QUANTIFYING THE VALUE OF REDUNDANT MEASUREMENTS AT GRUAN SITES

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Rationale

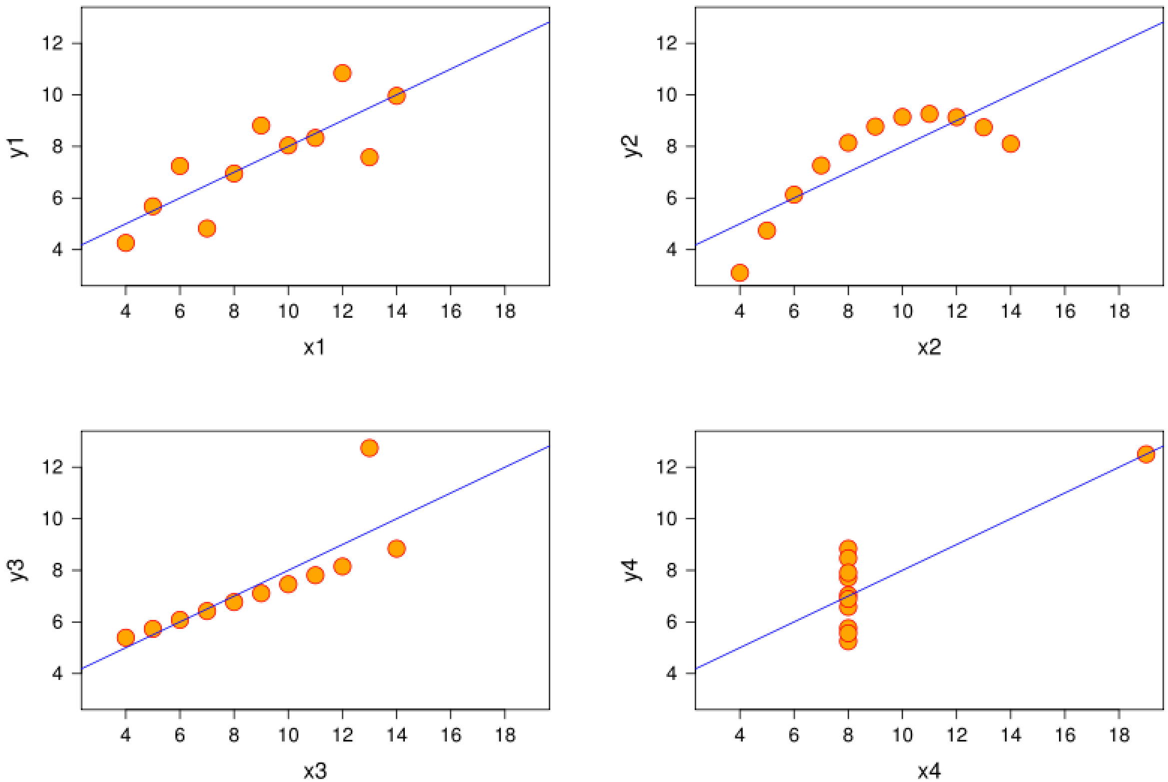
It is undoubted that redundant measurements provide an added value with advantages that are related to:

- Increasing the sampling rate
- Exploiting instrument synergy
- Improving continuity
- Evaluating the quality of the retrievals by looking for consistency

OBJECTIVE: The aim of the topic is to find the best combination of instruments that can lead to those three goals and you use MC to achieve that.

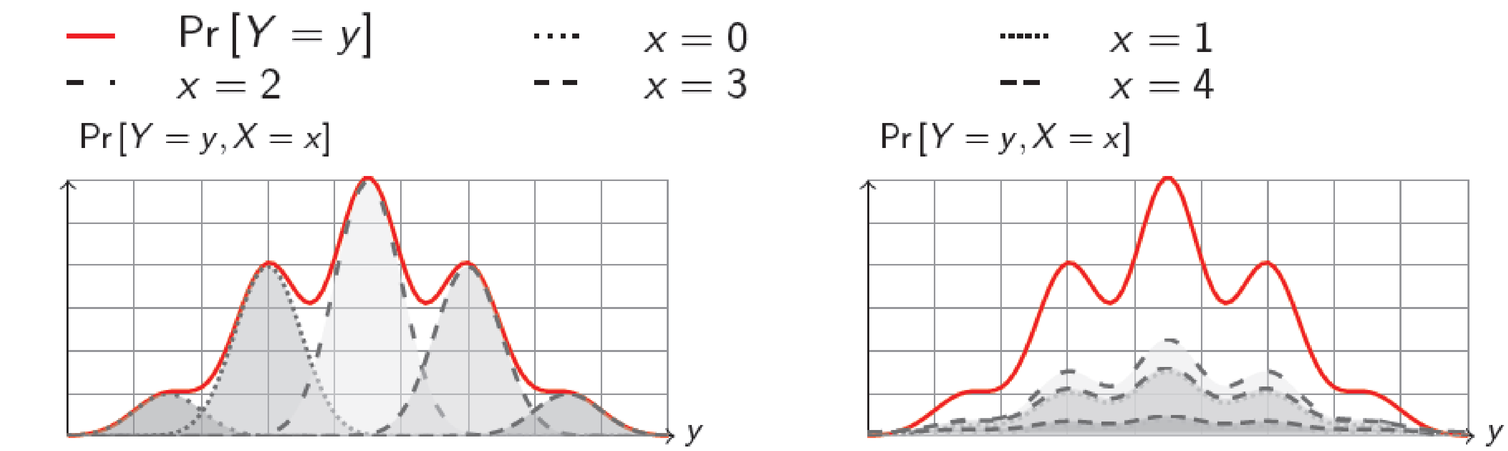
How to quantify redundancy?

Pearson's correlation coefficient : the strength of a linear relationship between two variables with random distribution; not be sufficient if linear assumptions are not valid.



The image below shows scatterplots of Anscombe's quartet, a set of four different pairs of variables created by Francis Anscombe. The four y variables have the same mean (7.5), standard deviation (4.12), correlation coefficient (0.81) and regression line (y = 3 + 0.5x). From Wikipedia.

Outliers



$X_0 =$

0	1	2	3	4
y_0	y_1	y_3	y_7	y_{15}
$\dots$	y_2	y_5	y_{11}	$\dots$
	y_4	y_6	y_{13}	
	y_8	y_9	y_{14}	
	$\dots$	y_{10}	$\dots$	
		y_{12}		
		$\dots$		

$X_1 =$

0	1	2	3	4
y_7	y_0	y_1	y_5	y_6
$\dots$	y_2	y_3	y_8	$\dots$
	y_{13}	y_4	y_{10}	
	y_{15}	y_9	y_{12}	
	$\dots$	y_{11}	$\dots$	
		y_{14}		
		$\dots$		

NEED FOR A RELIABLE METRIC OF REDUNDANT MEASUREMENTS

Entropy

Following the definition of entropy in thermodynamics, given n events occurring with probabilities $p_1 \ldots\ldots p_n$ the **Shannon entropy** is defined as:

$$H(X) = -\sum_{x \in X} p(X) \log(p(X))$$

Therefore, H is a measure of probabilistic uncertainty or dispersion of the probabilities of events. The entropy is calculated from a **histogram** in which the probabilities are the histogram entries.

H is not equivalent to variance (σ). Only for particular classes of distributions (eg, Gaussian distributions) H is simply some function of σ and these two can be considered almost equivalent.

H generalizes the concept of measurement uncertainty in view of calculating mutual correlation.

In the following normalized entropy will be used, defined as, $\frac{H}{\log n}$ where n is the number of states, i.e histogram entries.

Mutual correlation

Mutual correlation (MC) is a measure of the statistical dependence between two random variables or, equivalently, the amount of information that one variable contains about the other (Cover and Thomas, 1991).

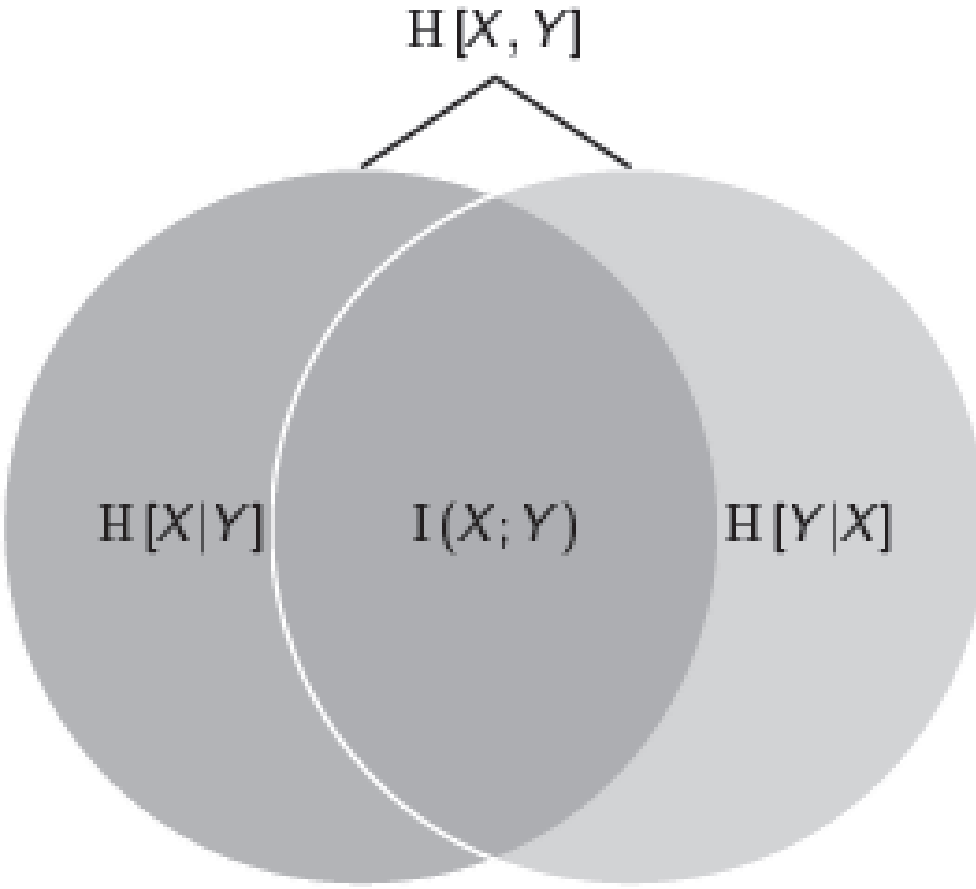
It can be qualitatively considered as a measure of how well one measurement explains the other: this means that it quantifies the reduction of uncertainty in a variable Y after observing another variable X. The advantage in using MC with respect to Pearson's or Spearman's correlation coefficient (ρ) is that MC is applied to both linear and non-linear correlations.

$$MC(X;Y) = \sum_{y \in Y} \sum_{x \in X} p(x,y) \log\left(\frac{p(x,y)}{p(x)p(y)} \right)$$

Many applications require a metric, i.e a distance measure not only between points but also between data clusters (or time series of data). Different distances are provided in literature. In our work, D is defined as:

D(X,Y)=1-MC(X,Y)/max(H(X),H(Y))

D is defined as a metric, i.e. satisfies the triangle inequality. To calculate both H and D, **optimal binning choice and minimal sufficient data** criteria have been considered.


H [X, Y]
H [X|Y]
I (X; Y)
H [Y|X]

Dataset

This is followed by the presentation of the datasets considered in this work provided by five GRUAN sites:

1. The Atmospheric Radiation Measurement (ARM) Program Southern Great Plains in Oklahoma (Miller et al., 2003), US;
2. CIAO in Potenza (Madonna et al., 2011), Italy;
3. Lindenberg in Germany (Adam, W. et al., 2005);
4. Payerne in Switzerland (Calpini et al., 2011);
5. Sodankyla in Finland (Hirsikko et al., 2013).

No GRUAN RS products considered (only RS-92 and need for consistency at different sites, e.g. Payerne make use of SRS 400, many retrievals based on manufacturer data processing)

GRUAN site/Instrument	Sonde	CFH	Lidar	MWR	MWP	GPS	FTIR
Lindenberg	RS-92 (4 x day)	!	X	Radiometrics	Radiometrics	GFZ	
Payerne	SRS 400 (2 x day)		X	HATPRO		GFZ	
Potenza	RS-92 (1 x week)		X		Radiometrics	!	
Sodankyla	RS-92, IMet1 RSB	X	!			!	Bruker
Southern Great Plains	RS-92 (4 x day)		X	Radiometrics		Suominet	AERI

List of instruments available (and model when applicable) at the Lindenberg, Payerne, Potenza, Sodankyla and Southern Great Plains GRUAN sites whose datasets have been considered in the study of uncertainty and redundancy. With the symbol !, the availability of the instrument at the site is reported though the corresponding data have been not used in this study. CFH stands for Cryogenic Frost-point Hygrometer, MWR for microwave radiometer, MWP for microwave profiler.

Dataset

Focus on water vapor data (column and profile). Simultaneous data from all the available instruments have been selected according to two conditions:

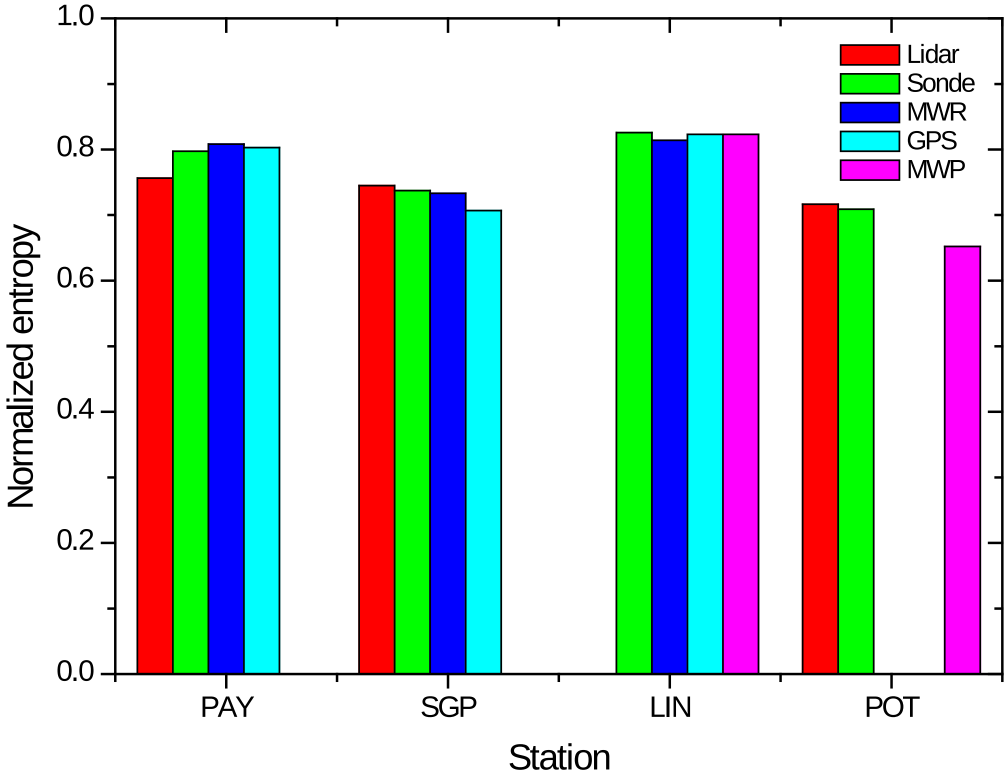
1. clear sky (using lidar measurements or radiosonde humidity) and, when lidar data are available, a relative uncertainty of lidar water vapour mixing ratio at 7 km a.g.l. lower than 25%.
2. Raman lidar measurements are integrated over 10 minutes around the sonde synoptic launch time (00, 06, 12, 18 UT) to keep a good signal-to-noise in the investigated region;
3. microwave radiometer and microwave profiler measurements are provided every 10 minutes;
4. GPS data only are provided every 15 minutes, due to constraints of the data processing at the considered sites, and the closest measurements to the sonde launch time within 10 minutes have been compared.
5. ARM Raman lidar measurements are calibrated using the MWR and this affects the independency of the IWV comparison for lidar at the SGP; instead, at PAY and POT, the Raman lidar is calibrated using radiosonde humidity profiles in the lower troposphere.

Dataset

- A linear regression was performed on the whole time series (3 years) of integrated water vapor (IWV) and vertical profiles of water vapor mixing ratio, at the altitude levels, to remove natural or artificial trends. This was done to suppress the bias component of the uncertainty budget.

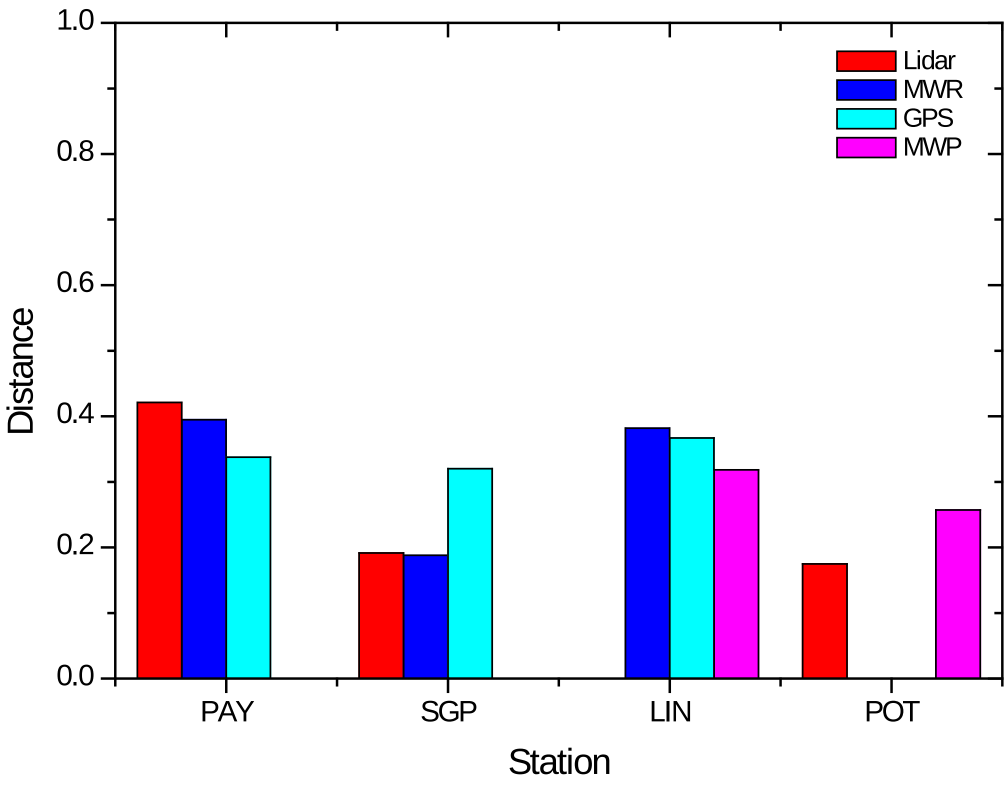
- Therefore, the reported entropies will be only related to the random uncertainty of a time series. MC quantifies the part of the random uncertainty of a time series that can be reduced using ancillary information.

Entropy



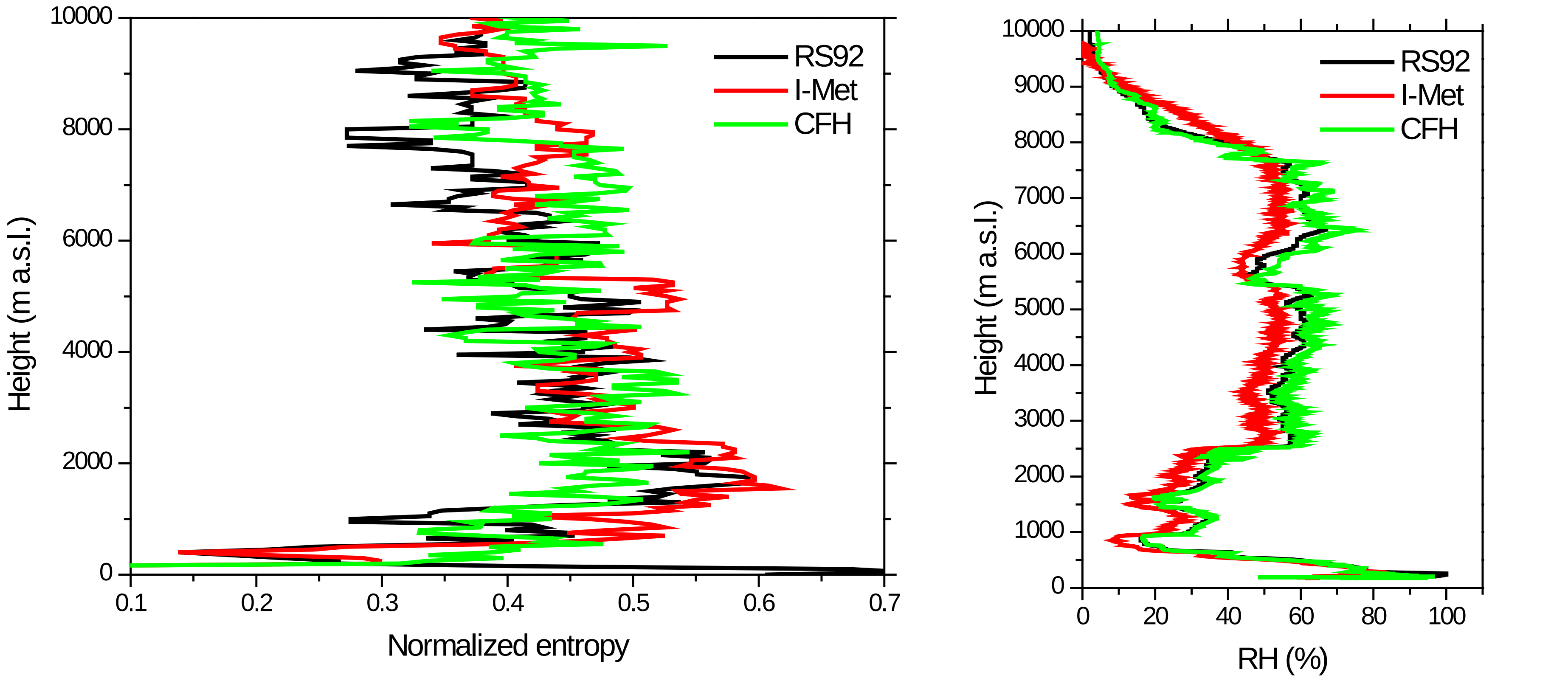
Comparison of the entropies retrieved for the all the instruments measuring IWV at the four site of Lindenberg (LIN), Payerne (PAY), Potenza (POT), and Southern Great Plains (SGP). The considered dataset includes all the available measurements within the period 2010-2012.

Distance



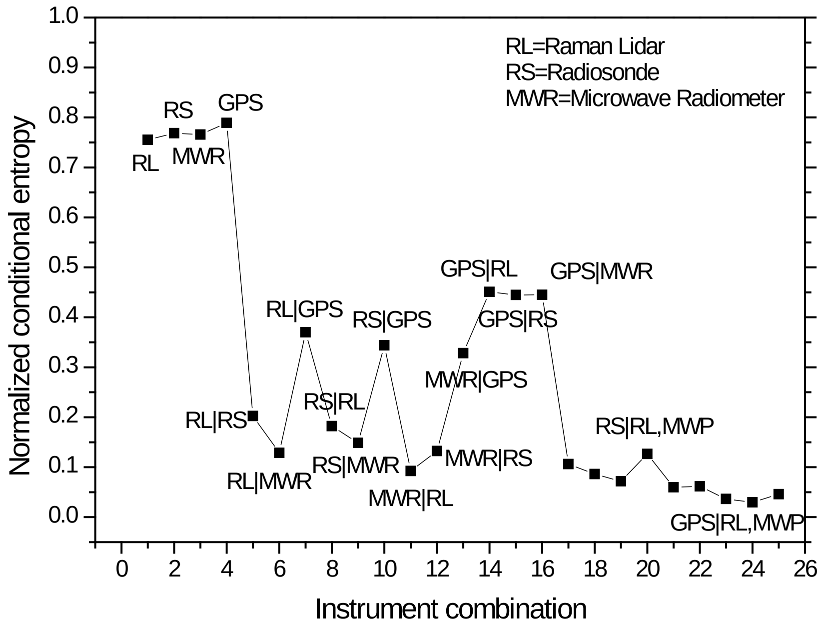
Comparison of the distances between couples of times series retrieved for the all the instruments measuring IWV with respect to the time series of IWV obtained from the radiosoundings at the four site of Lindenberg (LIN), Payerne (PAY), Potenza (POT), and Southern Great Plains (SGP). The considered dataset includes all the available measurements within the period 2010-2012.

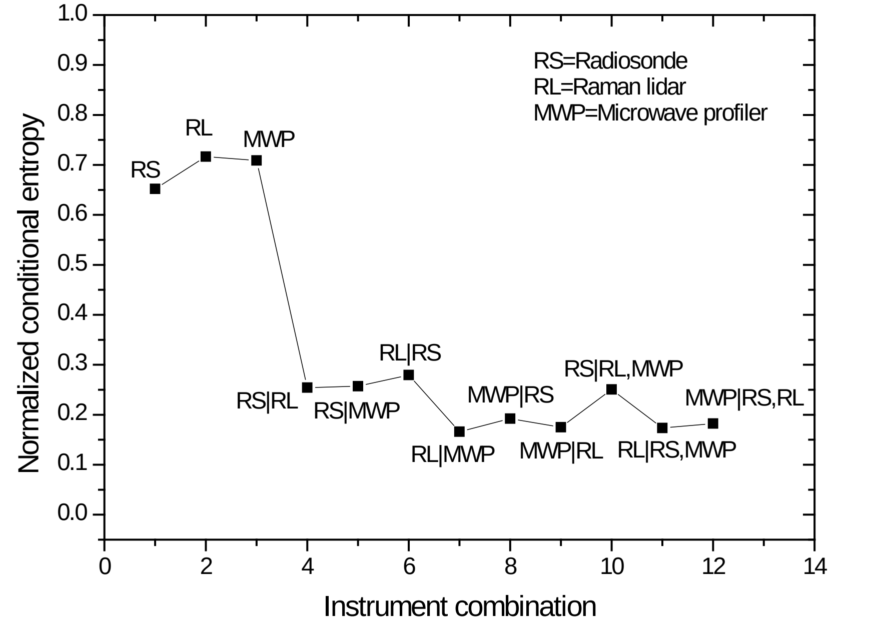
Entropy profile



Left panel, comparison of the entropies retrieved for the three instruments, RS92 and Intermet radiosondes (I-Met), and Cryogenic Frost-point Hygrometer (CPH) measuring in situ the water vapor vertical profile at Sodankyla site available on 2010; right panel comparison of the RH profiles in one case on 15 March 2010.

Conditional entropy

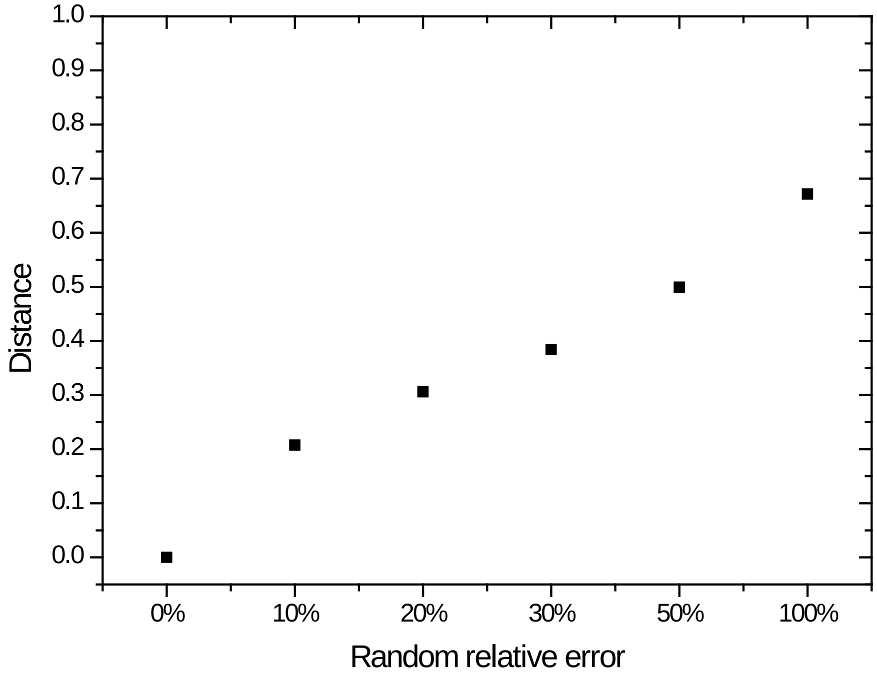




Comparison of the conditional entropies retrieved for the all the combinations of the instrument measuring IWV at the SGP site (right panel) and at Potenza site (left panel).

Redundancy criteria

Assuming that random uncertainty is quantified using entropy and assuming the radiosonde IWV time series as the reference affected by a random errors lower than 5 %, an IWV time series affected by a random error lower than 5 % is consistent with the true one if the corresponding value of D is lower than about 0.2 (total random error lower than 10 %).



Distance between the IWV time series retrieved from the radiosonde at one site (Lindenberg) and the corresponding time series obtained adding random noise to radiosonde time series show values higher than 0.2 should be classified as not redundant with the threshold of 5 % random error affecting the two compared time series.

Conclusions

- Entropy and MC can be used to evaluate the random uncertainty of a measurement time series in the ECV by analyzing measurement redundancy

- Redundancy criteria has to be identified.

- The presented approach is enough versatile to be used on different datasets, stations and instruments with the intent to provide the required feedback in terms of uncertainty and use of redundant measurements to reduce uncertainty in the knowledge of all the ECVs.

- Entropy and MC analysis could also represent a preliminary assessment of the feasibility and of the effective advantages in using retrieval algorithms integrating measurements provided by different observation platforms, for both ground based and satellite direct measurements or products.

Acknowledgements

ARM data are made available through the U.S. Department of Energy as part of the Atmospheric Radiation Measurement Program (www.arm.gov).

CIAO Potenza data are made available through CNR-IMAA (http://www.ciao.imaa.cnr.it).

Lindenberg data are made available through the Lindenberg Meteorological Observatory - Richard Aßmann Observatory of Deutscher Wetterdienst (http://www.dwd.de).

Payerne data are made available through the Federal Office of Meteorology and Climatology MeteoSwiss (http://meteoswiss.admin.ch).

Sodankyla data are made available through Finnish Meteorological Institute (http://www.fmi.fi).

GATNDOR
GRUAN Analysis Team for Network Design and Operations Research
Work status

F. Madonna and many other colleagues…..

Current membership

Fabio Madonna	CNR - IMAA, IT	chair
Dian Seidel	NOAA Air Resources Laboratory (R/ARL), U.S.	
John Dykema	Harvard University, U.S.	
Tom Gardiner	National Physical Laboratory, UK	
Alessandro Fassó	University of Bergamo, IT	
Junhong (June) Wang	NCAR/EOL, U.S.	
David Whiteman	NASA/GSFC, U.S.	
Kerstin Ebell	University Cologne, DE	
Hannes Vogelmann	KIT, DE	

GATNDOR publication list

- Sun, B., A. Reale, D. J. Seidel, and D. C. Hunt, 2010:Comparing radiosonde and COSMIC atmospheric profile data to quantify differences among radiosonde types and the effects of imperfect collocation on comparison statistics. *J. Geophys. Res., 115, D23104,* doi:10.1029/2010JD014457.

- Seidel, D. J., B. Sun, M. Pettey, and A. Reale 2011: Global radiosonde balloon drift statistics J. Geophys. Res., 116, D07102, doi:10.1029/2010JD014891.

- Fassò, A., Ignaccolo, R., Madonna, F., and Demoz, B. B.: Statistical modelling of collocation uncertainty in atmospheric thermodynamic profiles, Atmos. Meas. Tech. Discuss., 6, 7505-7533, doi:10.5194/amtd-6-7505-2013, 2013.

- T. Gardiner, F. Madonna, J. Wang, D. N. Whiteman, J. Dykema, A. Fassò, P. W. Thorne, and G. Bodeker (2013): Sampling and measurement issues in establishing a climate reference upper air network. AIP Conf. Proc. 1552, pp. 1066-1071.

- Madonna, F., M. Rosoldi, J. Güldner, A. Haefele·, R. Kivi, M. P. Cadeddu, D. Sisterson and G. Pappalardo, Quantifying the value of redundant measurements at GRUAN sites, Atmos. Meas. Tech. (to be submitted).

GATNDOR pending issues

New Members

- Dr. Kerstin Ebell
  Institute for Geophysics and Meteorology
  University of Cologne
  Redundancy+SASBE

- Dr. Hannes Vogelmann
  Karlsruhe Institute of Technology (KIT) Institute for Meteorology and Climate Research (IMK-IFU)
  Co-location (Garmisch data)

Their involvement is still poor and needs to be re-considered!

New Topics

- PhD position (funds?): "**Improving satellite validation through an assessment of best vertical resolution and of the value of uncertainty covariance matrix of atmospheric variables to use in Radiative Transfer modeling**".

No funds yet available for this! Maybe GAIA-Clim H2020 proposal, if funded might support this work?

Other possible topics: within WCRP/SPARC (World Climate Research Program/Stratosphere-Troposphere Processes and their Role in Climate) to study fine-scale atmospheric processes (e.g, gravity waves, turbulence, tropopause structures, boundary layer structures, etc) using very high vertical resolution radiosonde data. Since GRUAN soundings are very appropriate to this effort, there should be a good opportunity for synergistic research between SPARC and GRUAN. This would help GRUAN focus on process applications(as opposed to long-term monitoring, for example, which requires a long data record).

Status

- GATNDOR is still populated but the team is no more active on new topics.
- The team was established on the spirit of volunteers. It seems to me that now this spirit got lost somewhere in the GRUAN community. Does it make sense to have still GATNDOR or to merge it with the work of Task Teams?
- I think the idea behind GATNDOR is still winning (a team focused on specific science topics relevant for GRUAN) but the GRUAN community should be more interested in this team and the recruitment of volunteers should not be a problem.
- Dian, June, Alessandro, and me worked as volunteers with the support from several others interested in GRUAN. It is time to check if something has to change in the "GATNDOR model"
- Fabio, after four years, will leave as a chair after ICM6, hoping things will be cleared for GATNDOR.

GATNDOR: need for changes?

- It might be interesting to track when we first started on these projects, and how long they took to complete. This would provide perspective on what's reasonable to expect.
- GATNDOR is typical for unfunded research plans, even if the projects are important and interesting. The problem facing GATNDOR is mainly that the research we have identified as important to GRUAN and interesting is generally not funded. This is not really a sustainable situation and not a good model for a standing committee. Perhaps WG-GRUAN can oversee research needs for GRUAN and work to rally scientists and obtain resources for priority GRUAN research, without the need for a standing GATNDOR activity, which is bound to have more ideas for projects than resources to carry them out.
- Still, the focus on peer-reviewed research to provide a scientific underpinning for GRUAN should be a high priority.
- GATNDOR could work in future according to the following model. The team will take care of sending co-chairs projects that are highly relevant for GRUAN purposes. The team should quantify the real efforts and costs related to the projects. GRUAN community (co-chairs and TTs) should look for the funding support.

Collaborators

Finally, it is also very important to acknowledge all the collaborators that strongly supported the team work.

B. Demoz, B. Sun, R. Ignaccolo, J. Güldner, N. Cimini, R. Kivi, M. P. Cadeddu, D. Sisterson and G. Pappalardo, T. Reale, M. Pettey, ……….

THANK YOU!