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AN AUTOMATIC CALIBRATION SYSTEM FOR WATER VAPOR RAMAN LIDAR

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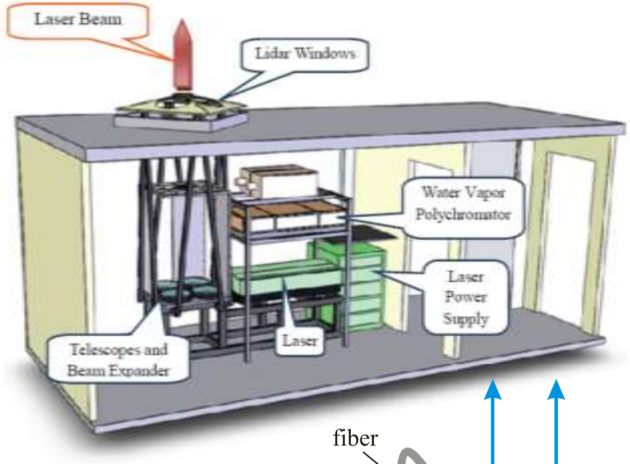
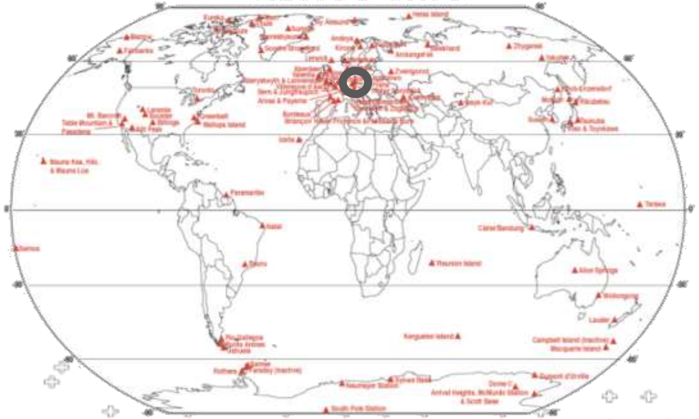
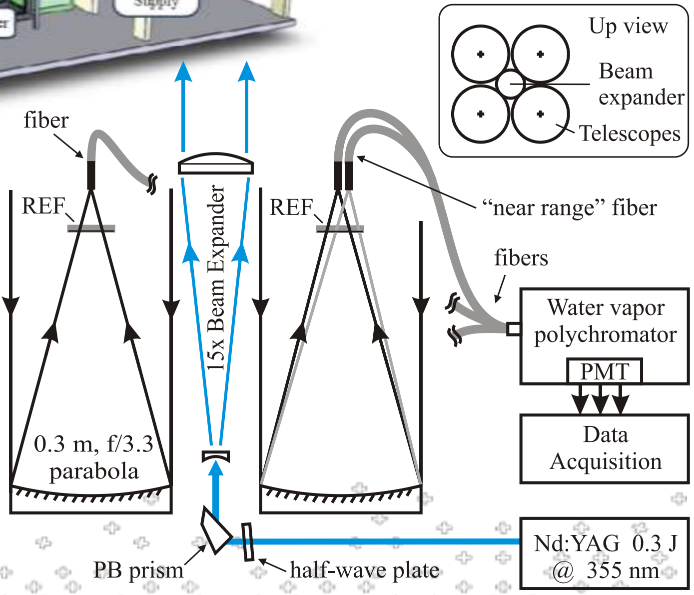
The RAman Lidar for Meteorological Observations - RALMO

- Operated in Payerne, Switzerland
- Since 2008
- Fully automatic Raman lidar
- Day and nighttime operation
- Narrow FOV and bandwidth
- High laser-pulse energy



NDACC Sites





Why do we need an automatic calibration?

The traditional calibration method requires always a reference to calibrate the water vapour profile. Radiosounding is the traditional and best established reference used to calibrate a WV LIDAR profile, but it is not available at every site and every time. The proposed automatic calibration uses only one (or just a few) radiosounding calibration over many years and a continuous reference represented by **the LIDAR signal** itself (solar background) or **an internal LED signal**.

RALMO detects the Raman scattered light from atmospheric water vapor (E_{H2O}) and nitrogen (E_{N2}), which allows to derive the water vapor mixing ratio (***ω***). The profiles of ***ω*** obtained by RALMO are traditionally calibrated using collocated radiosounding. The expression of ***ω*** can be obtained rearranging the terms in the LIDAR equation at each altitude *z* for H_2O and N_2:

$$\omega(z) = \boxed{C} \frac{E_{H2O}(z)}{E_{N2}(z)} \frac{T_{H2O}(z, \lambda_{H2O})}{T_{N2}(z, \lambda_{N2})} = C \frac{S_{H_2O,obs}}{S_{N_2,obs}}$$

Radiosounding-based LIDAR calibration factor

The calibration factor *C* is the system calibration factor and it depends on:

$$C(\lambda, t_0) = \frac{\xi(\lambda_{N2})}{\xi(\lambda_{H2O})} \frac{\gamma(\lambda_{N2})}{\gamma(\lambda_{H2O})} \frac{\sigma_{N2}}{\sigma_{H2O}}$$

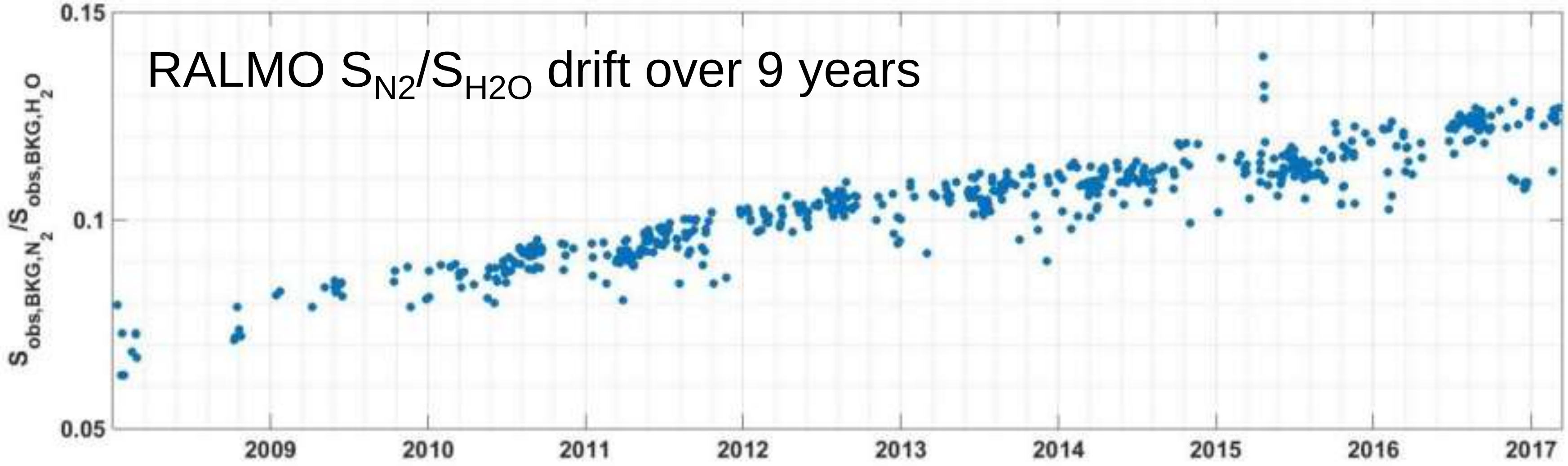
ξ is the acquisition system's optical efficiency at the wavelength λ

γ is the detectors' sensitivity

σ_x is the Raman-backscattering cross section

C can be calculated by ***ω***-radiosonde profiles at time t_0 when the radiosounding is available. If no radiosoundings are available for $t > t_0$, the temporal evolution of *C* can only be modelled or extrapolated over $t > t_0$ correcting for the uneven aging of the optical acquisition system.

Our hypothesis is that the differential aging of the N_2 and H_2O mostly relies on photomultipliers due to the different background load at the two wavelengths and is responsible for a drift in the calibration factor, *C*.



- The internal calibration system set in place at Payerne is fully automatic and is based on an internal stabilized light source (LED) or on the solar background shining onto the N_2 and H_2O photomultipliers (PMTs).

- The internal calibration system allows calculating C^* calibration factors based on the differential aging of the two PMTs.

- $C^*(t)$ can be calculated at any time $t > t_0$ by correcting the factor $C(t_0)$ for the aging correction factor, f_{aging}, of the N_2 and H_2O PMTs.

- Due to f_{aging}, the true signal, S_{true}, of the atmospheric compound X (H_2O or N_2), is not equal to the measured signal $S_{X,\ obs}$.

$$S_{X,true}(t) = f_{aging,X}(t)\, S_{X,obs}(t)$$

The equation of water vapour, ***ω*****,** can be written as a function of the aging correction factor :

$$\boldsymbol{\omega}(t) = C\,\frac{f_{H_2O}(t)}{f_{N_2}(t)}\,\frac{S_{H_2O,obs}(t)}{S_{N_2,obs}(t)}$$

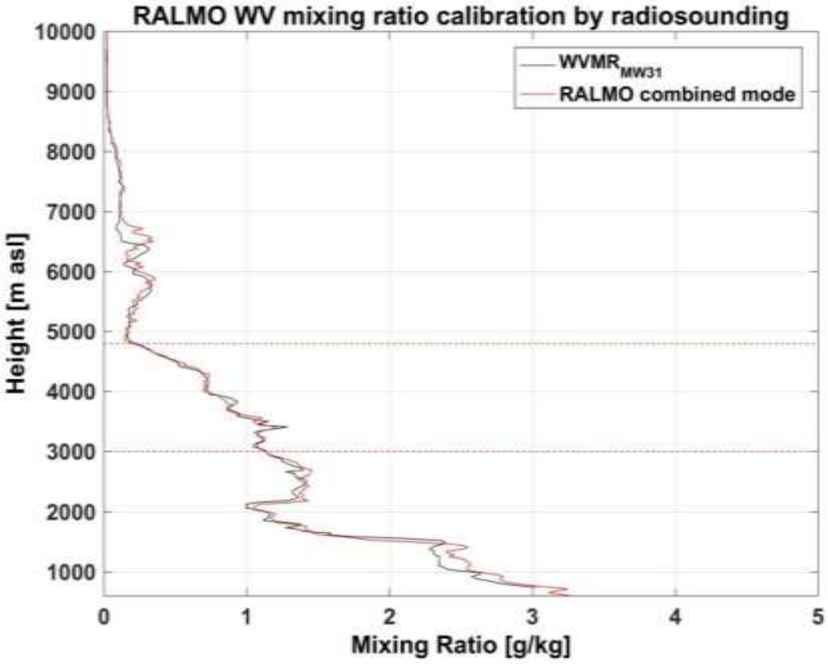
When the internal signal source is used, the ratio $\frac{f_{H_2O}(t)}{f_{N_2}(t)}$ in the equation can be expressed as the inverse ratio of the internal signals $S_{N2,\,INT}$ / $S_{H2O,\,INT}$

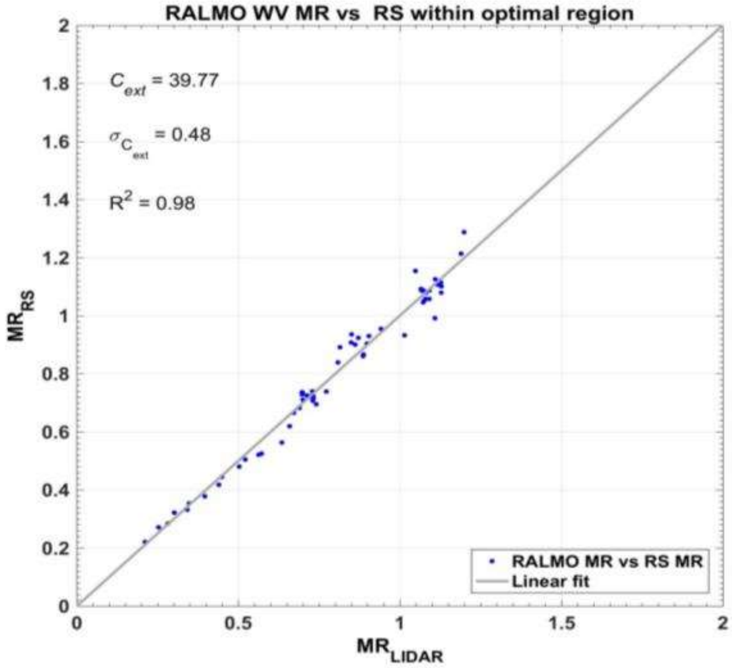
By performing a radiosounding calibration at t_0, and combining the atmospheric and internal signals, the temporal evolution of the corrected calibration factor, C^*, can be calculated at any time $t \geq t_0$,

$$C^*(t) = \frac{r_{aging}(t)}{r_{aging}(t_0)}\,C(t_0)$$

$$r_{aging} = \frac{S_{N2,INT}}{S_{H2O,INT}}$$

The calculation of $C(t_0)$ by $\boldsymbol{\omega}$-radiosonde profiles requires the selection of an optimal region where to perform the calibration. This region is selected manually by the operator:



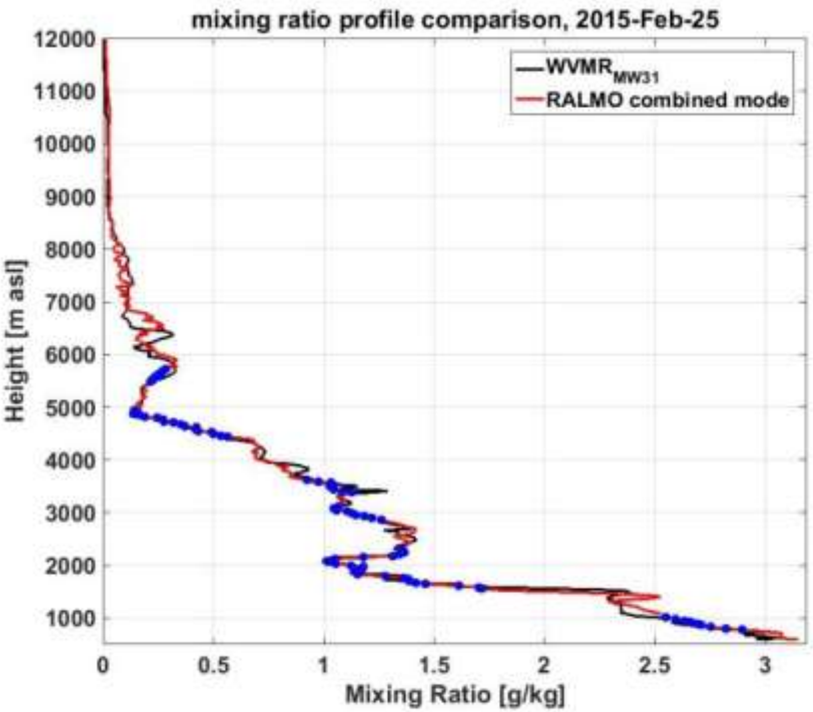


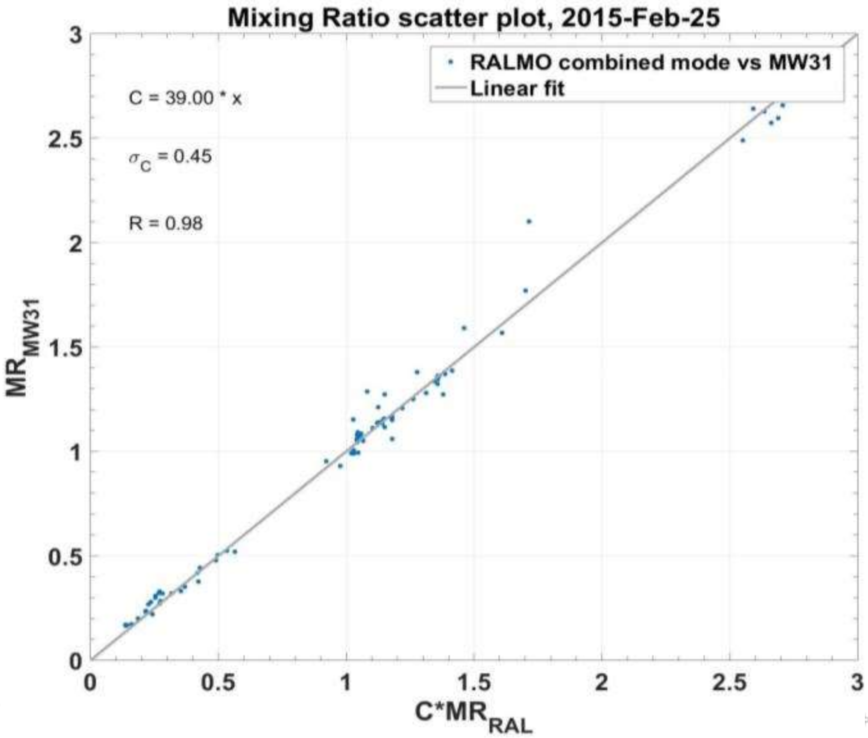
The manual calibration suffers the following limitations:

- It is subject to the individual operator's selection.
- It is highly sensitive to the choice of the optimal region.
- Can induce inhomogeneity in the time-series of *C*.

The manual calibration has been disrupted in 2016. Instead, an unmanned procedure based on the automatic selection of high $\boldsymbol{\omega_{RS}}$-$\boldsymbol{\omega_{RAL}}$ correlation regions has been adopted. The new procedure removes all the above limitations.

Unmanned calibration: all regions along the LIDAR profile having a correlation better than $R^2 = 0.6$ over a 200-m vertical slice are automatically selected for the calibration.





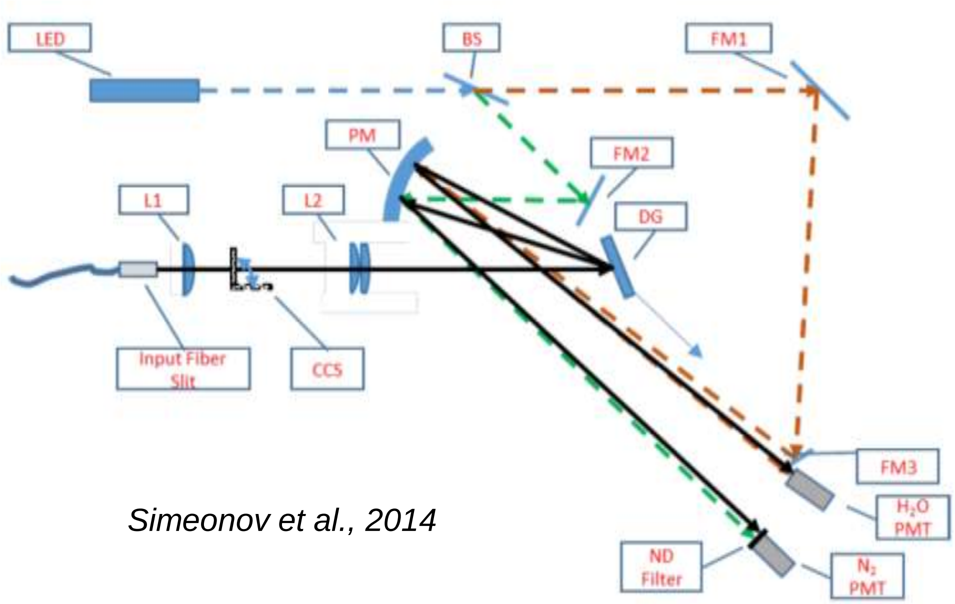
The unmanned calibration of the LIDAR $\boldsymbol{\omega}$ by radiosounding ensures:

- An objective choice of the calibration regions.
- A consistency of the calibration method over several years.
- A significant reduction of the labour time

The unmanned calibration has been fully adopted at Payerne to recalculate the timeseries of *C* for 2008-2017.

BUT the obtained timeseries of *C* factors shows a drift through time due to the differential aging. We have developed a method to calculate this drift and to use it to calculate $C^{*}(t)$ without using radiosounding except for the calibration at time t_0.

The first setup of automatic internal calibration we tried was a LED source installed inside the H_2O and N_2 polychromator. The LED acted as the internal (stabilized) signal allowing to calculate $C^*(t)$ after an initial radiosounding calibration at t_0.

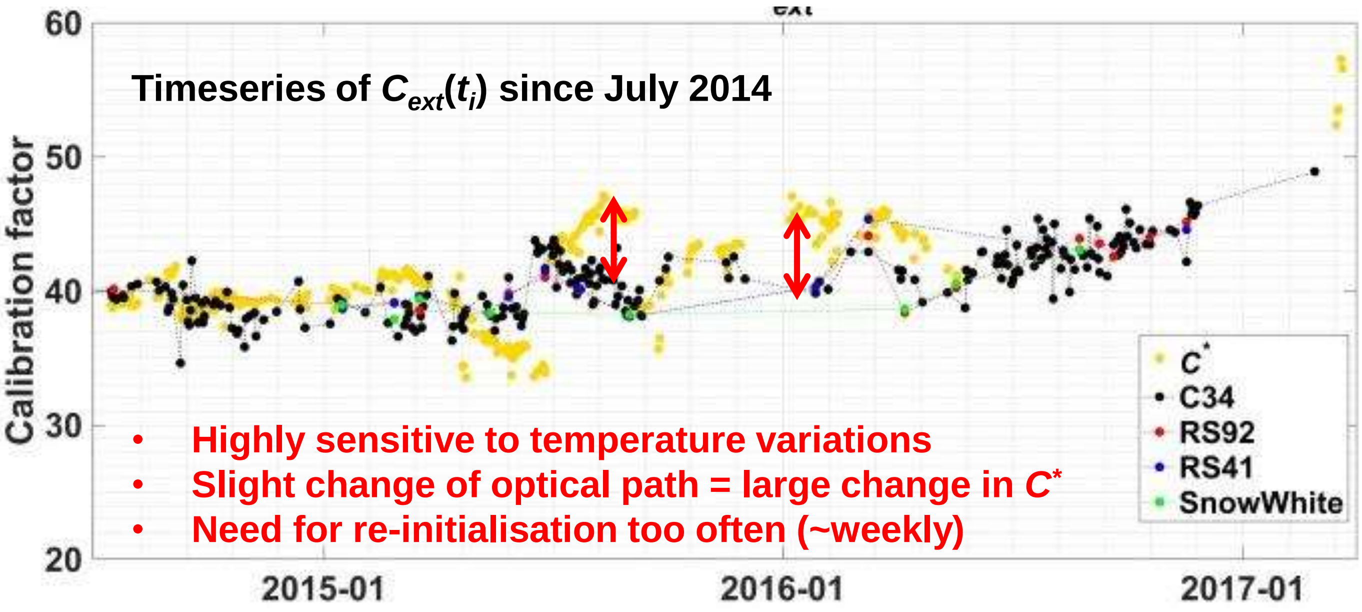


Simeonov et al., 2014

In order to assess the automatic internal calibration we let run the unmanned calibration over the entire RALMO dataset and obtained the time series of $C(t_i)$

It is important that, during the assessment phase, the time series $C^*(t)$ matches the calibration factors $C(t_i)$.

The $C(t)$ values are obtained by unmanned calibration with different radiosondes: the operational SRS-C34 and SRS-C50 (black), the RS92 (red), the RS41 (blue) and the SnowWhite (green).



The timeseries of $C^*(t)$ does not match well the timeseries of the $C(t_i)$ points. Especially during the year 2015 differences up to 20% can be observed between $C^*(t)$ and $C(t_i)$

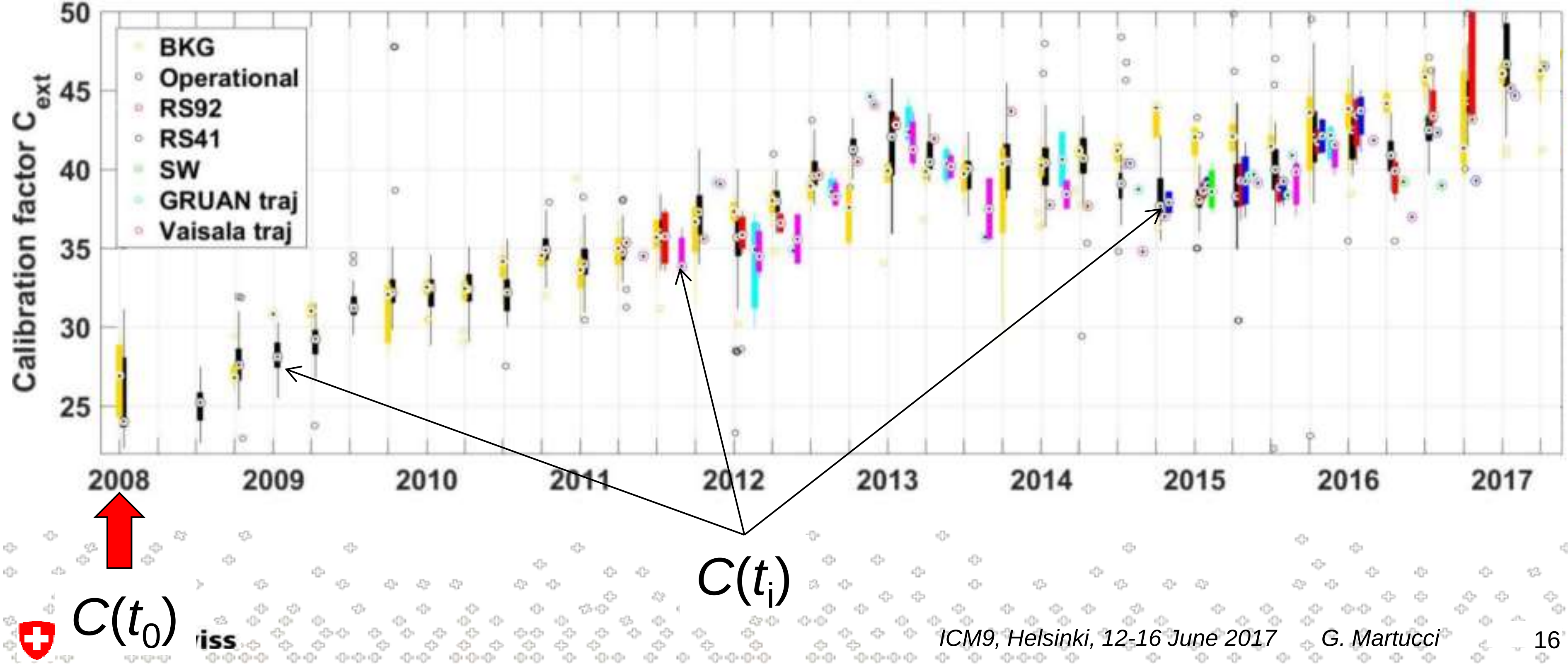
- A more robust, automatic calibration system uses the ratio of the solar background (BKG) at the N_2 and H_2O wavelengths.

- The signal made by the sun photons is measured by RALMO at a fixed elevation angle 20°, i.e. the maximum elevation angle on the 21st of December at Payerne. The BKG act as the internal signal to correct the calibration factor obtained at time t_0 for the differential aging.

- The BKG signal is calculated as the median of the LIDAR signal over the range interval 50-60 km. BKG is always available during clear-sky periods. The seasonal cycle is minimized by taking a fixed 20° elevation angle.

- At time t_0 (beginning of our timeseries) an unmanned calibration by radiosounding is performed. For $t > t_0$, a new C*(t) is calculated every day and used to calculate **ω** for the next 24 hours.

The timeseries of C*(t) (yellow) shows that even in the extreme case of **only 1 calibration** made using radiosounding at $t = t_0$ it is possible to reproduce very well the timeseries of calibration factors obtained using different radiosondes and methods.



- A new procedure to calibrate the RALMO water vapor mixing ratio (**ω**) consists of the daily automatic correction of the calibration factor *C* obtained by radiosounding calibration at time t_0.

- The correction of *C* (C^*) is based on an automatic monitoring of the differential aging of the N_2 and H_2O PMTs.

- For the evaluation of the internal calibration method the calibration factors $C(t_i)$ obtained by different types of radiosondes have been calculated for the period 2008-2017. The C^* values obtained using the LED showed a limited reproducibility of the $C(t_i)$ factors, essentially due to temperature dependence of the calibration system.

- **The $C^*(t)$ factors obtained using the BKG show an excellent agreement with the $C(t_i)$ factors and provide the possibility to calibrate RALMO along the entire dataset (9 years) with only one radiosounding calibration (initialization).**

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