Cloud Effect on Temperature Profiles from Microwave Radiometry

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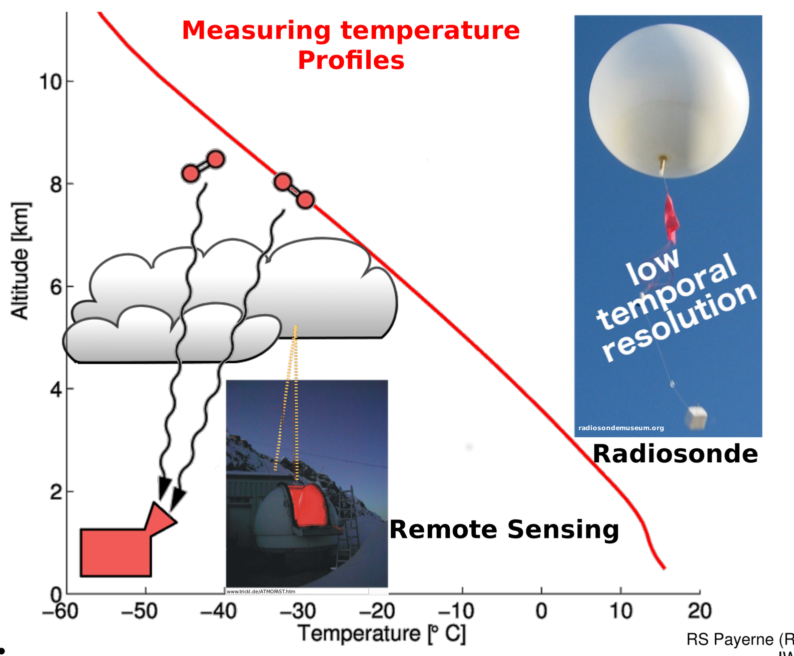
1. Background and Objective

Temperature profiles are important for the study of dynamical and radiative processes in the atmosphere and for weather and climate modeling.

▶ **How to measure temperature in the Troposphere?**

Remote Sensing:

- Continuous measurements (high temporal resolution)
- But: Many techniques are limited to clear sky situations

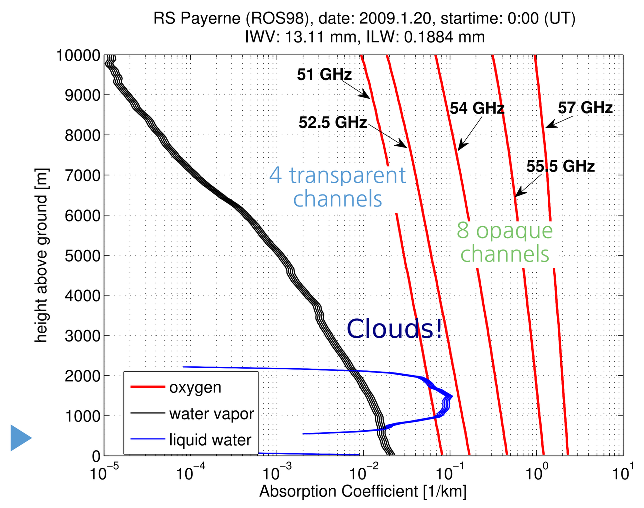


Radiosondes:

- Precise in situ temperature measurements
- But: temporally restricted measurements (twice per day)

Microwave radiometer:

- Continuous measurements during both clear-sky and cloudy conditions
- But: still sensible to cloud liquid water at certain frequencies



Absorption coefficient of oxygen and water[1]. The lower O_2 channels have similar coefficients to liquid water. ▶

Objective of this study:

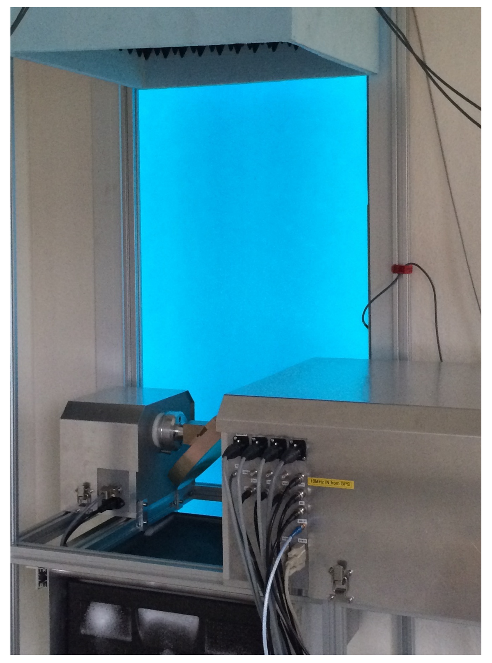
- Improve temperature measurements from a microwave radiometer (TEMPERA) by including clouds in the retrieval
- Investigate the sensitivity of the retrieval to different cloud models

2. Instruments

TEMPERA (TEMPErature RAdiometer)[2]:

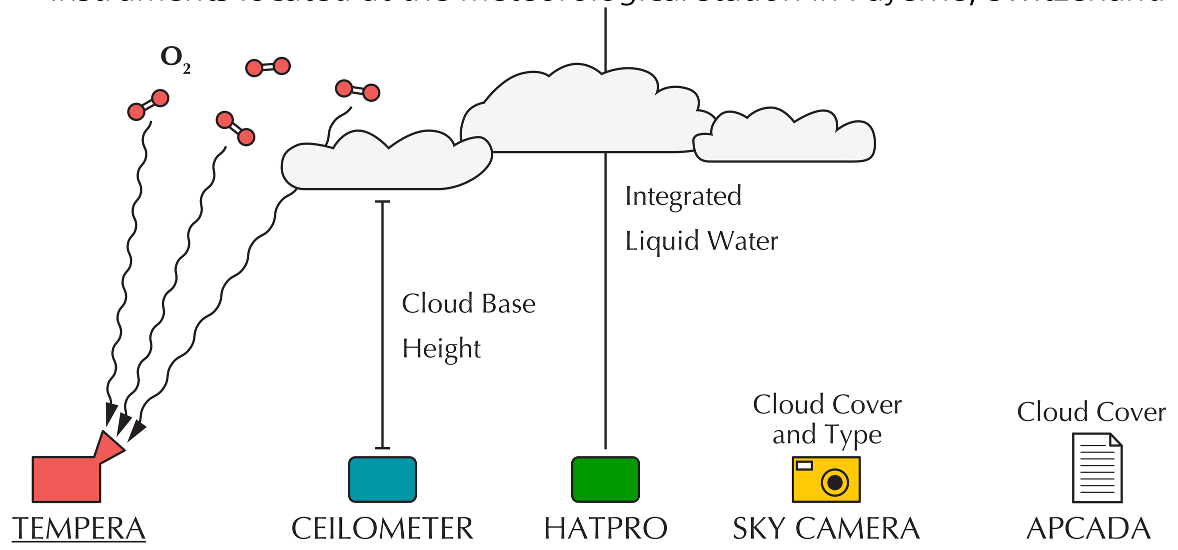
- Measures rotational transitions of molecular oxygen
- 12 frequency channels in the range 51-57 GHz
- Retrieval software package: ARTS2/Qpack2[3]

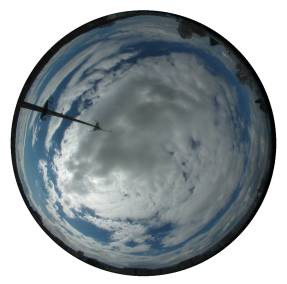
Cloud detection: several instruments are used to detect and characterize different types of clouds.



▲ Microwave temperature radiometer TEMPERA.

▼ Instruments located at the meteorological station in Payerne, Switzerland





◀ Image from the sky camera.

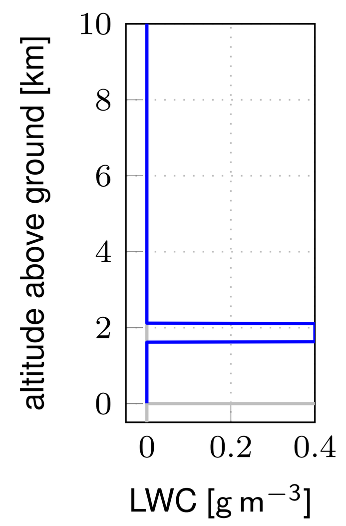
3. Temperature retrievals with a simple cloud model

▶ A simple cloud model with a constant liquid water content (LWC) was included into the temperature retrieval.

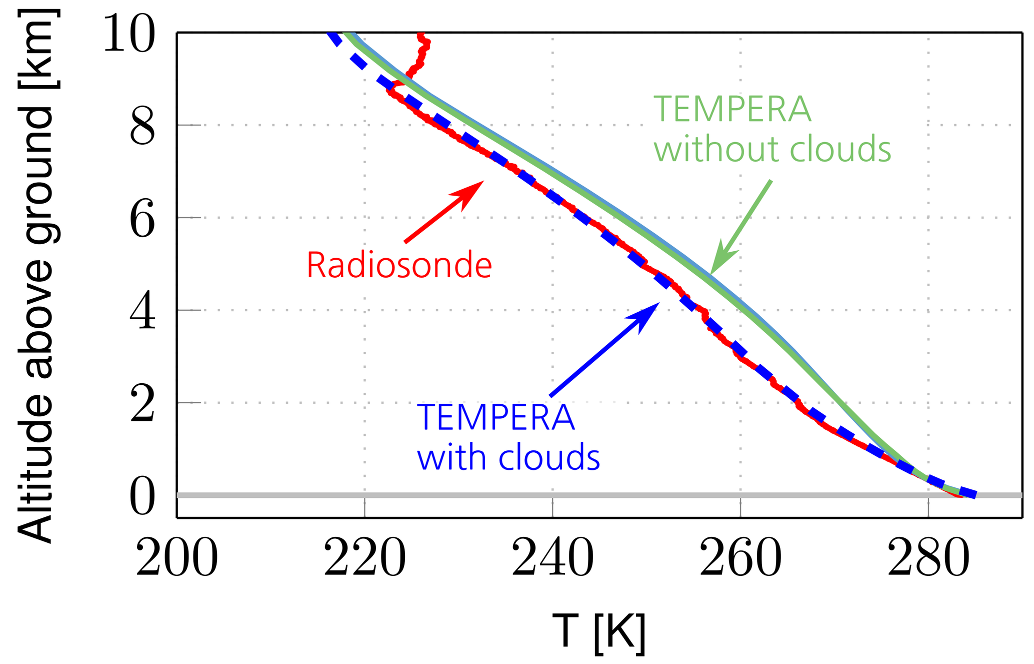
For this, the absorption coefficient of liquid water has been considered in the **radiative transfer equation**:

$$\underbrace{T_b(\nu, z_0)}_{\text{Brightness temperature at surface}} = \underbrace{T_0}_{\text{Cosmic background temperature}} e^{-\overbrace{\tau(z_1)}^{\text{Optical depth}}} + \int_{z_0}^{z_1} \overbrace{T(z)}^{\text{Temperature at height z}} e^{-\tau(z)} \boxed{k_a} dz$$

Absorption coefficient: includes O_2, N_2, water vapor, and liquid water (cloud model)

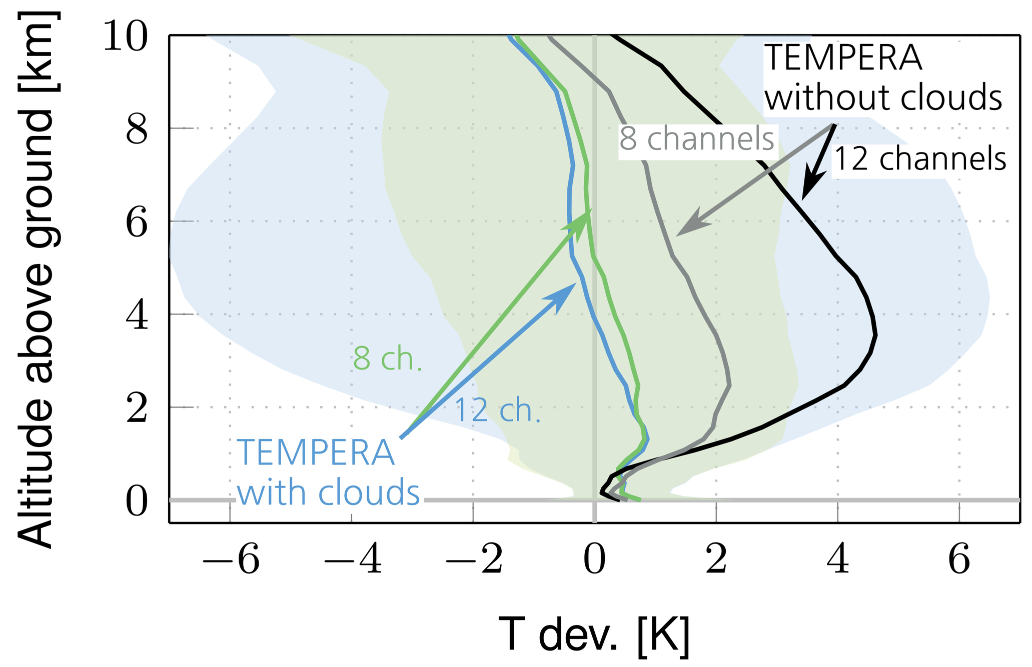


▲ Liquid water content (LWC) profile used as a cloud model in the retrieval.



▲ Temperature profile from TEMPERA (with and without clouds considered in the retrieval) and corresponding radiosonde profile (20-May-2015,10:56).

Substantial improvement of the temperature retrievals from TEMPERA compared to the radiosonde measurements for most of the cases.



▲ Mean bias between TEMPERA retrievals and radiosonde measurements (311 cloudy cases in 2014 and 2015). Shown is the mean bias for retrievals without including clouds (12 channels (black) and 8 channels (grey)), and for retrievals with a simple cloud model (8 channels (green) and 12 channels (blue)). The shaded areas represent the standard deviation.

▶ Two retrieval settings have been tested:

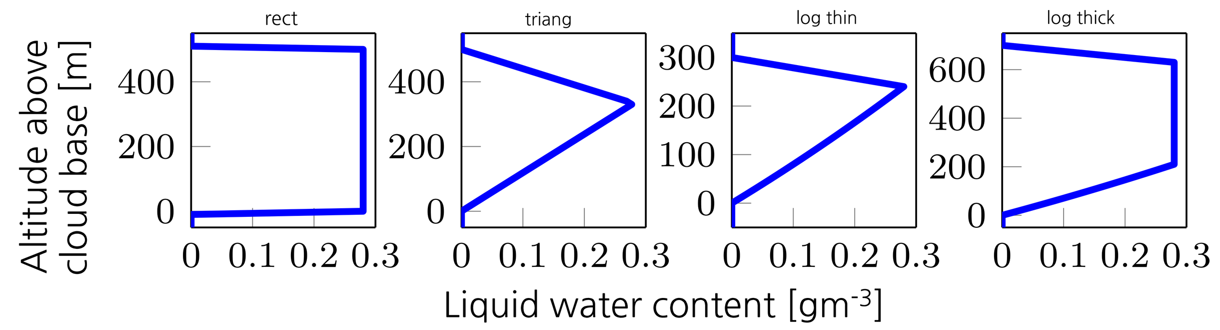
- using all 12 channels
- using only the higher 8 frequency channels (more opaque)

The averaged bias (TEMPERA-radiosonde) of two years of data shows a very good improvement when clouds are considered in the retrieval.

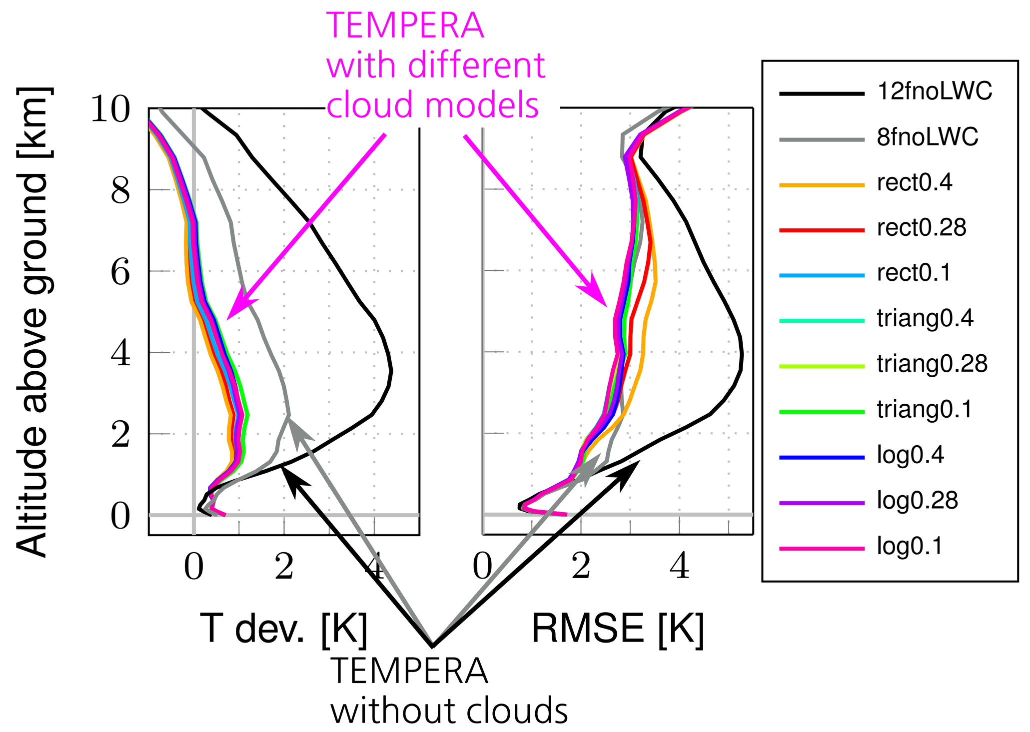
4. Temperature retrievals with different cloud models

▶ Cloud liquid water profiles of different shapes with different amounts of liquid water (0.1 gm^{-3}, 0.28 gm^{-3}, and 0.4 gm^{-3}) have been tested in the temperature retrieval.

Different cloud situations have been analyzed.

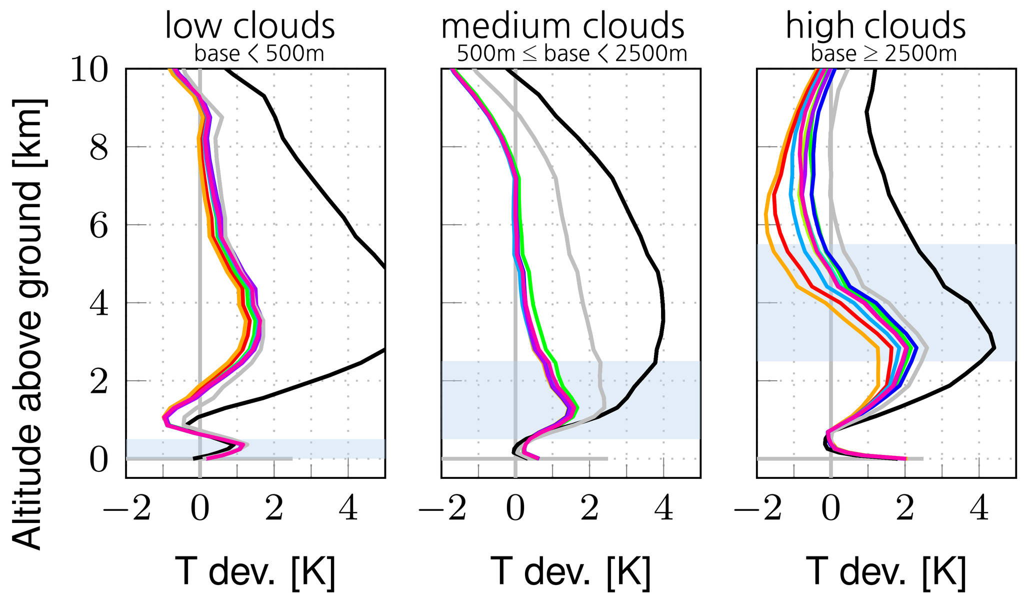


◀ Different shapes of liquid water profiles that are used as cloud models in the retrieval.



▲ Mean bias (TEMPERA-radiosonde) and root mean squared error (RMSE) for TEMPERA retrievals using different cloud models (colored lines). The black and grey lines show the bias when no clouds are included.

- The temperature bias is reduced when clouds are included
- The retrieval is sensitive to the chosen cloud model
- The sensitivity is on average small
- The RMSE with clouds is similar to the RMSE of eight channels without clouds (grey line)



▲ Mean bias (TEMPERA-radiosonde) for TEMPERA retrievals using the different cloud models for cloudy situations with different cloud base altitudes.

- For low clouds, the improvement when clouds are considered in the retrieval is smaller
- In situations with high clouds, the retrievals are more sensitive to the choice of the cloud model

5. Conclusions

- For cloudy conditions, the temperature retrievals from the TEMPERA radiometer improve substantially when liquid water is considered (mean bias with clouds ≈ ±1 K compared to around 2 to 4 K without clouds).
- Even though the eight higher (opaque) frequency channels are less sensitive to liquid water, the resulting profiles are also improved by considering clouds.
- The retrievals are sensitive to the distribution and the amount of liquid water in the cloud model (especially for high clouds and for clouds with a high total amount of liquid water). However, the averaged differences are only small.
- The more transparent frequency channels might be a source of uncertainty (larger standard deviations and root mean squared errors).

References:
[1] Navas-Guzmán, F., Stähli, O., and Kämpfer, N. (2014). An integrated approach toward the incorporation of clouds in the temperature retrievals from microwave measurements. AMT, 7(6):1619-1628.
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[3] Buehler, S., Eriksson, P., Kuhn, T., von Engeln, A., and Verdes, C. (2005). ARTS, the atmospheric radiative transfer simulator. Journal of Quantitative Spectroscopy and Radiative Transfer, 91(1):65-93.

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