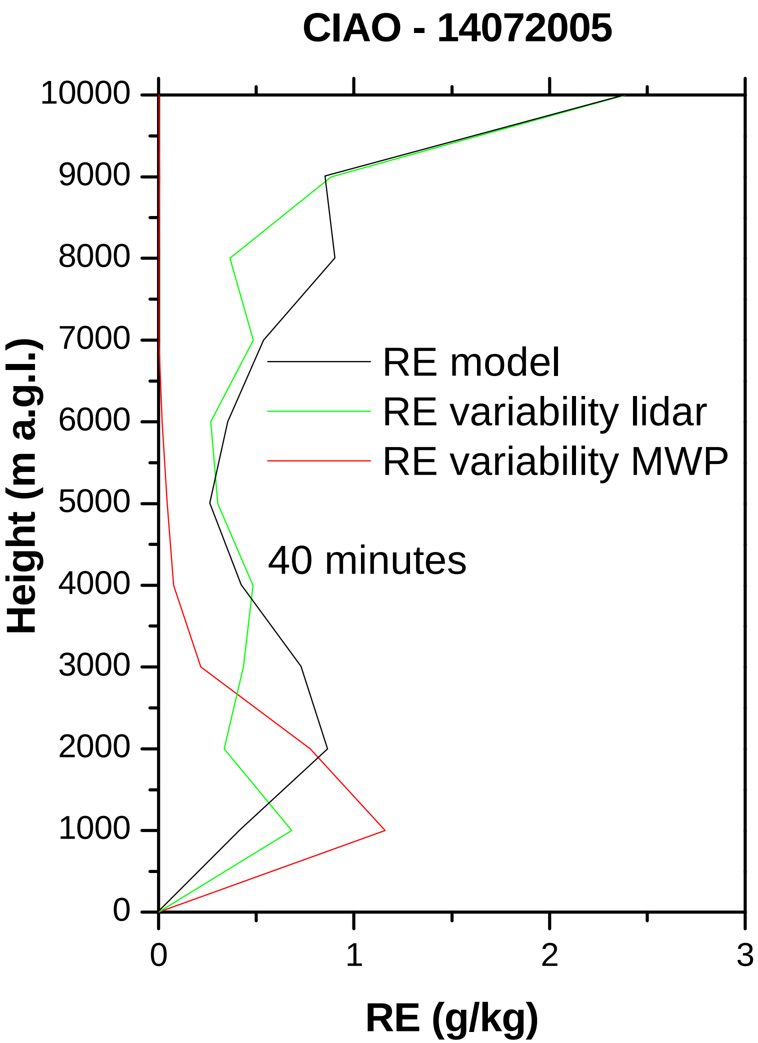
- From Raman Lidar

  Calculating water vapour mixing ratio variability over a certain vertical range and time domain

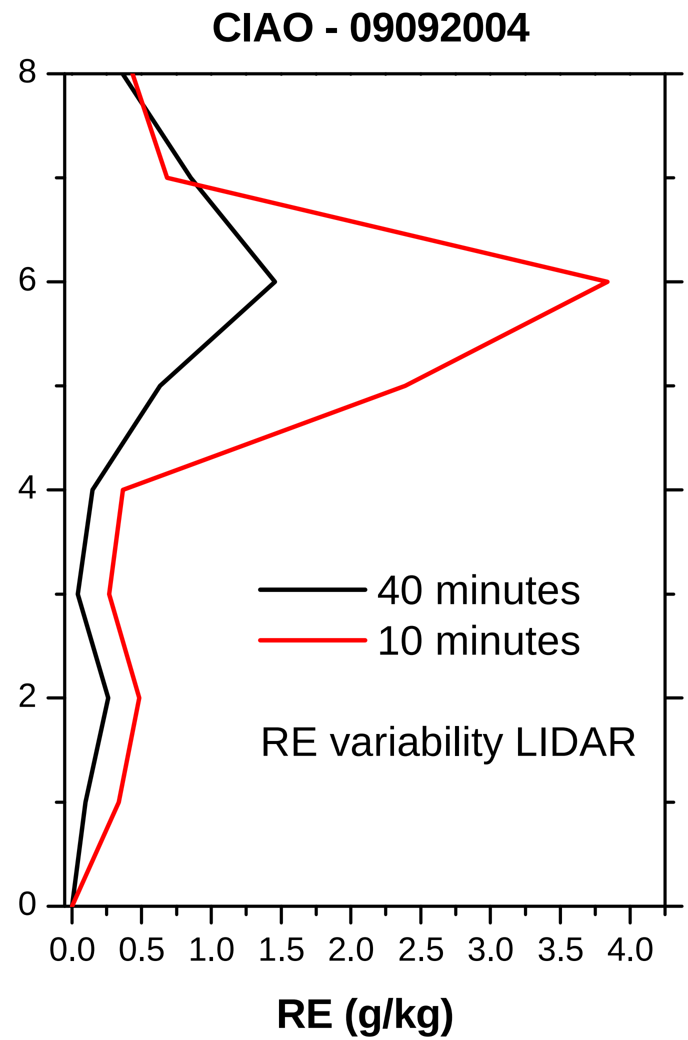
- From MWP

  Considering the IWV (column) and assuming a scale height for water vapour field in a certain time domain

# Comparison



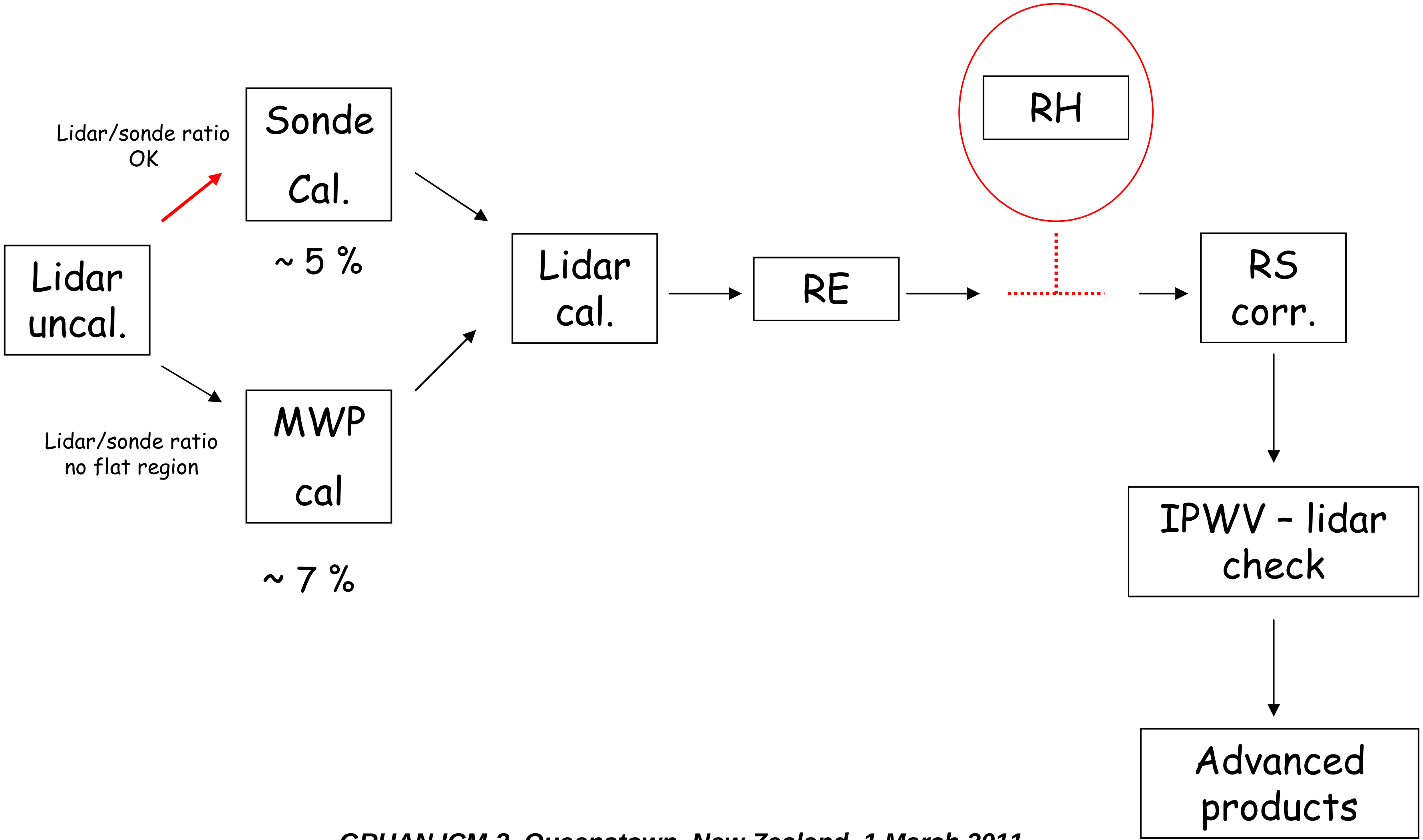
CIAO - 14072005
Height (m a.g.l.)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
1
2
3
RE (g/kg)
RE model
RE variability lidar
RE variability MWP
40 minutes

CIAO - 09092004
8
6
4
2
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
RE (g/kg)
40 minutes
10 minutes
RE variability LIDAR

# Scheme MWP - Lidar - RS

To compare/calibrate/integrate sensors, RE contribution should be reduced by time averaging of ground-based observations (different Δt for different Δz)



# Summary and conclusions

- Representativeness to be considered when two techniques are studied together
- In case of RS, RE is very important for the evaluation of bias identification/correction using ground-based remote sensing
- Preliminary idea for RS - lidar – MW intercalibration provided (to be assessed)

# Towards ICM-4

- More about temperature
- Finalize intercomparison frame
- GPS study for representativeness
- Elaboration of Bayesian approaches for evaluating the impact of different error sources and information content with respect to the required representativeness and sensitivity to climate changes
- Remarks on the possible sensor synergy for increasing the accuracy and reducing the profiling uncertainty will be provided
- Other proposals? Inputs are really welcome
- ACTRIS funds and Research Fellowship

# Summary of relevant literature


- Ferretti, A. Prati, C. Rocca, F., Multibaseline InSAR DEM reconstruction: the wavelet approach, *Geoscience and Remote Sensing, IEEE Transactions on.* On page(s): 705 - 715 , Volume: 37 Issue: 2, Mar 1999.
- Frehlich, R., and R. Sharman, 2004: Estimates of turbulence from numerical weather prediction model output with applications to turbulence diagnosis and data assimilation. Mon. Wea. Rev., 132, 2308–2324.
- Hewison, T., Profiling Temperature and Humidity by Ground-based Microwave Radiometers, University of Reading, PhD Thesis, Department of Meteorology September 2006
- Immler, F. J., Dykema, J., Gardiner, T., Whiteman, D. N., Thorne, P. W., and Vömel, H.: Reference Quality Upper-Air Measurements: guidance for developing GRUAN data products, Atmos. Meas. Tech., 3, 1217-1231, doi:10.5194/amt-3-1217-2010, 2010.
- Kitchen, 1989
- Lorenc, A. C., 1986: Analysis methods for numerical weather prediction, *Q. J. R. Meteorol. Soc., 112*, 1177-1194.
- Wulfmeyer, V., H.-S. Bauer, M. Grzeschik, A. Behrendt, F. Vandenberghe, E. Browell, S. Ismail, R. Ferrare: 4-Dimensional variational assimilation of water vapor differential absorption lidar data. *Monthly Weather Review*, Vol. 134, No. 1, pp. 209-230. Feb. 2006.
- Miloshevic et al., 2009
- Whiteman et al., 2001
- Cadeddu et al., 2009
- Cimini et al., 2007 Meteor. Zeisch.
- Hewison et al., PhD thesis.
- Frehlich et al., 2004.

........


- **Instrument models**
- LIDAR Temperature NDACC
- LIDAR Water vapour NDACC (no database)
- GPS NOAA, Suominet, .....
- MWR to be implemented in MWRnet...campaigns only, see COPS-2007, LAUNCH, LUAMI
- TBC

Thank you

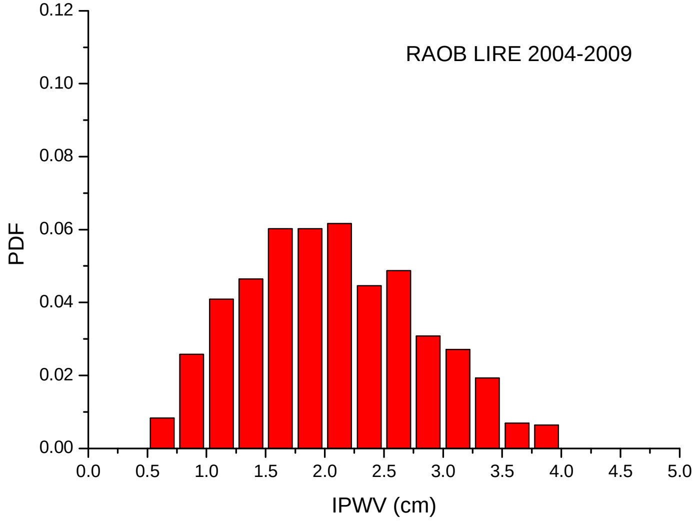
## Further remarks:

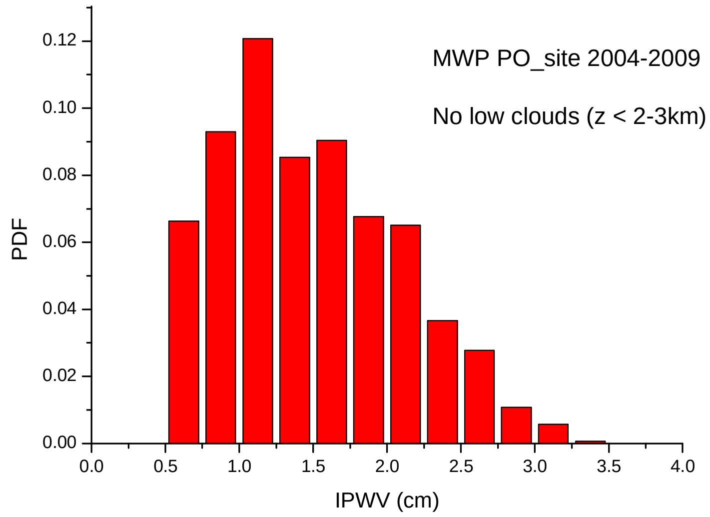
CIMO campaign data are now available for applying and testing the proposed methods/algorithms. CIMO campaign was devoted to a RS intercomparison but includes also several ground-based remote sensing sensors. This database could be considered after the application to dataset collected at the selected GRUAN sites.

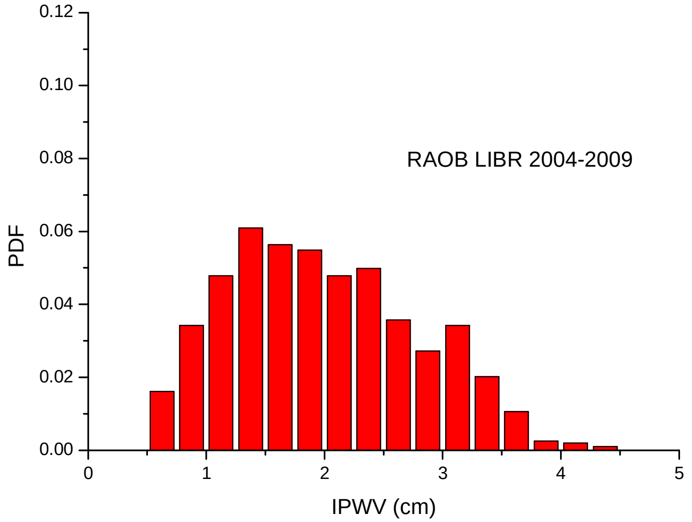
# Concept for an optimal observation platform RS

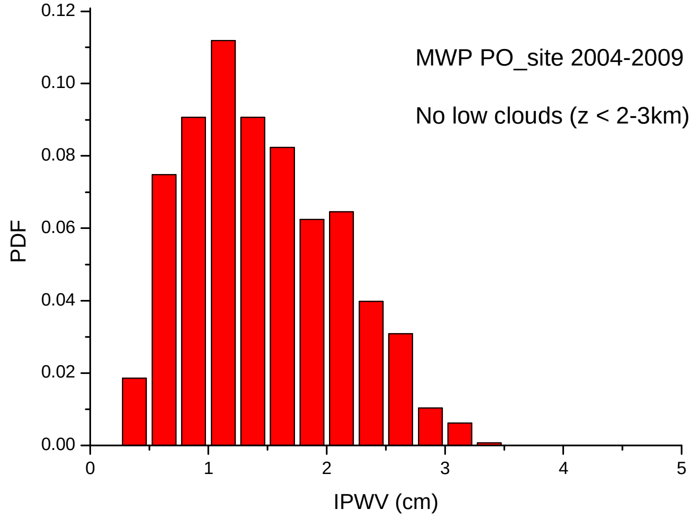
- This item is related to the establishment of a suitable strategy for performing integrated ground based observations and providing the "best" estimation of temperature and humidity over GRUAN sites exploiting sensor synergy.
- Raman lidar (5 min or better)
- Scanning microwave profiler (conical scan 5 minute or less)
- GPS (1 minute or less)
- Similar application with the GPS. Assessment of GPS vs MWR should be further considered
- Other questions for GRUAN community: how to optimally use the instrumental combination for reducing uncertainty? the measurement co-location is mandatory?
- N.B: investigation of the climate coverage of MWP measurements?

# Statistics IPWV

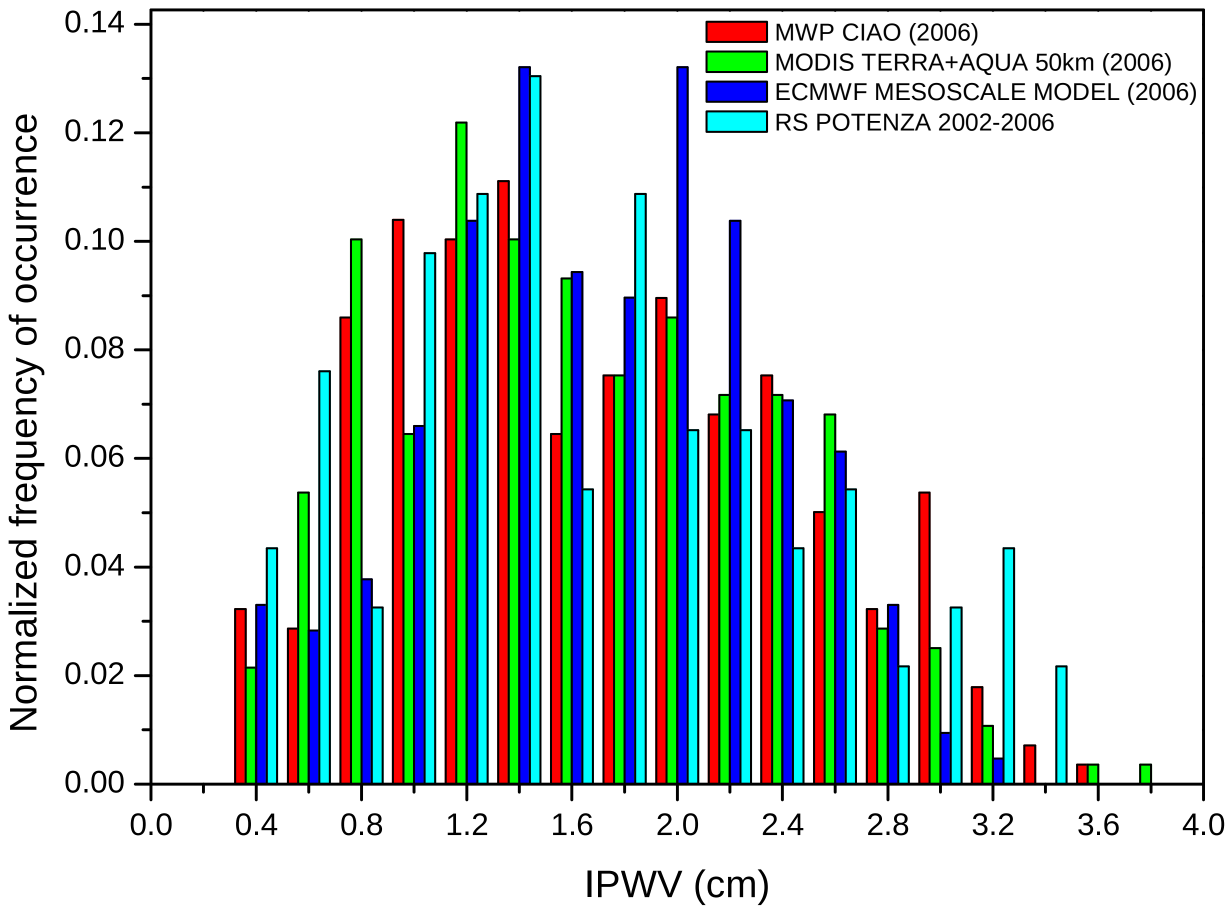


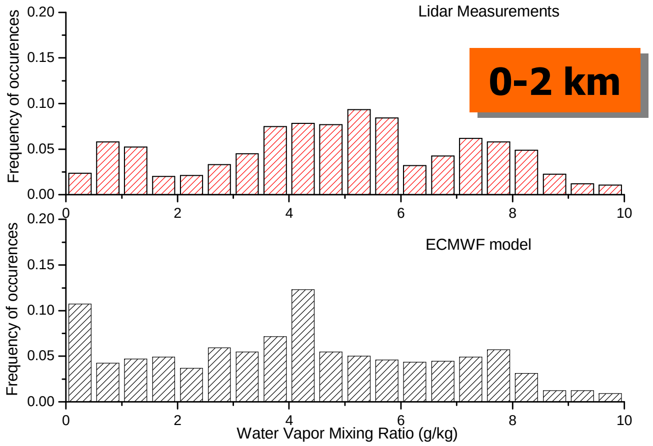



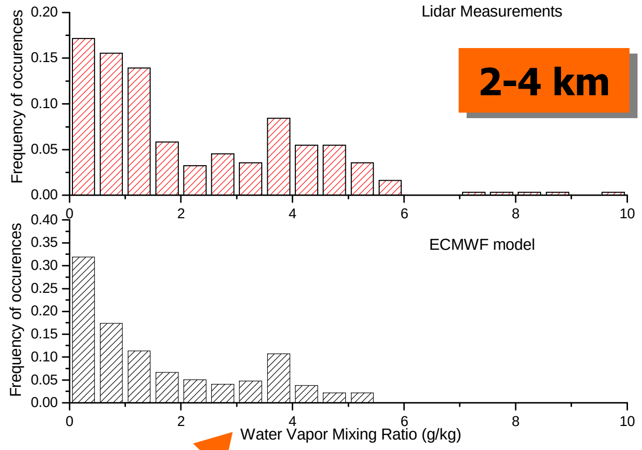
# Trend analysis satellite




2006 cumulative distribution of MWP+MODIS+ECMWF vs 2002-2006 RS distribution

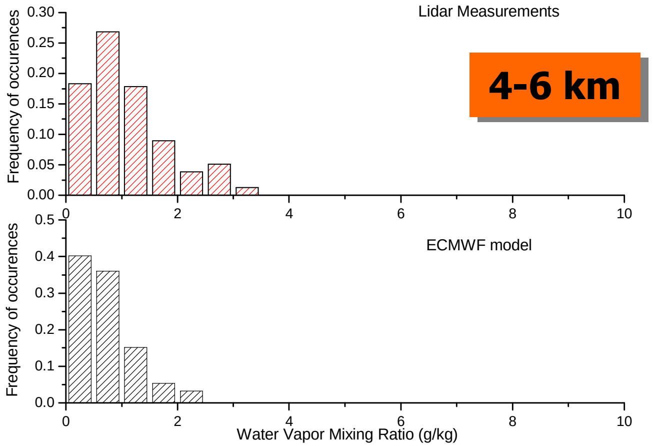
Next: Study of representativeness on a larger spatial domain.

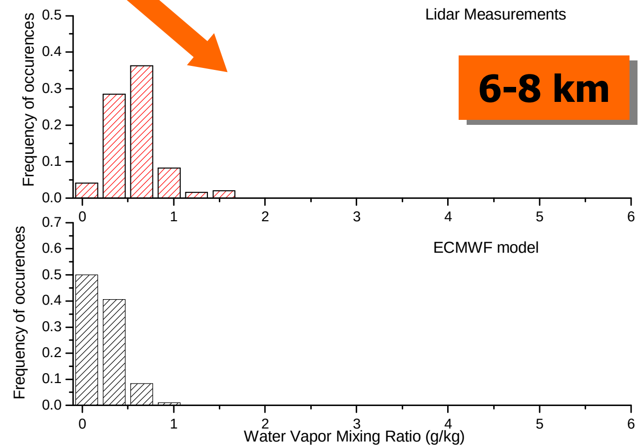



3 modes are sligthly shifted in ECMWF

Higher values occurrences underestimated by ECMWF



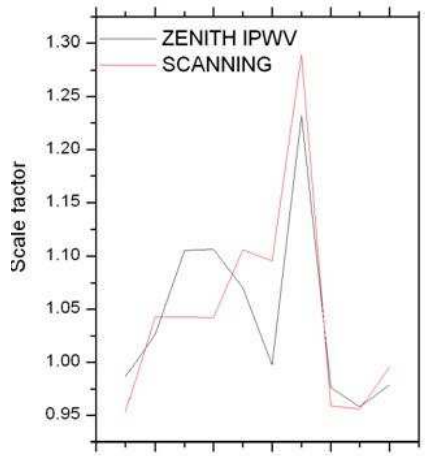
# Trend analysis - LIDAR

# Remarks on data averaging

# Remarks on sat. vap. pressure

# Remarks about scanning measurements

- If scanning measurements are available, scaling of water vapour profiles with the MWR IPWV retrieved considering opposite angles or one-side only angle could be considered. This estimation are representative of a larger horizontal domain and could better fulfil the purpose of calibrating sondes. The IPWV retrieved at opposite angles is useful to detect horizontal trends; the stronger the horizontal trend, the larger will be the RS RE.
- The RS-92 SGP are equipped with a GPS signal that allows us to better select the angles to be considered in the microwave retrieval according to the wind speed and, therefore, the RS flight direction. Moreover, recent improvements in microwave retrieval including scanning measurements increases the reliability of the IPWV retrieval using also scanning Tbs.
- However, the slant IPWV is sensitive to the lower levels, where is most of WV; RS might not have travelled through these levels even if these levels are lined on the MWP-RS line-of-sight. A possible solution could be to perform a conical scan of the atmosphere centred around the direction axis followed by the RS during the flight. The aperture of the scan will be defined after (EMERGE community could strongly contribute to define possible solution). A first proposal could be to perform a conical scan over an aperture of +/-15° respect to th e RS flight direction.




- 06/09 07/09 08/09 09/09 10/09
- Figure 3: comparison of the scale factor retrieved according to the ARM LSSONDE algorithm for calibrating radiosonde water vapour profiles using the IPWV retrieved by a microwave radiometer considering zenith only and scanning Tbs respectively. The comparison is relative to a set of 10 sondes launched in Sep. 2004.

# Remarks on the error propagation

- Analytical or numerical methods?

**Extinction calculated by SLIDING LINEAR FIT**

$$\ln\left[\frac{N(z)}{z^2P(z)}\right] = A + Bz$$

**so that it is simple to calculate the derivative in the formula.**

**The ANALYTICAL error is:**

$$\Delta\alpha_{aer}(\lambda_0, z) = \frac{\Delta B}{1+\left(\frac{\lambda_0}{\lambda_R}\right)^k}$$

Fallo per il WV