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OPERATIONAL AND GRUAN RADIOSOUNDING VALIDATION OF PRR TEMPERATURE DATA RETRIEVED BY THE RAMAN LIDARA FOR METEOROLOGICAL OBSERVATIONS (RALMO) AT PAYERNE

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11th Implementation-Coordination Meeting of GRUAN, 20-24 May 2019, Singapore

Background

- Continuous measurements of temperature are needed to fill the gap of under-sampled troposphere.
- Need of well established, good-quality reference to validate the temperature profiles retrieved by RALMO.

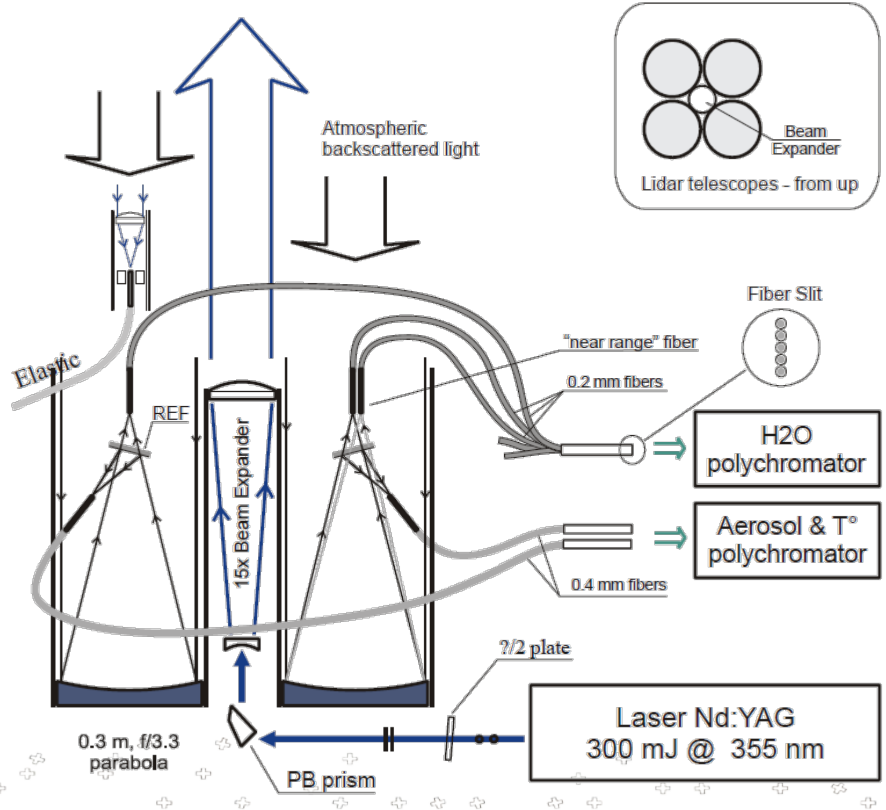
Aim of the study

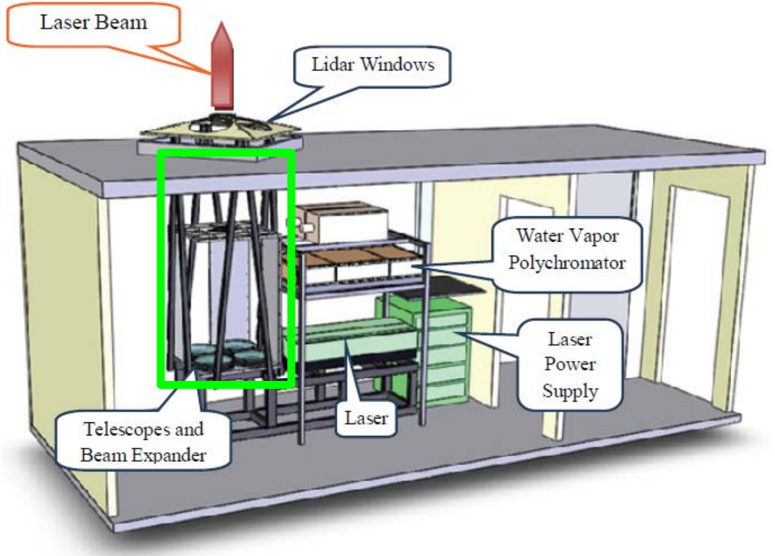
1. To validate the operational radiosounding system in use at Payerne using the GRUAN RS92
2. To use the validated sonde to validate 1.5 years of temperature data retrieved from RALMO, July 2017-October 2018.

Applications

- Long timeseries of temperature data with small systematic and total uncertainty can be used for DA experiments.
- Good-quality temperature data can be used, in combination with humidity measurements, for studies of supersaturation at the base of liquid clouds.

The RAman Lidar for Meteorological Observations - RALMO





- Operated in Payerne, Switzerland
- Since 2008
- <u>Fully automatic Raman lidar</u>
- Day and nighttime operations
- Narrow FOV and bandwidth
- High laser-pulse energy, 450 mJ

Validation of the reference radiosounding systems

- MeteoSwiss participates in the GRUAN programme with the Vaisala sonde RS92 since 2012. 300 RS92 sondes have been launched since 2012 at Payerne.

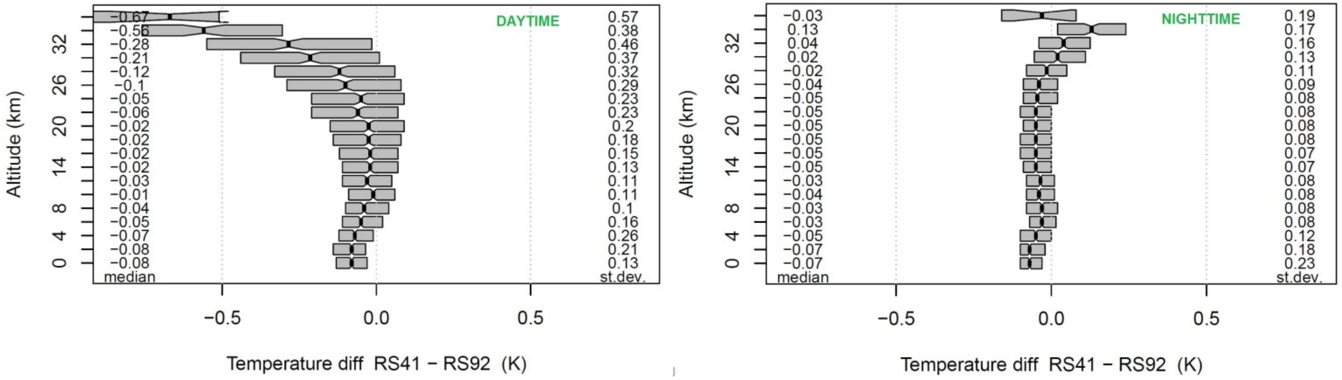
- The RS92 sonde has been used by MeteoSwiss as working standard in the framework of the quality assurance programme of the different versions of the Meteolabor Swiss RadioSonde (SRS). Starting from 2012, the SRS-C34 and SRS-C50 have been compared to the RS92 sonde.

- In 2014, the Vaisala RS41 sonde was added to the GRUAN programme and performed numerous multi-payload flights with the RS92 and the SRS carried under the same balloon

During the studied period, two RS operational systems have been launched regularly at 11 UTC and 23 UTC, i.e. the **SRS-C50** (February 2017- March 2018) and the Vaisala **RS41** (March-October 2018).
With multi-sensor flights the SRS-C50 and RS41 have been validated by the GRUAN sonde RS92

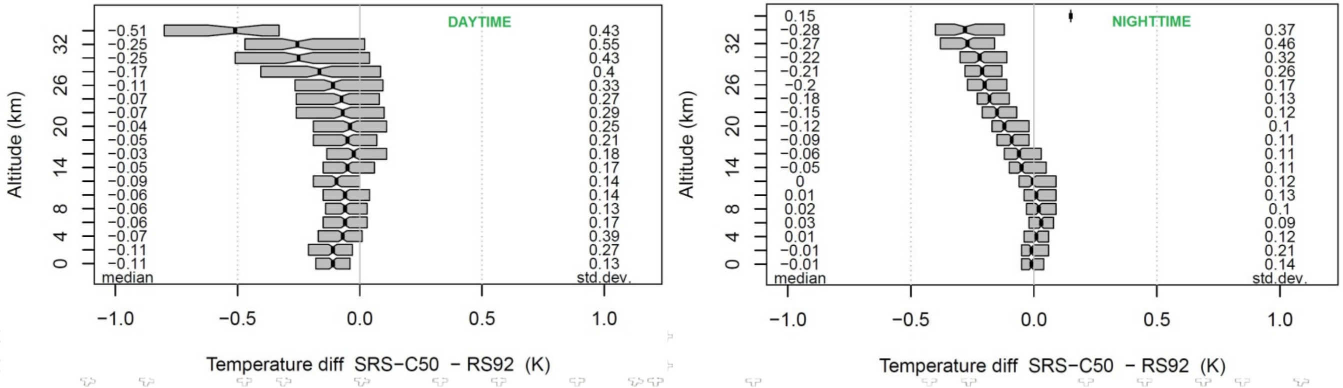
Validation of the reference radiosounding systems

June 2015 - December 2018



The nighttime infrared radiation significantly affects the SRS measurements especially in the stratosphere

February - December 2018

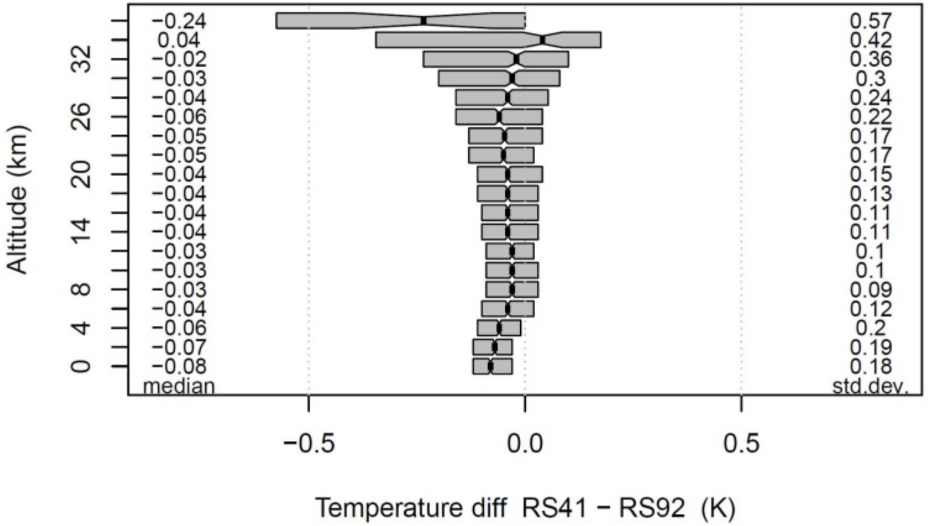


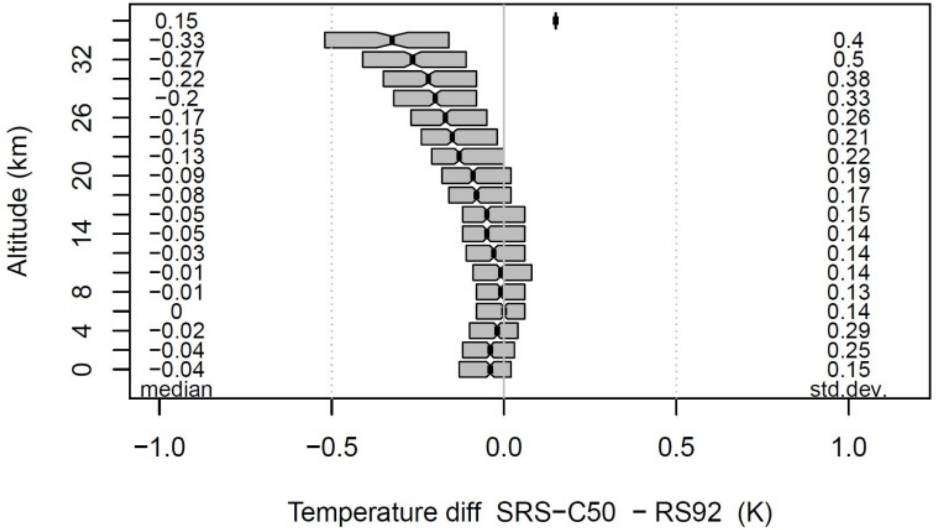
The comparisons with the RS92 show that for both RS the **daytime differences undergo a larger variability** along the 0-14~km vertical range compared to the nighttime statistics.

Possible reasons for the larger variability are:

- during the comparison flights the RS92 and the two RS have **different exposure to the solar radiation causing different responses of the thermocouple sensors**, the effect becomes larger with altitude as the solar radiation increases with height.
- Radiation correction of the SRS-C50 is less efficient in the stratosphere

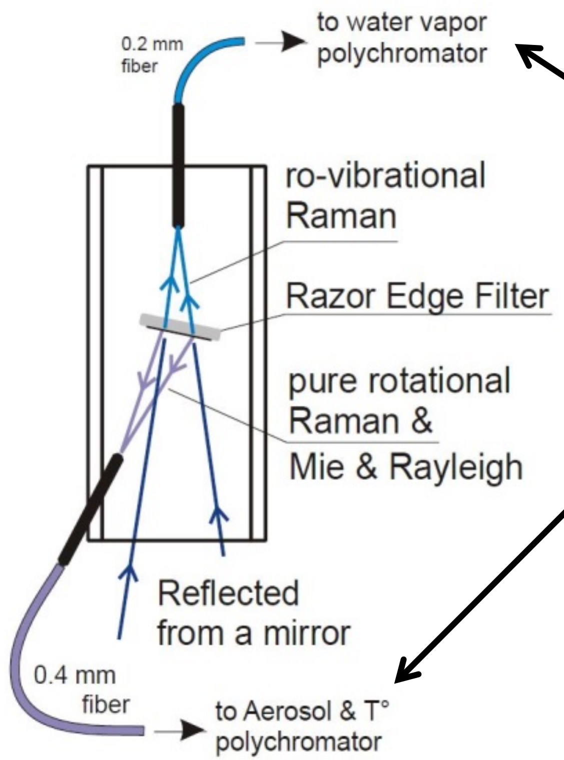
Validation of the reference radiosounding systems





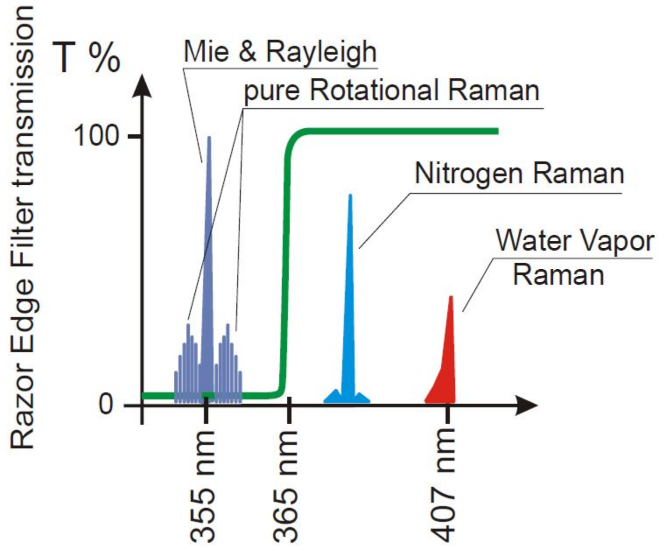
The overall (11~UTC and 23~UTC) performance of the two RS in terms of bias with respect to the reference sonde RS92 confirms that in the first 15~km the two RS remain below the -0.1 K bias. The **RS41 shows closer value to the RS92 than the SRS-C50 especially in the stratosphere**.

Temperature polychromator of RALMO



The N_2 and H_2O signals are transmitted through the REF onto the 0.2-mm optic fiber and transmitted to the water vapor polychromator.

The elastic (Rayleigh and Mie) and PRR scattering are reflected by the REF onto 0.4-mm optic fibers and transmitted to the PRR polychromator.



The PRR polychromator separates spectrally several pure-rotational Raman lines and isolates elastic scattering consisting of Rayleigh and Mie lines (*Cabannes* line).

Temperature polychromator of RALMO

Nitrogen					
J_{low}			J_{high}		
$J_{low}^{AntiStokes}$ (n)	λ	**Efficiency**	$J_{high}^{AntiStokes}$ (n)	λ	**Efficiency**
4	354.1672	0.2330	10	353.5700	0.2028
5	354.0675	0.6206	11	353.4708	0.5798
6	353.9678	1	12	353.3717	0.9961
7	353.8682	0.6671	13	353.2726	0.7134
8	353.7687	0.2713	14	353.1737	0.3118
9	353.6693	0.0094	15	353.0749	0.0274
J_{low}			J_{high}		
J_{low}^{Stokes} (n)	λ	**Efficiency**	J_{high}^{Stokes} (n)	λ	**Efficiency**
3	355.1681	0.0002	10	355.8714	0.1943
4	355.2685	0.2388	11	355.9720	0.5678
5	355.3689	0.6307	12	356.0726	0.9873
6	355.4694	1	13	356.1732	0.7278
7	355.5698	0.6496	14	356.2738	0.3248
8	355.6703	0.2535	15	356.3744	0.0342
9	355.7709	0.0029			

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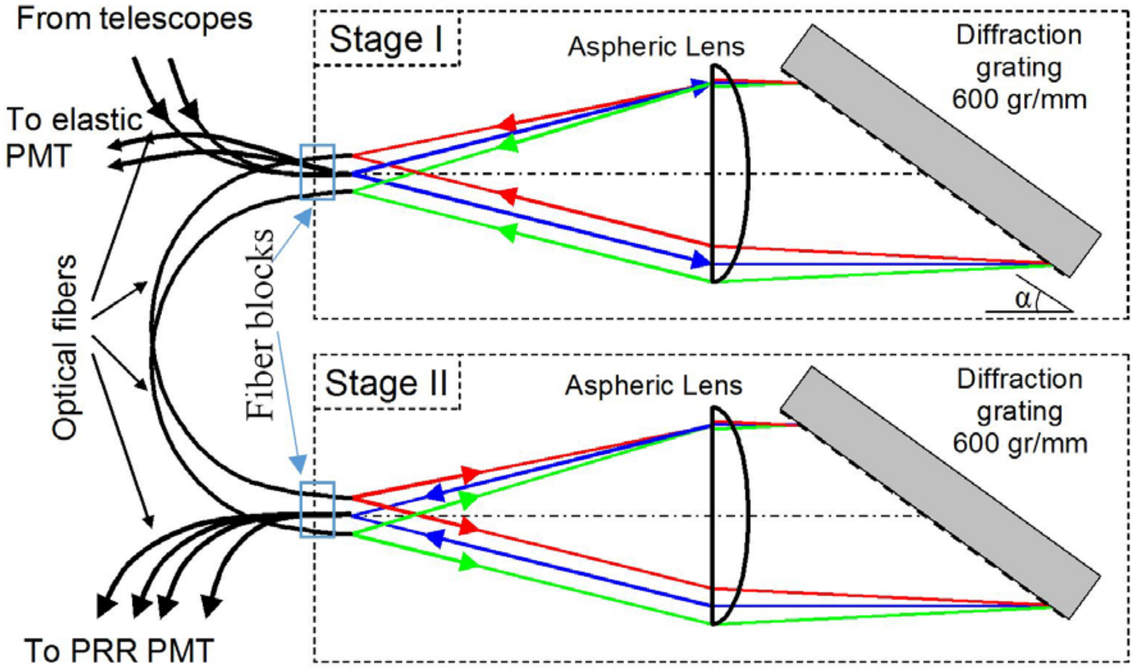


Retrieval of PRR temperature and uncertainty budget

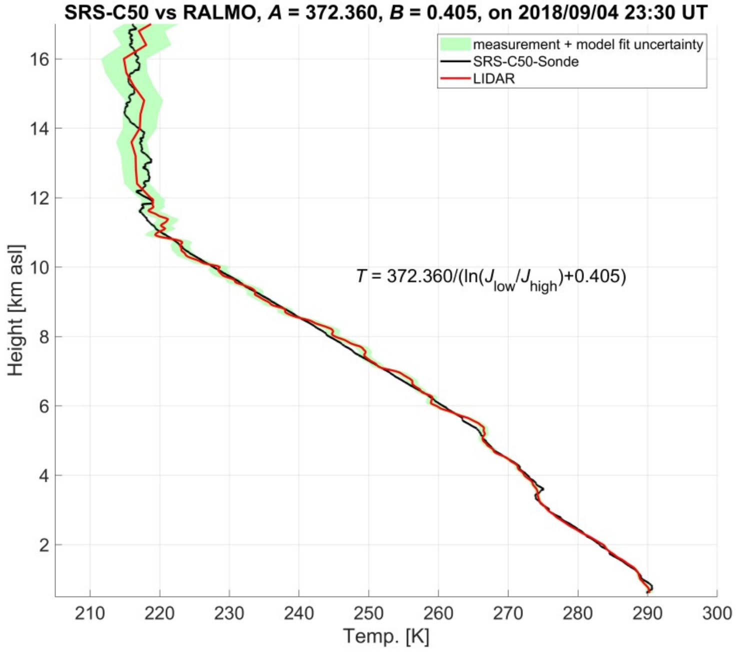
Based on the calculations shown by Behrendt et al., (2005) and for systems that detect only one PRR line in each channel (J_{low} and J_{high}), the relationship between *T* and *Q*, the ratio of J_{low} and J_{high}, takes the simple form where the approximation symbol indicates that the detection system detects more than one PRR line.

$$Q = \frac{J_{low}}{J_{high}} \qquad T \approx \frac{A}{B + \ln Q}.$$

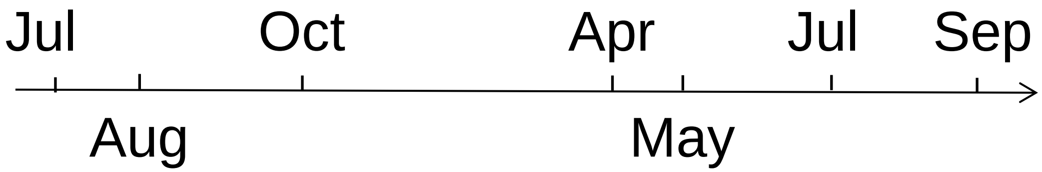
The total uncertainty of the retrieved temperature profile calibrated by a co-located radiosounding is the combination of the assumed independent error contributions due to the linear fit between LIDAR and sonde plus the Poisson noise:

$$\Delta T = \sqrt{\Delta T_{fit}^2 + \Delta T_{sig}^2}$$

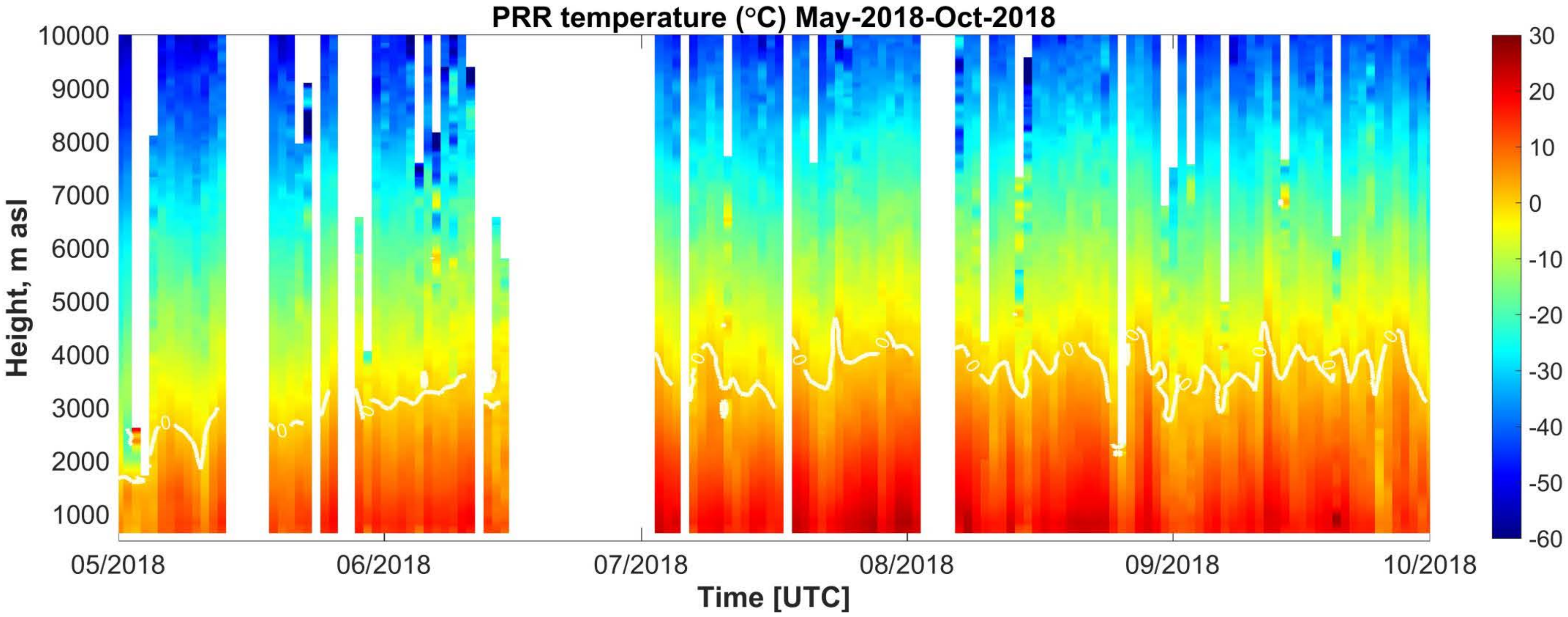
Calibration of RALMO by RS and stability over time



YYYY-MM-DD HH:MM	A	B	σ_A	σ_B	fitting model
2017-07-06 23:30	370.37	0.41	0.6427	0.0024	linear
2017-08-24 23:30	372.74	0.42	0.9218	0.0034	linear
2017-10-16 23:30	373.22	0.42	0.5194	0.0019	linear
2018-04-17 23:30	371.83	0.40	0.7836	0.0029	linear
2018-05-11 23:30	374.89	0.42	0.8513	0.0033	linear
2018-07-07 23:30	369.49	0.39	1.0194	0.0038	linear
2018-09-11 23:30	374.77	0.41	0.8677	0.0032	linear



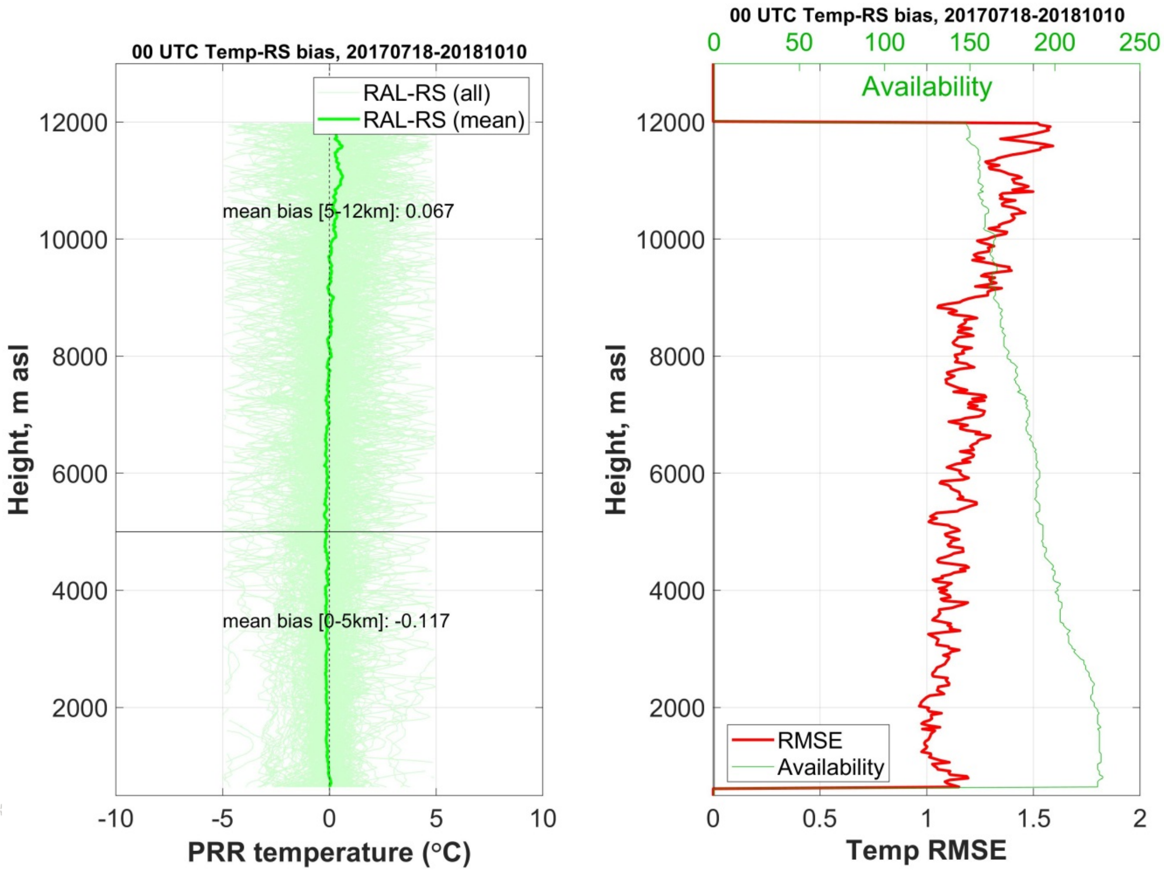
Continuous temperature measurements



Validation of PRR temperature: nighttime

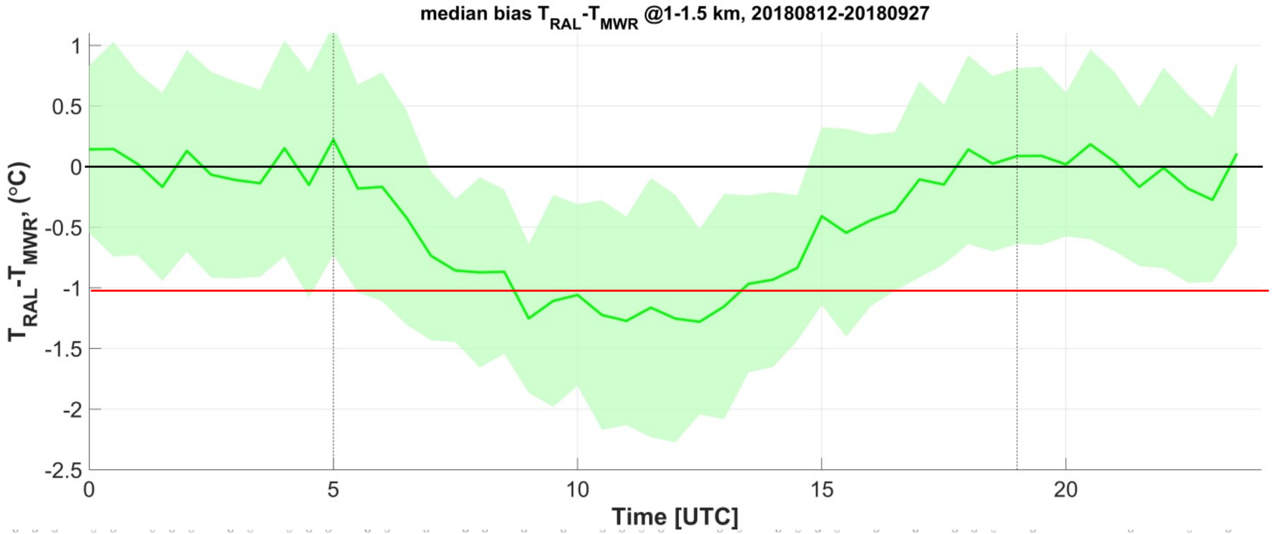
Mean nighttime bias RALMO-RS is **−0.12 K over 0- 5 km and -0.09 K over 5-12 km**. The mean RMSE is 1.1 K along the first 8 km.

RALMO has been calibrated relatively rarely, the mean bias and RMSE represent well the robustness and stability of RALMO



Validation of PRR temperature: daytime

The analysis of daytime bias and RMSE is still ongoing. Currently the daytime statistics suffer a mean 1 K negative bias and 1.5 K RMSE. The large difference between day and night is caused by the combined effect of imperfect dead-time and background correction. The $\underline{J_{low}/J_{high}}$ is highly sensitive to both saturation and background. <u>A difference of ±1% in the ratio can lead to a variation of ±2K</u>. The mean daily cycle of the temperature bias of RALMO with respect to the HATPRO MWR has been studied. It comes out that from sunrise to sunset the bias changes and reaches a maximum accordingly to the solar Zenith angle.



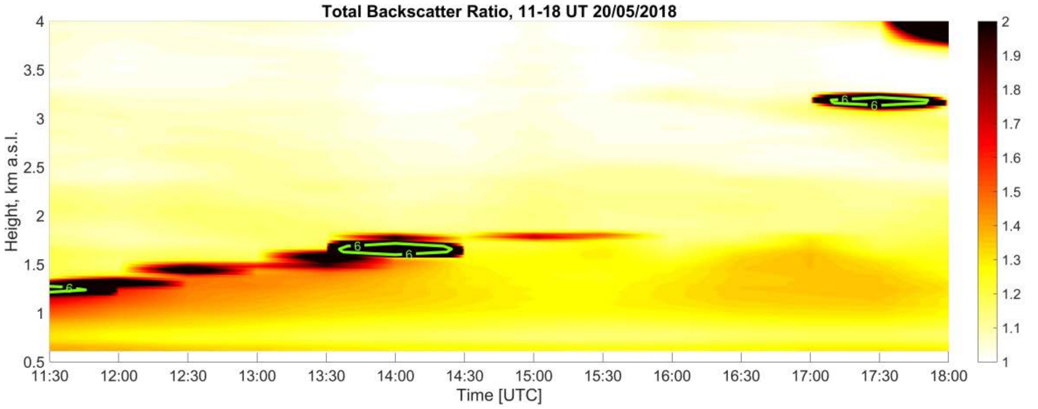
Measurement of supersaturation in liquid stratus clouds

A radiosounding-based validation of the relative humidity (RH) measured by RALMO has been performed by Navas Guzmán et al. (2019), finding that **in the first 2 km the RH suffers a mean systematic and total uncertainty of ΔRH= +2% ± 6 %RH**

Previous studies (Hudson et al. (2010); Martucci and O'Dowd (2011)) show that for different types of liquid stratus clouds forming within continental polluted or marine clean air masses, the **characteristic values of supersaturation span between 0.1 % to >1 %, respectively**.

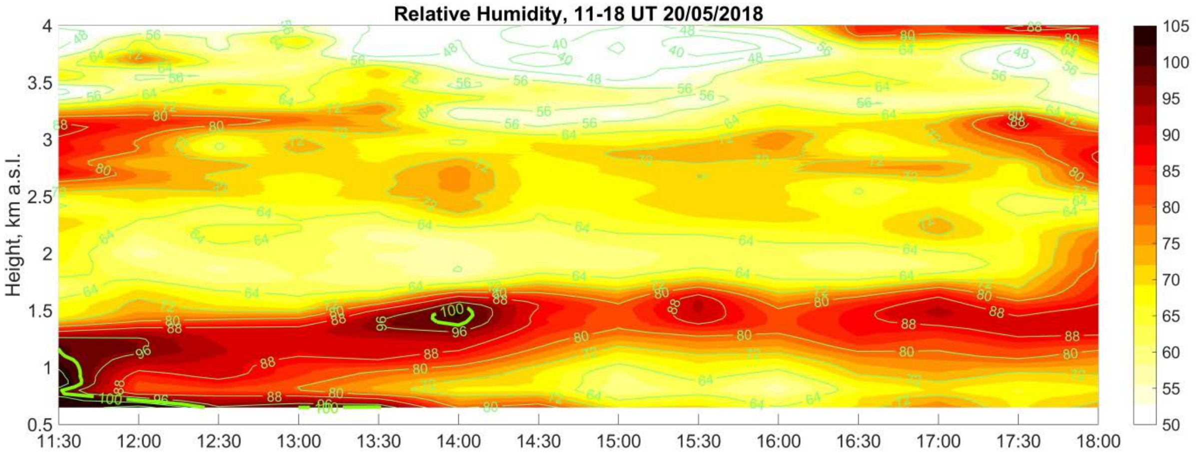
The RH retrieved from RALMO cannot be used quantitatively, as the relative error is bigger than the expected maximum supersaturation. Then a qualitative study about the occurrence of supersaturation in liquid clouds is performed instead.

Measurement of supersaturation in liquid stratus clouds



At the top of the developing convective boundary layer, fair-weather **cumulus clouds** form starting from very low altitude above the ground before 11:00 UTC and reaching ≈2 km between 14:00 UTC and 15:00 UTC. The RH reach **local maxima of supersaturation** correspondingly to the maxima in backscatter.

Supersaturation is observed at 11:30 UTC between 830 m and 1160 m asl (**ss = 100.43%−102.32%)** and at 14:00 UTC between 1400 and 1520 m asl (**ss = 102.25%−102.93%**). Correcting RH for its bias in the first 2 km, it turns that ss is achieved only at its high-end for the first event with ss = 0.32% and results in the range of values **ss = 0.25%−0.93%** for the second event



Summary

- Almost 1.5 years (July 2017-October 2018) of LIDAR pure rotational Raman temperature data have been compared to reference radiosounding temperature profiles at Payerne at 12~UTC and 00~UTC.
- The reference radiosounding systems are the Meteolabor SRS-C50 sonde and the Vaisala RS41, validated by direct comparison with the GRUAN-certified Vaisala RS92 sonde.
- The nighttime temperature profiles retrieved from RALMO PRR data are in excellent agreement with the reference radiosounding system showing a maximum mean cold bias of -0.12 K and a RMSE of ~1.1 K in the first 8 km.
- The daytime temperature validation is ongoing, trying to remove the background- and saturation-induced additional bias.
- A qualitative study to assess the supersaturation of water vapor in liquid stratus clouds has been performed, fitting very well the microphysical scenario of continental warm stratus supersaturation values.

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