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I: A 15-year climatology of solar background calibrated temperature profiles measured by the RAman Lidar for Meteorological Observations.

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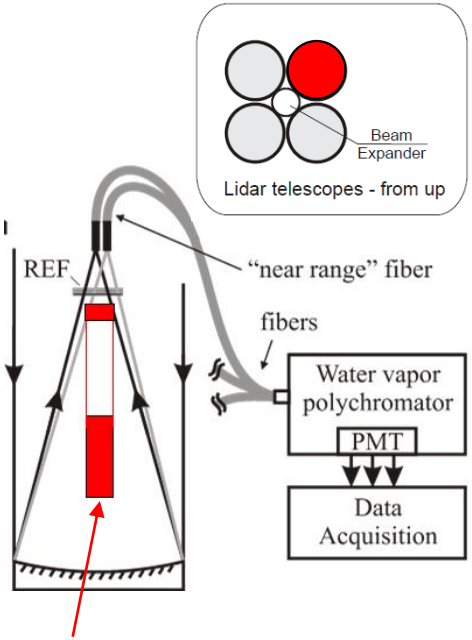
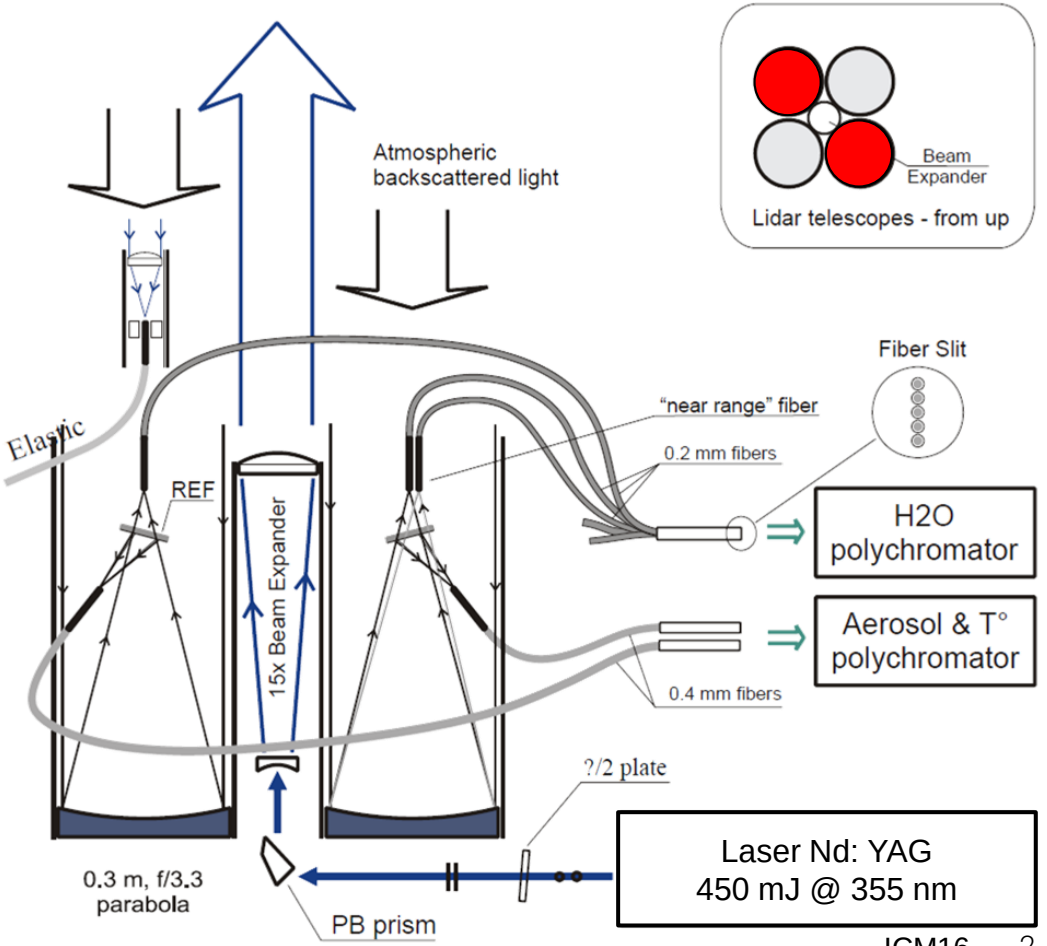
RAman **L**idar for **M**eteorological **O**bservations

- Fully automated day and night
- Operated in Payerne since 2008.
- 450 mJ laser-pulse energy, 30 Hz
- Analog and digital channels
- Holographic grating filter
- NI and Licel acquisition systems





See poster #70 upgrade of the MeteoSwiss Raman lidar RALMO for depolarisation measurements, R. Matthey

Solar background calibration

an application to PRR temperature

- Raman lidar equation: X denotes high-J or low-J rotational Raman channel.

$$N_{JX,t}(z) = C_{JX}\, P_0\, \frac{O(z)}{z^2}\, n(z)\, \Gamma^2_{\mathrm{atm}}(z) \left(\sum_{i=\mathrm{O_2,N_2}} \eta_i \sum_{J_i} \tau_{JX}(J_i) \left(\frac{d\sigma}{d\Omega} \right)^{(i)}_{\pi} (J_i) \right) + C_{JX}\, F^{\mathrm{bg}}_{JX}$$

- For *z* where atmospheric backscatter is negligible, (i.e., for all z > 45 km):

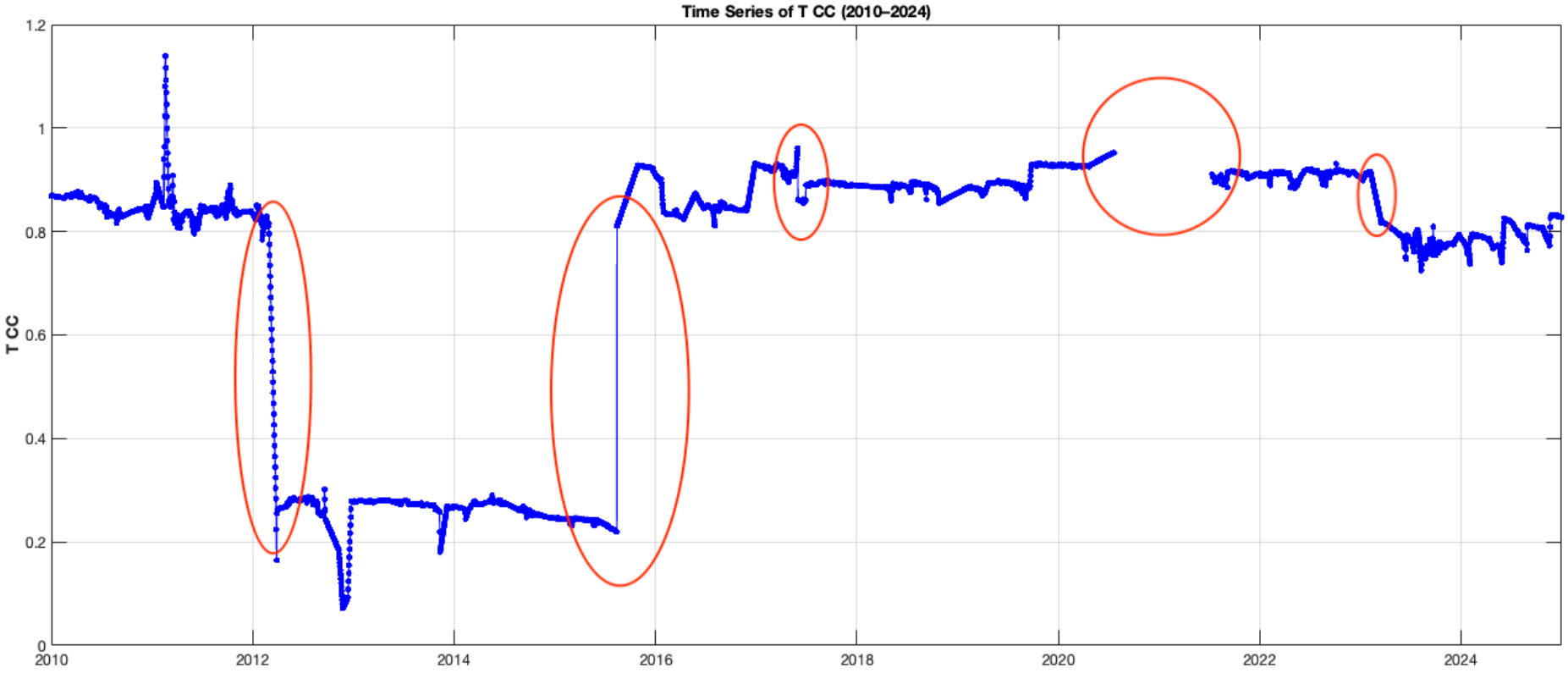
$$\frac{N_{JH}(z > 45\,\mathrm{km})}{N_{JL}(z > 45\,\mathrm{km})} = \frac{C_{JH}\, F^{\mathrm{bg}}_{JH}}{C_{JL}\, F^{\mathrm{bg}}_{JL}} \propto \frac{C_{JH}}{C_{JL}}$$

- The temporal evolution of the ratio of the lidar constants from t_0 to t:

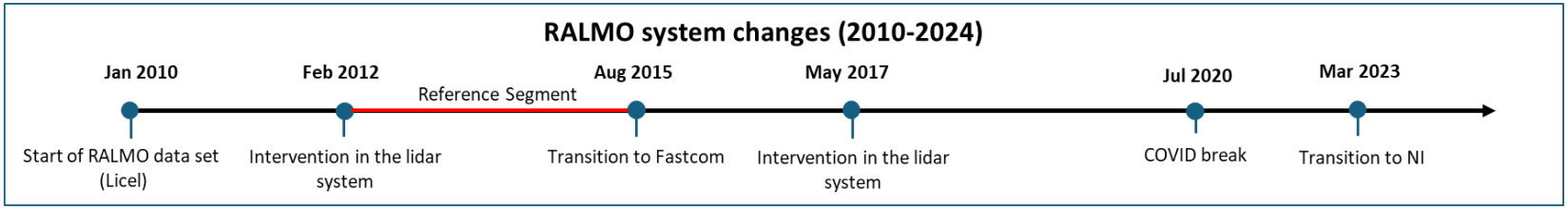
$$\frac{C_{JH}(t)}{C_{JL}(t)} = \frac{C_{JH}(t_0)}{C_{JL}(t_0)} \cdot \left(\frac{N_{JH}(t)}{N_{JL}(t)} \Big/ \frac{N_{JH}(t_0)}{N_{JL}(t_0)} \right)$$

z > 45 km

Background Calibration timeseries



Homogenization of RALMO data



- Identify system changes breakpoints (five)
- Select reference segment

(e.g., stable years, best agreement with RS (2012-2015))

→

- Estimate the step in the lidar data induced by the system change using $\Delta t = 1$ year.
- $(RALMO_{after} - RS) - (RALMO_{before} - RS) \approx RALMO_{after} - RALMO_{before}$

→

- Fit a smoothing spline to the step function
- Correct the full segment by the obtained bias

↓

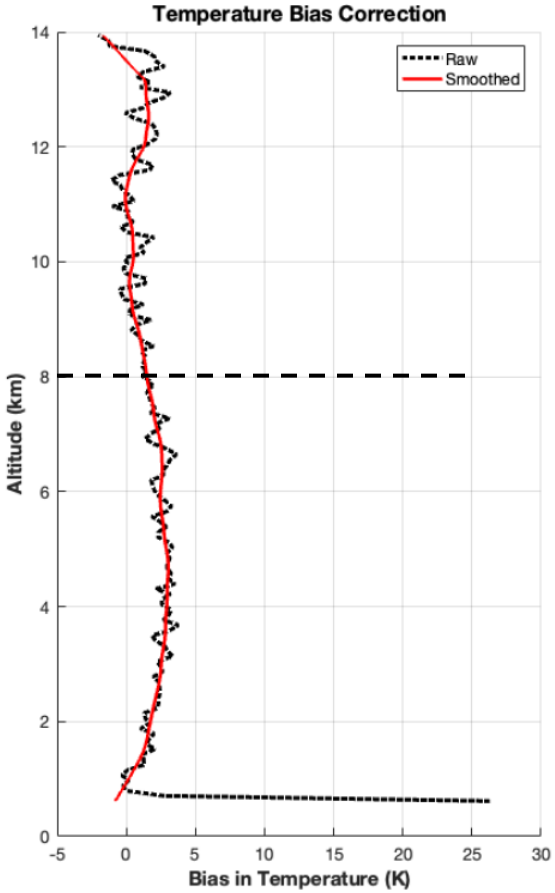
- The bias-corrected segment is the new reference for the next segment.
- Repeat the double difference procedure and correct for the bias.

←

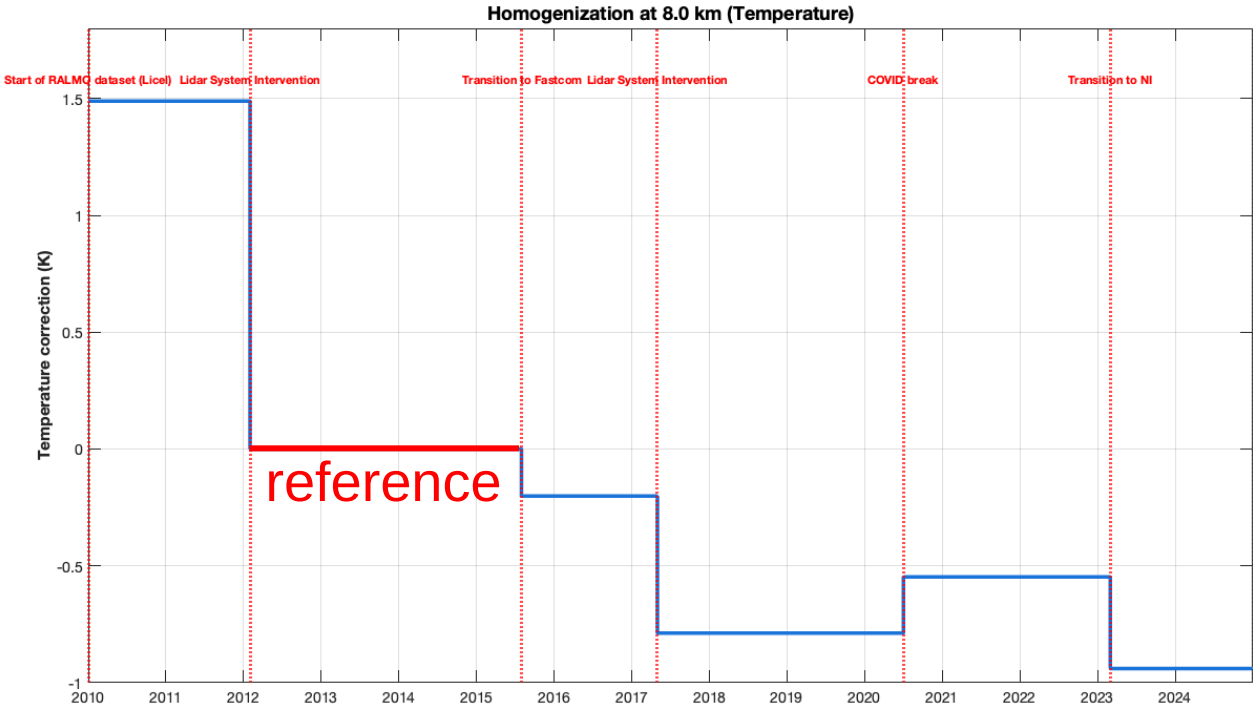
REFERENCE SEGMENT:

- Minimal instrument drift within each segment.
- Bias changes smoothly with altitude.
- Prefer clear-sky, night-time conditions for comparisons.

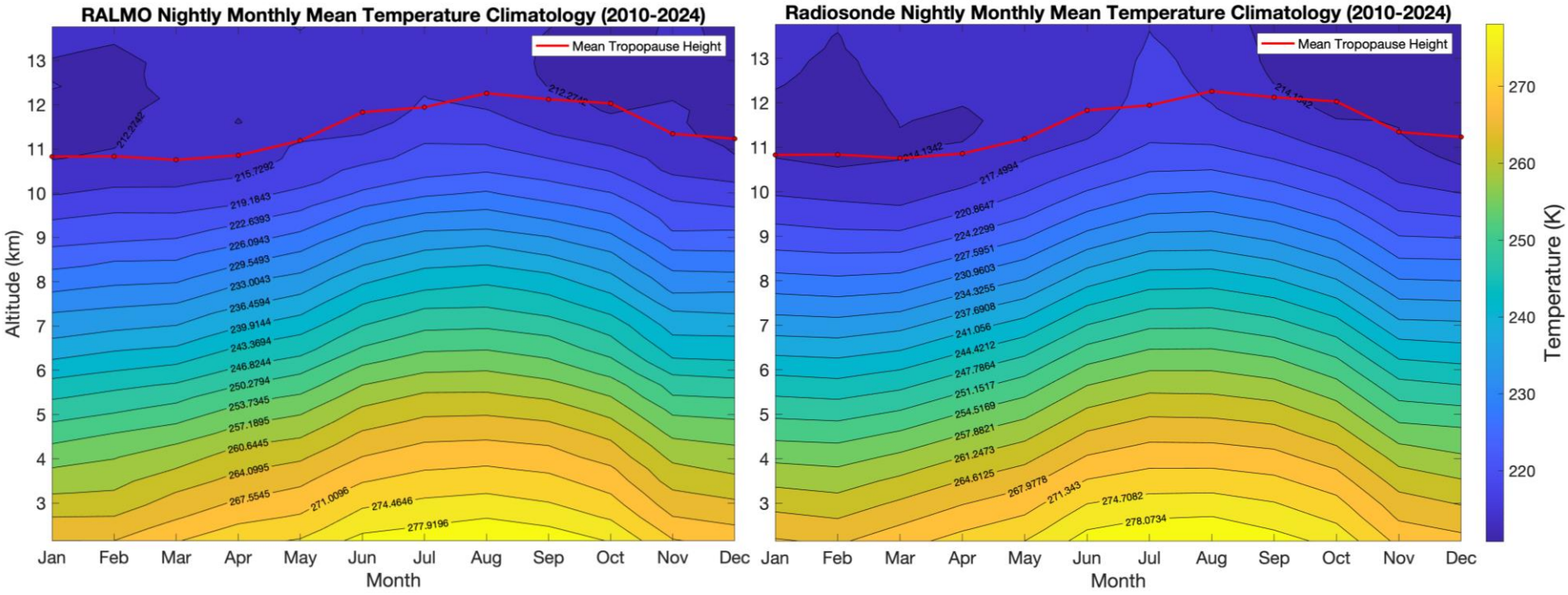
Mean differences $\Delta T_{\text{after-before}}$



Break-point 1, Feb 2012: $\overline{T}_{RAL}^{2013-2012} - \overline{T}_{RAL}^{2011-2012}$

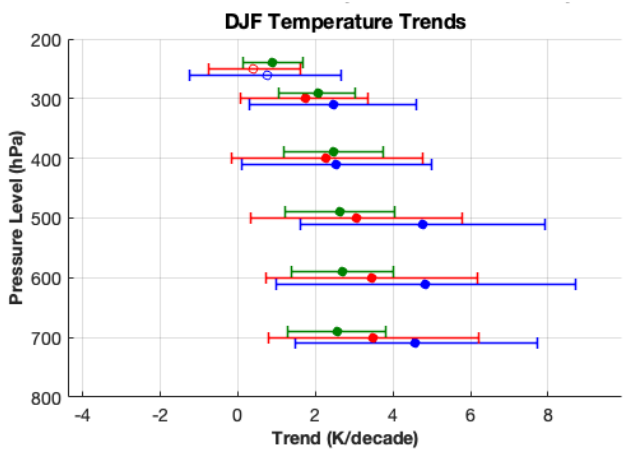


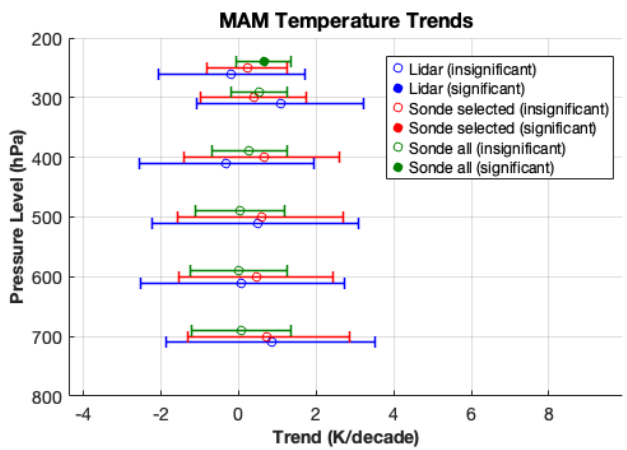
Nightly Monthly Mean Temperature Climatology (2010-2024)



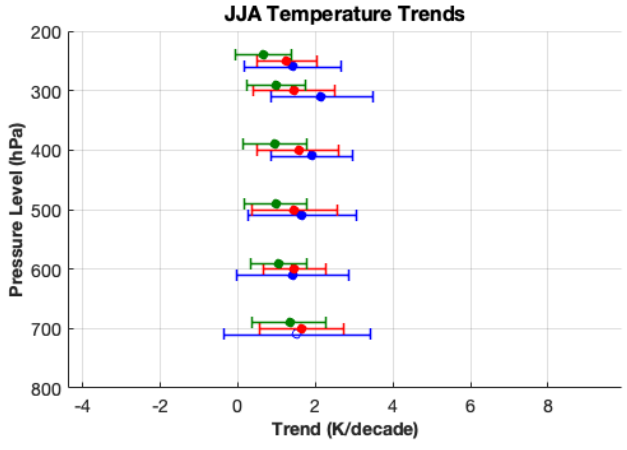
Seasonal T_{RAL} and T_{RS} trends

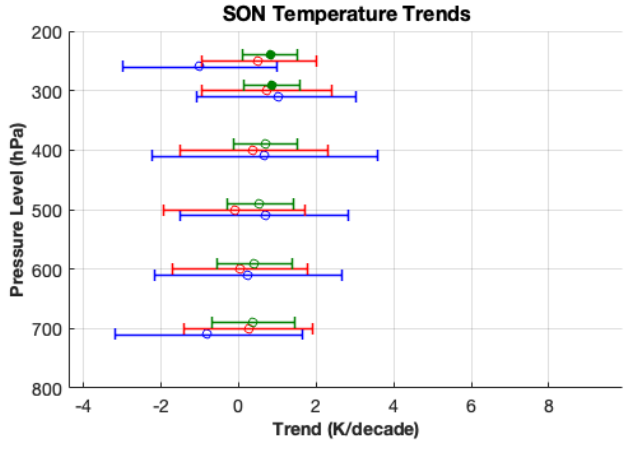
Stronger warming





Stronger warming





Summary

- The solar background calibration method for the temperature accounts for sudden changes as well as slow drifts of the system often associated with misalignments or ageing of optical components.
- The calibrated timeseries has been homogenized via correction of temperature biases at the known break-points.
- The calibrated and homogenized timeseries 2010-2025 have been compared with the reference radiosonde timeseries: good agreement through the troposphere up to the tropopause.
- **The seasonal trend analysis of Ralmo and RS data show a general warming across most pressure levels in all seasons.**
- Strongest warming occurs in DJF and JJA (especially at 500–800 hPa), with weaker, more variable trends in SON; statistical significance (≥90%) mainly in DJF and JJA.

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II: Homogenization of the Payerne radiosonde PTU data timeseries since 1959

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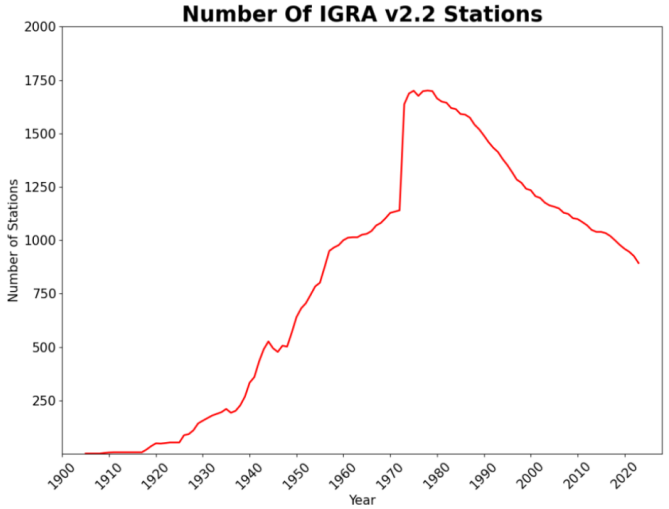
(π) Retired from MeteoSwiss

The Integrated Global Radiosonde Archive (IGRA)

IGRA uses quality assurance algorithms that check for **nonphysical values**, **inconsistencies** amongst PTU variables at one single and across multiple atmospheric levels, removes **climatological outliers**, **temporal and vertical inconsistencies**

There are 41 IGRA2 stations in Europe that have long continuous measurements started at least before 1970 and reaching today (2025)



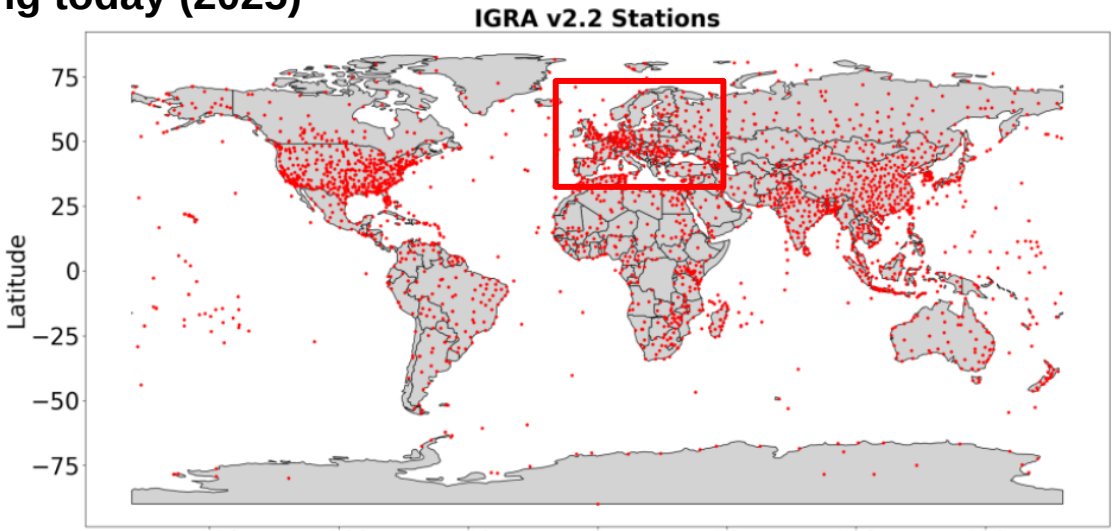


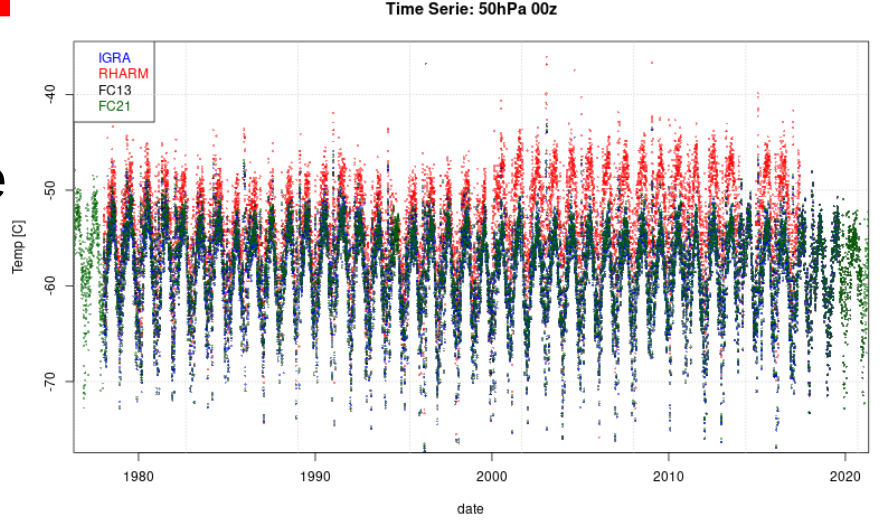
Figure 2: Map of the locations for all available IGRA v2.2 stations. (credit: Imke Durre and Bryant Korzeniewski)

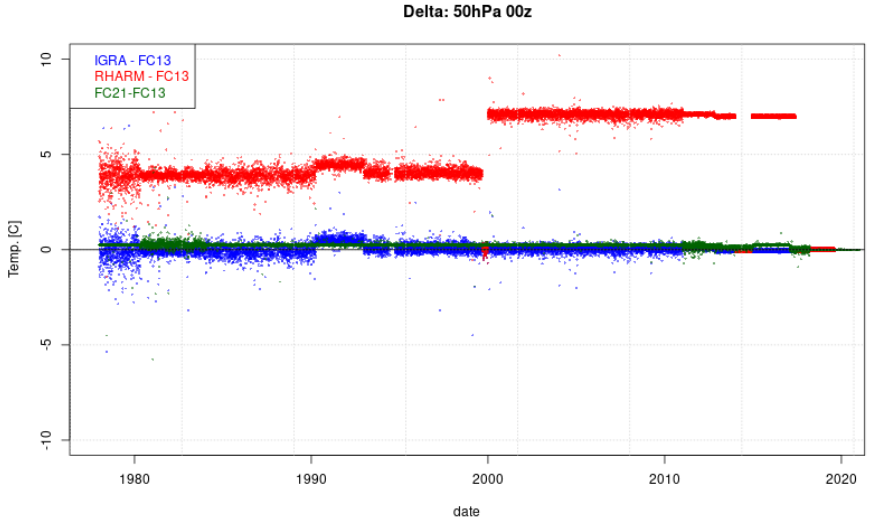
Why homogenization?

Apart from **IGRA**, also other projects like **RHARM** provide a standard homogenization over a global scale, including hundreds of stations. However, these global homogenizations use general correction terms and methodologies that can create additional inhomogeneities.

e.g.:

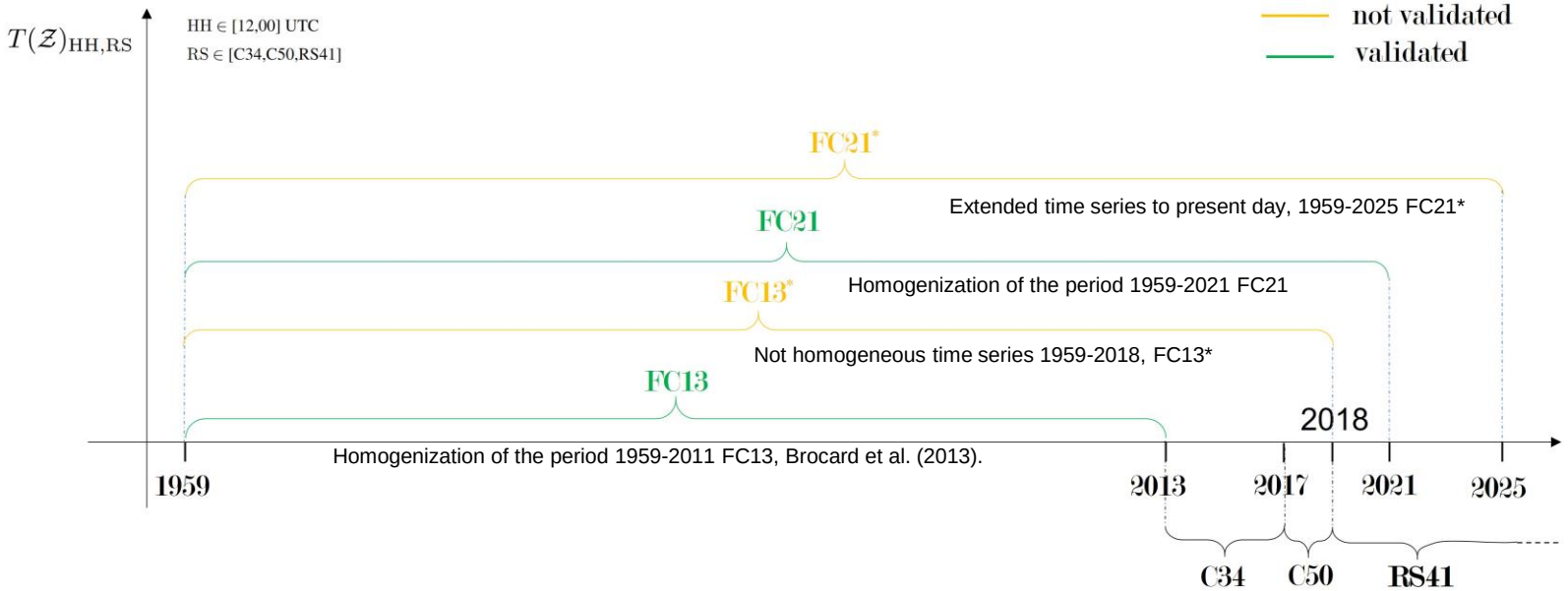
RHARM and IGRA vs FC13 and FC21. Large discrepancies at several levels, e.g. at 50 hPa at 00z.





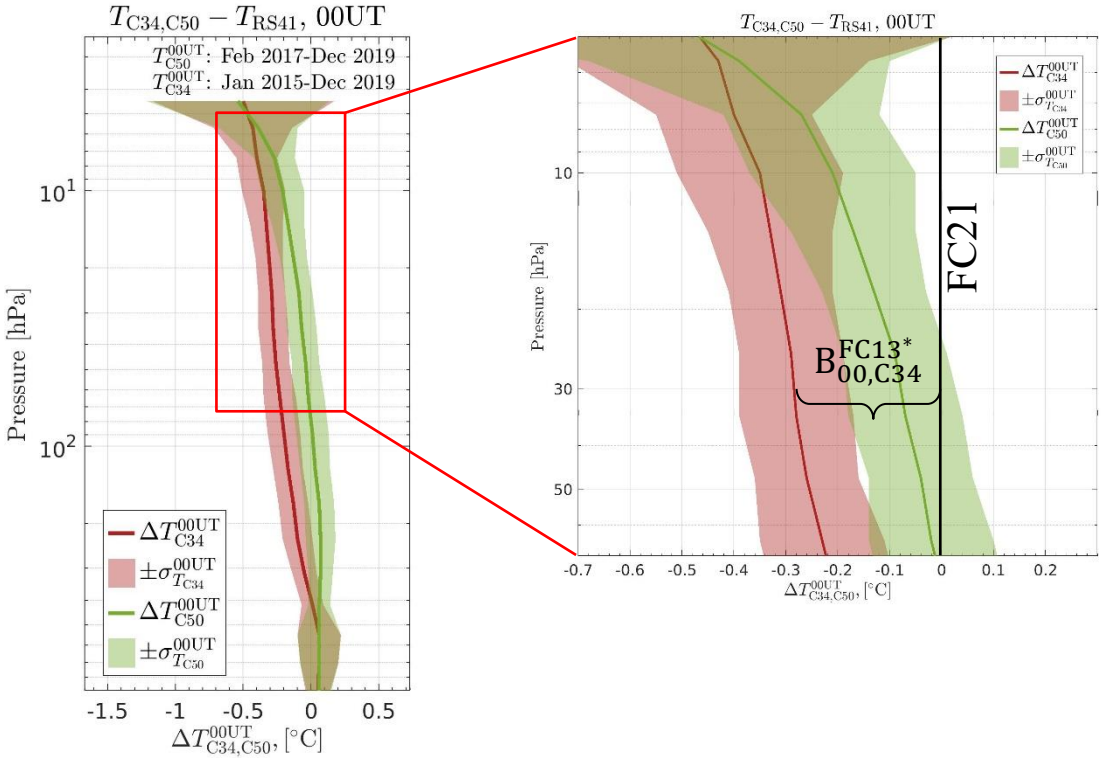
How we proceeded:

- **Start point**: homogenization of the PTU time series **FC13** since 1959 with reference to the SRS-C34 radiosonde (Brocard et al., 2013).
- Completion of the **FC13** time series with the SRS-C50 and the Vaisala RS41 (**FC13***) and homogenization with respect to the reference RS41 (**FC21**), Jeannet et al. (2022).
- Extension of the **FC21** homogenized time series to March 2025 (**FC21***) adjusted to the reference period of RS41 measurement 2018-2025.



Mean C34 and C50 bias profile at 00 and 12 UTC

Direct and indirect intercomparison of the different radiosonde models through the past years to homogenize the timeseries by correction of each radiosonde for their **mean biases** with respect to the RS41.



$$Z = 30 \text{ hPa}$$

$$T(Z)_{00,C34}^{FC13^*} = T(Z)_{00,C34}^{FC21} + B(Z)_{00,C34}^{FC13^*}$$

Normalization of T time series

$$T(Z)^{\mathrm{FC21^*}}_{\mathrm{HH,RS}} = T(Z)^{\mathrm{FC21}}_{\mathrm{HH,RS}} + \mathbf{B}(Z)^{\mathrm{FC21^*}}_{\mathrm{HH,RS}}$$

B is the potential bias that must be assessed by the break-point analysis and should be equal to zero (or be negligible) in order for the FC21* time series to be validated.

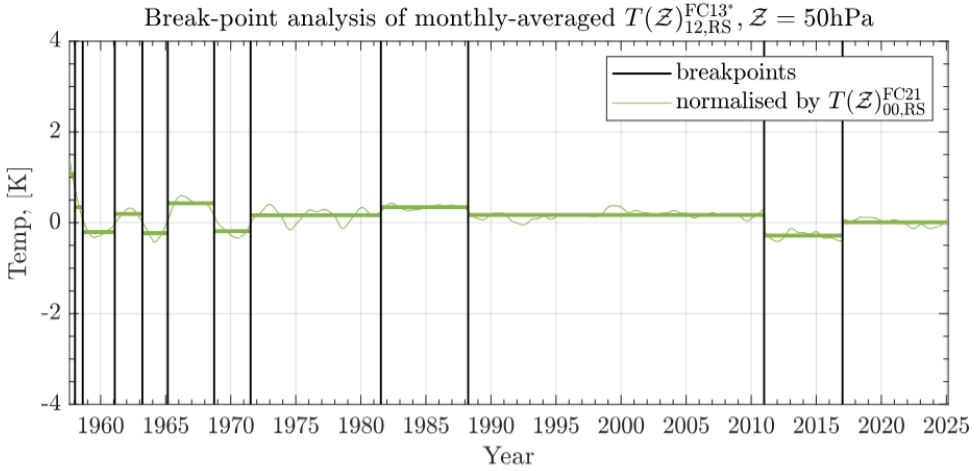
$$T(Z)^{\mathrm{FC21^*}}_{\mathrm{HH,RS}} - T(Z)^{\mathrm{FC21}}_{\mathrm{HH+12,RS}} = \Delta T^{\mathrm{FC21}}_{\mathrm{HH,HH+12,RS}} + \mathbf{B}(Z)^{\mathrm{FC21^*}}_{\mathrm{HH,RS}} \approx \mathbf{B}(Z)^{\mathrm{FC21^*}}_{\mathrm{HH,RS}}$$

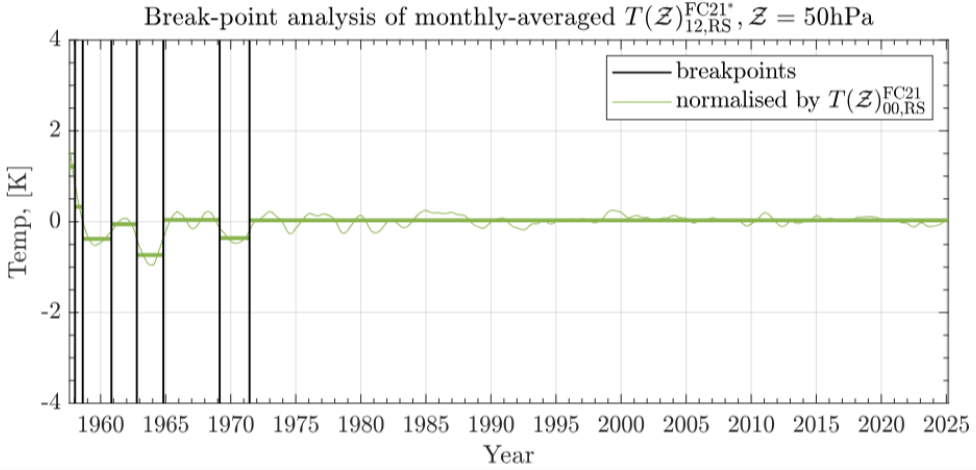
Under the hypothesis that the daytime and night-time temperatures do not significantly differ after correction for the solar radiation, the term $\Delta T^{\mathrm{FC21}}_{\mathrm{HH,HH+12,RS}}$ can be neglected in the stratosphere.

In the stratosphere, at e.g. $Z \in [30, 50, 70]$ hPa

The temperature values $T(Z)^{\mathrm{FC21}^*}_{\mathrm{HH,RS}}$ are normalized by the FC21 temperature values $T(Z)^{\mathrm{FC21}}_{\mathrm{HH+12,RS}}$ at HH+12. The normalization by $T(Z)^{\mathrm{FC21}}_{\mathrm{HH+12,RS}}$ allows to remove:

i. The low-frequency signal (seasonal cycle).
ii. The long-trends along the time series, including the warming of the atmosphere that occurred starting from the end of the 1980's as part of the global climate change.
iii. The high-frequency signal related to the short-term meteorology (few days), including rapid change of air masses most affecting the tropospheric layers.





The break-point analysis of the FC13* finds break-points at the transition times between one radiosonde model and the next. At each break-point, the bias $\mathrm{B}(Z)^{\mathrm{FC13^*}}_{\mathrm{HH,RS}}$ is comparable to the bias extracted from the bias profiles

For the FC21* time series, no break-points and no biases have been found by the analysis during the same period, confirming that the FC21* time series is homogeneous till March 2025

In a nutshell:

- The FC21* has been validated for homogenization purpose using the break-point analysis.
- The temperature measured at the level Z and time HH have been normalized by the FC21 temperature measured at the same level Z and time HH+12, so to remove all non-instrumental source of break along the FC21*.
- The extended temperature time series FC21* **is homogeneous** with respect to the RS41.
- The FC21* can then be used for climatological purposes including trend studies.

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