Temperature retrievals with ground based, fully polarimetric measurements in the 60GHz Oxygen Band

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ARTS workshop 05.06.2024

Illustration from: www.jungfrau.ch

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The Microwave Group

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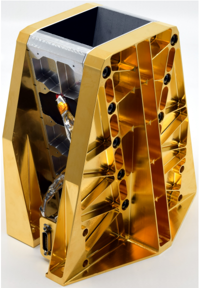
- Over 30 years of experience in microwave radiometer development.
- Currently 17 members.
- Combining technical innovation and atmospheric research.
- Development of ground based and space born radiometer technologies for remote sensing of: Ozone, Water Vapour, Temperature, and Wind.
- Building of high precision calibration targets and optics.
- Long term observations in Switzerland, Norway and South Korea.

The Ozone radiometer GROMOS-C at the Arctic research station Ny Alesund on Svalbard.



Calibration target for the Arctic Weather Satellite (AWS) radiometer.

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Waves in the atmosphere

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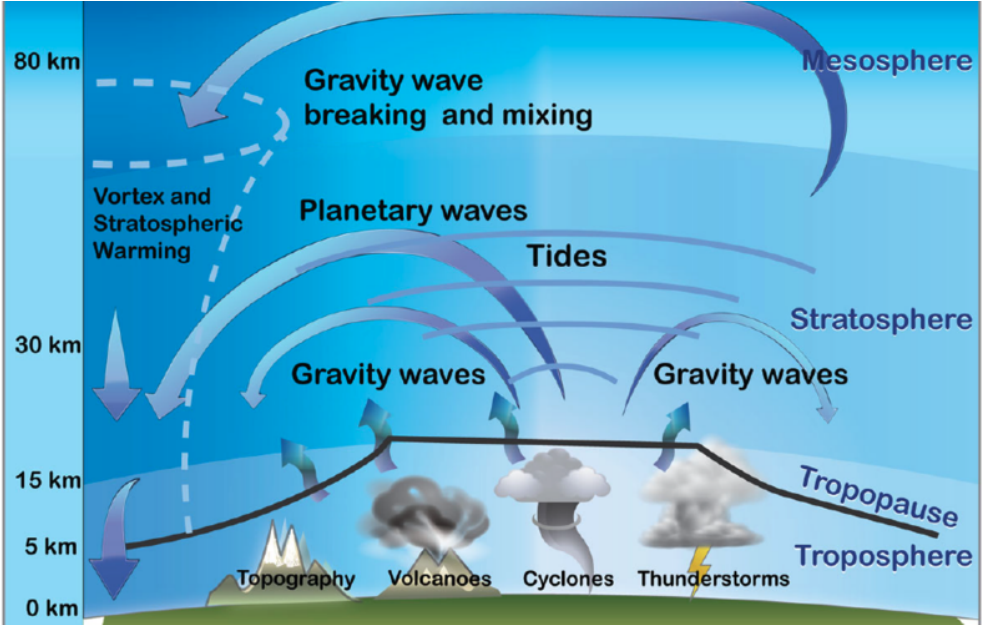
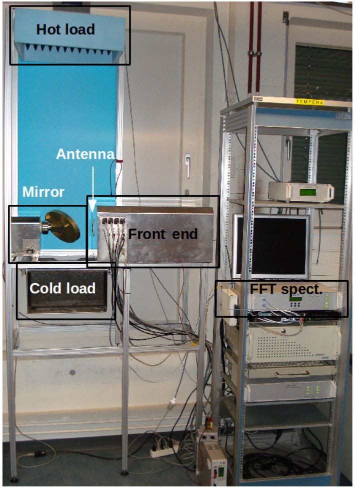
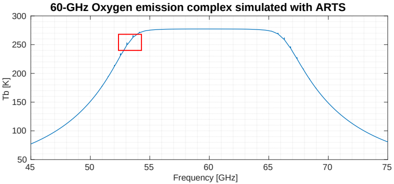


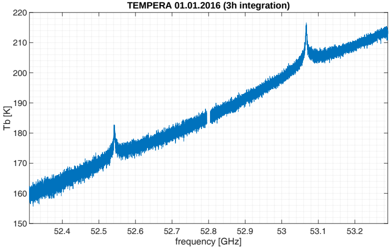
Illustration from: Blanc et al. 2018

TEMPErature RAdiometer (TEMPERA)



TEMPERA at the Institute of Applied Physics at the University of Bern. Navas-Guzmán et al. (2015)





Krochin et al. 2024

- Ground based microwave radiometer for atmospheric temperature sounding.
- Build in 2013 in the microwave group (Stähli et al. 2013).
- Operational since 2014
- Single polarisation
- 32’768 channels a 30 kHz bandwidth
- 1 GHz total bandwidth

The TEMPERA dataset

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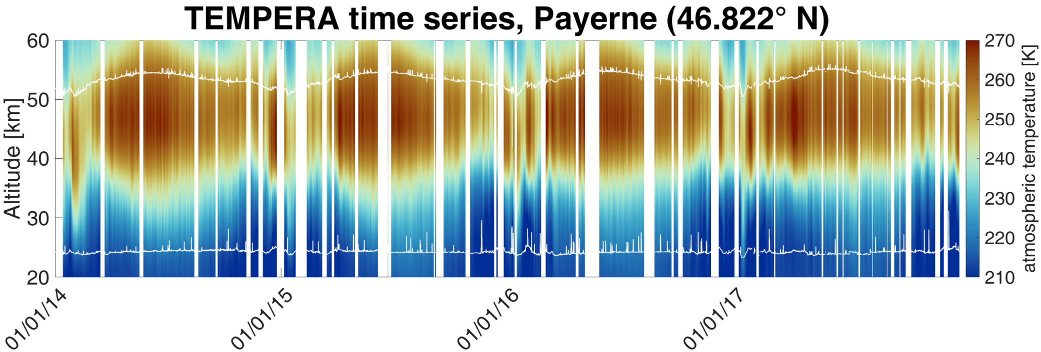
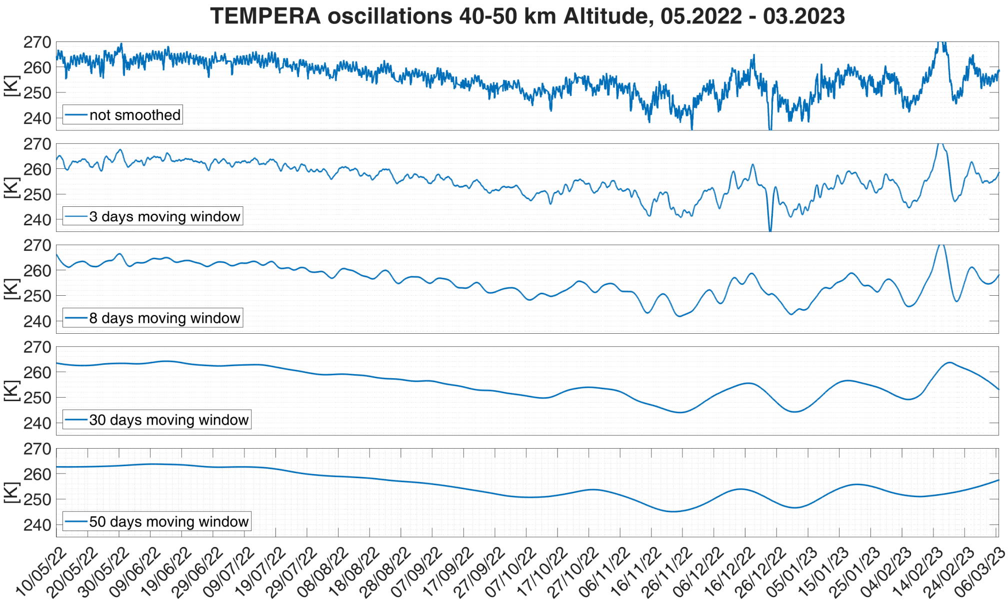


- Temperature profiles inverted with ARTS OEM.
- Effective altitude range is 25-50 km.
- 1-3 h time resolution

The TEMPERA dataset



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Thermal tide analysis from TEMPERA retrievals

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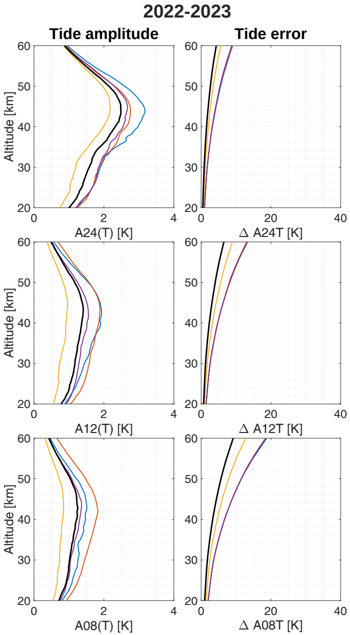

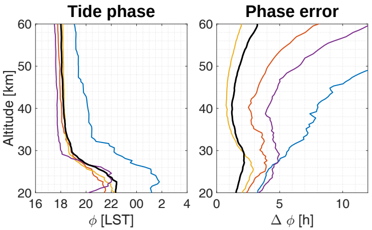

- Thermal tides are global scale gravity waves with periods of a fraction of a day (1, 1/2, 1/3).
- Forced by absorption of solar radiation by water vapour and ozone.
- Results of amplitudes and phases are in an expected range.
- First continuous observations of Thermal tides over longer time periods (Krochin et al. 2024).

$$T(t_k) = T_{0k} + \sum_{n=1}^{3} \left[a_{nk} \sin\left(\frac{2\pi}{P_n} t_k\right) + b_{nk} \cos\left(\frac{2\pi}{P_n} t_k\right) \right]$$

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TEMPERA measurement response

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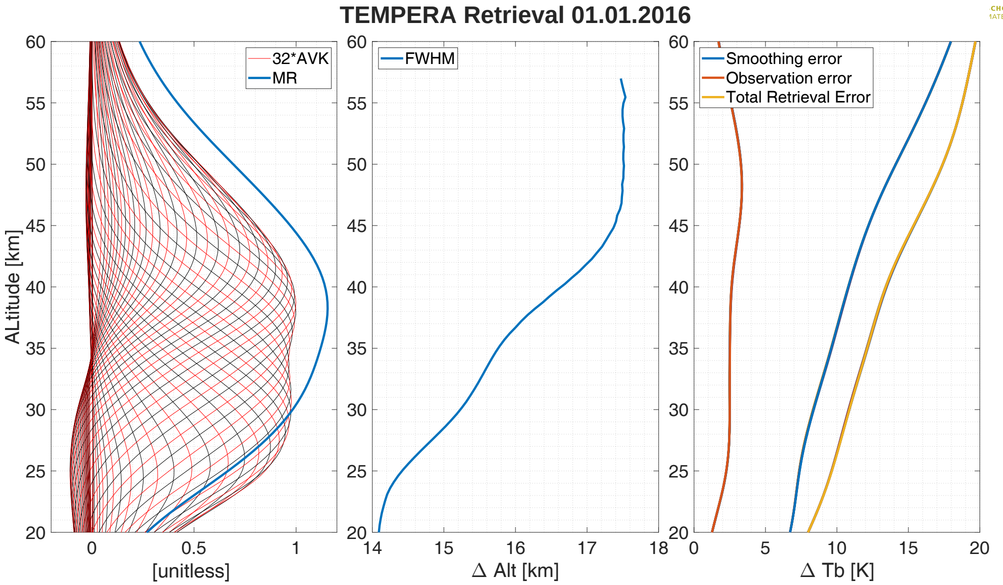

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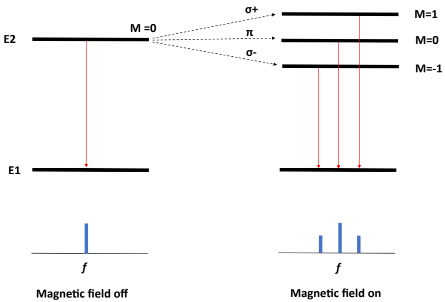
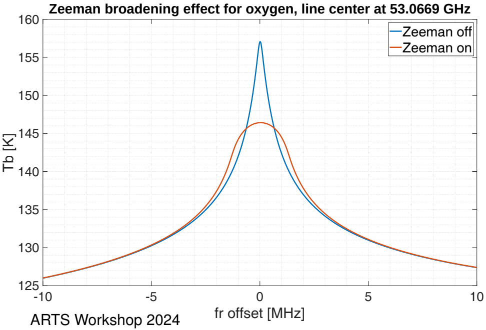
Altitude limitation: The Zeeman effect





$$\Delta f = \frac{\mu_B}{h}\left(g_{J''_N} M'' - g_{J'_N} M'\right) ||\vec{B}||$$

R. Larsson et al. 2019

Zeeman effect:

- O_2 magnetic moment couples to Earths magnetic field.
- One emission line splits up in several ones and appears broadened.
- Zeeman broadening dominates over pressure broadening above $\approx$ 40 km.

Zeeman line shape depends on:

- Magnetic field (strength and orientation)
- Line of sight
- Polarisation state

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The Stokes polarisation vector

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$$\mathbf{E(t)} = \left(\mathbf{E}_x + \mathbf{E}_y e^{i\Delta\phi}\right) e^{i\omega t}$$

$$I = |\mathbf{E}_x|^2 + |\mathbf{E}_y|^2$$

$$Q = |\mathbf{E}_x|^2 - |\mathbf{E}_y|^2$$

$$U = 2\Re\left\{\left\langle \mathbf{E}_x \mathbf{E}_y^* \right\rangle\right\}$$

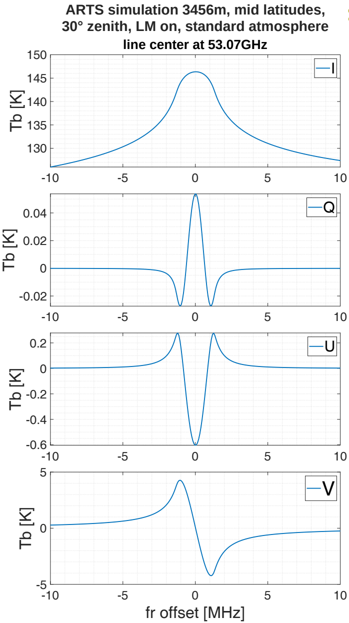
$$V = -2\Im\left\{\left\langle \mathbf{E}_x \mathbf{E}_y^* \right\rangle\right\}$$

$$I = |\mathbf{E}_{RCP}|^2 + |\mathbf{E}_{LCP}|^2$$

$$V = |\mathbf{E}_{RCP}|^2 - |\mathbf{E}_{LCP}|^2$$

$$\left\langle \mathbf{E}_x \mathbf{E}_y^* \right\rangle = \frac{1}{T} \int_T \mathbf{E}_x \mathbf{E}_y^* e^{-i\Delta\phi} dt$$

$$T \gg \frac{2\pi}{\omega}$$



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TEMPERA-C

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HFSJG High Altitude Research Stations
Jungfraujoch & Gornergrat

- Fully polarimetric microwave radiometer designed to measure all 4 Stokes components.
- Build and designed in the microwave group.
- Measures in the same frequency range as TEMPERA.
- Installed at the Jungfraujoch research station (3’456m a.s.l.) since March 2024.
- 2 x 4096 channels a 24 kHz and total bandwidth of 100 MHz for each of the 4 Stokes components.

TEMPERA-C calibration: Theory

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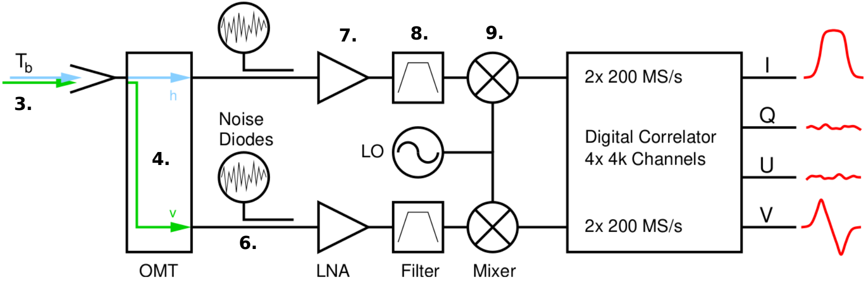
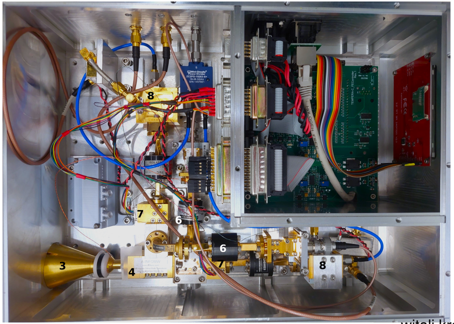


Ideal receiver:

$$V_a = |g_a|^2 \langle E_a E_a^* \rangle + V_{Na}$$
$$V_b = |g_b|^2 \langle E_b E_b^* \rangle + V_{Nb}$$
$$V_X = \langle g_a g_b^* E_a E_b^* \rangle + O_X$$



TEMPERA-C calibration: Theory

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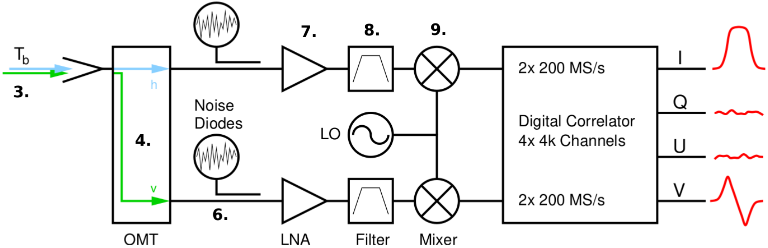

In reality:

$$V_a = |g_a|^2 \langle E_a E_a^* \rangle + |g_a|^2 |c_b|^2 \langle E_b E_b^* \rangle + 2\Re\left\{\langle g_a^2 c_b^* E_a E_b^* \rangle\right\} + V_{Na}$$

$$V_b = |g_b|^2 \langle E_b E_b^* \rangle + |g_b|^2 |c_a|^2 \langle E_a E_a^* \rangle + 2\Re\left\{\langle g_b^2 c_a^* E_b E_a^* \rangle\right\} + V_{Nb}$$

$$V_X = \langle g_a g_b^* \left(1 + c_a^* c_b\right) E_a E_b^* \rangle + \langle g_a g_b^* c_a^* E_a E_a^* \rangle + \langle g_a g_b^* c_b E_b E_b^* \rangle + O_X$$

$$g_a g_b^* = |g_a||g_b| e^{\delta_X i}$$

$$g_a^2 c_b^* = |g_a|^2 |c_b| e^{\delta_a i}$$

The coefficients $c_a, c_b, \delta_X, \delta_a, \delta_b$ can be found by using a rotating polarised grid (Gasiewski et al. 1993).

TEMPERA-C calibration: Results

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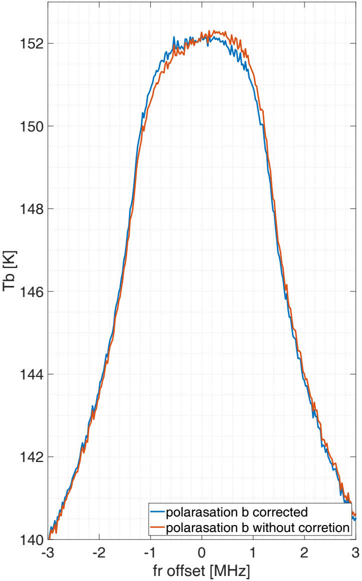

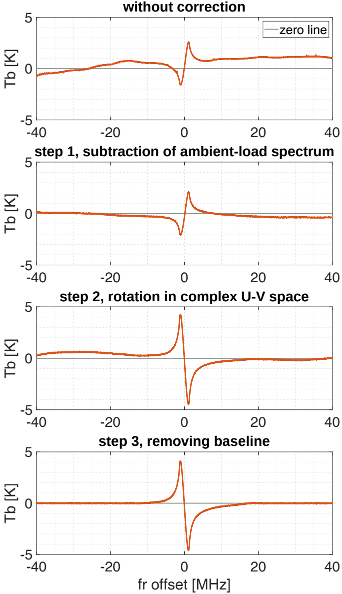

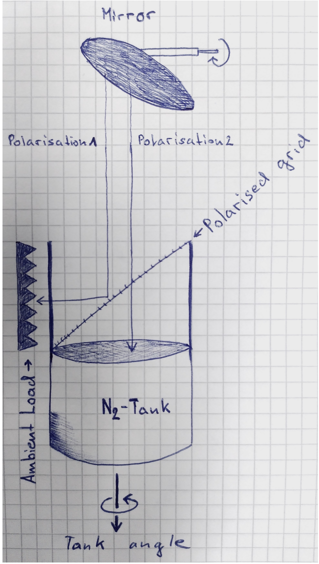

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Line Mixing

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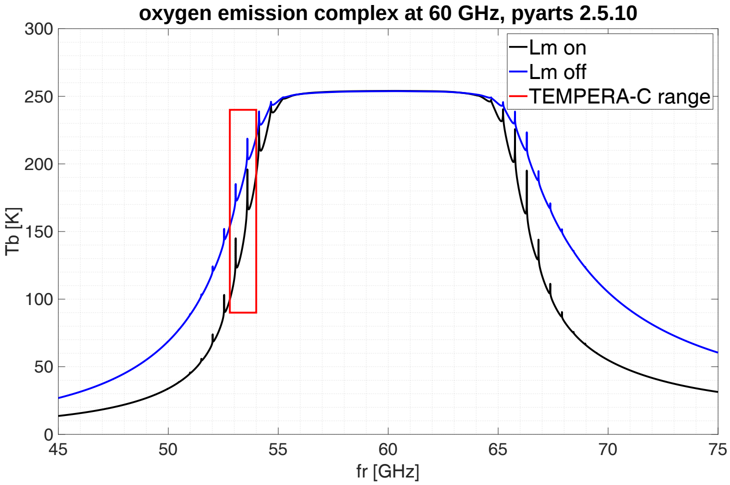
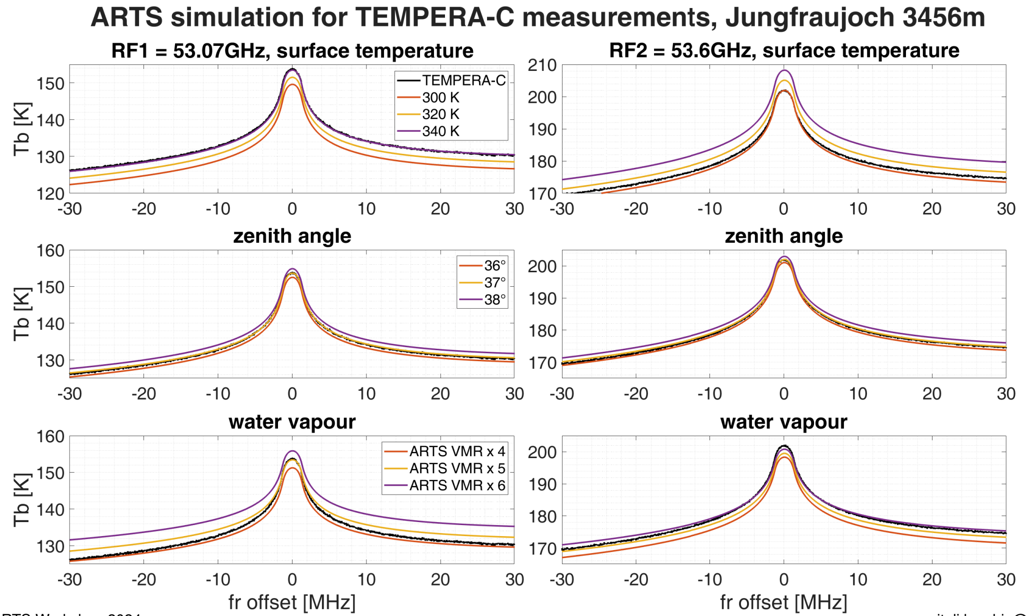


- Line Mixing: Collisions with broadening gas lead to a population transfer between rotational states.
- Dominates in the troposphere.
- Before: Tropospheric correction with high error, and lower altitude limit of 25 km.
- Now: Simultaneous inversion for all altitudes and lower altitude limit around 15 km.

TEMPERA-C forward model study



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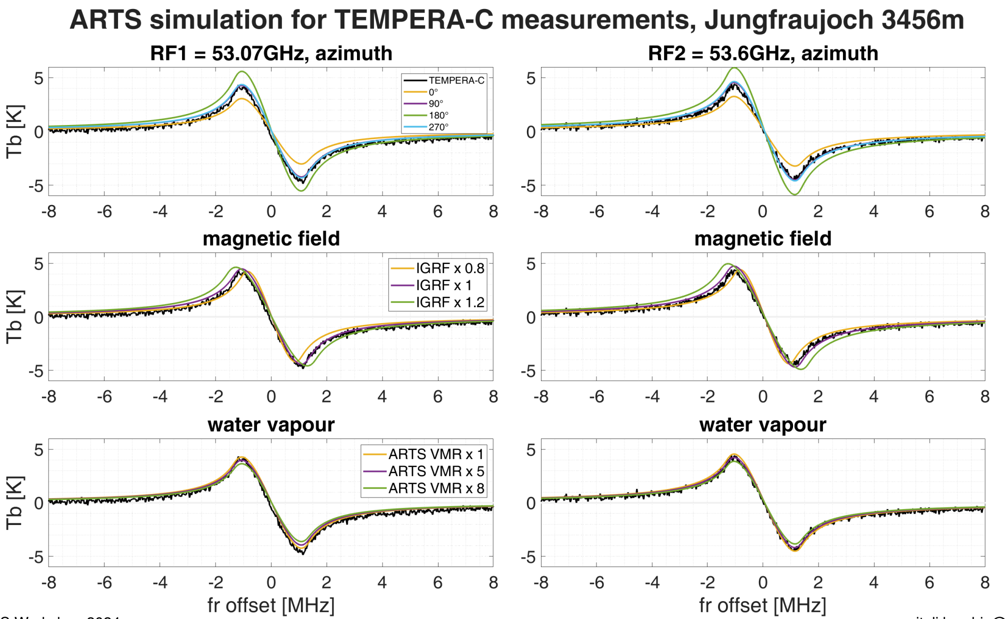
TEMPERA-C forward model study



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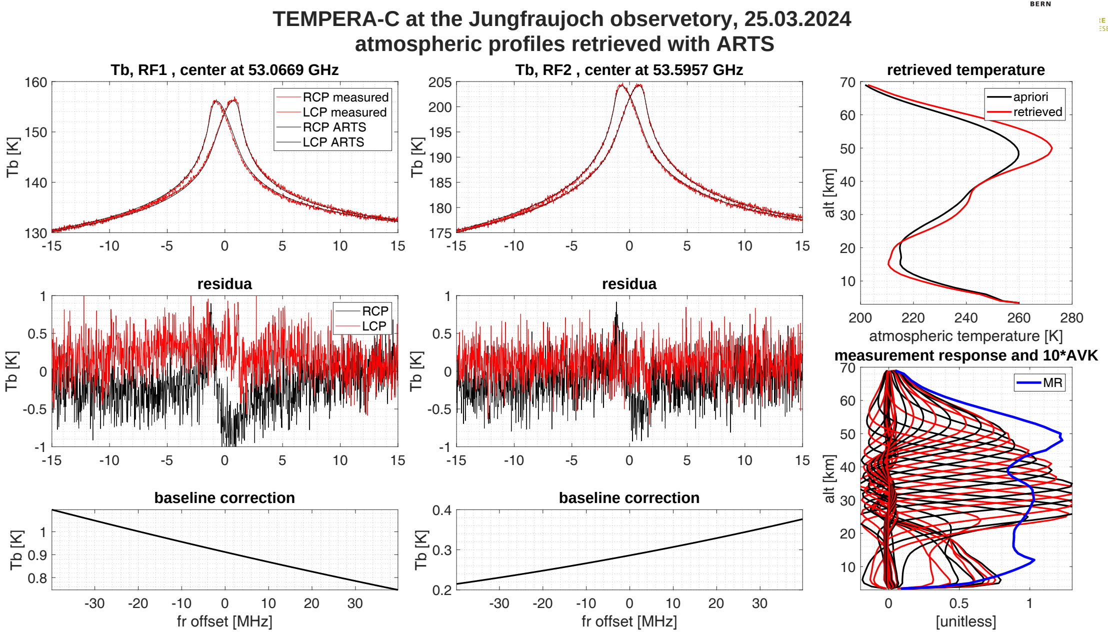
TEMPERA-C first inversion with ARTS OEM



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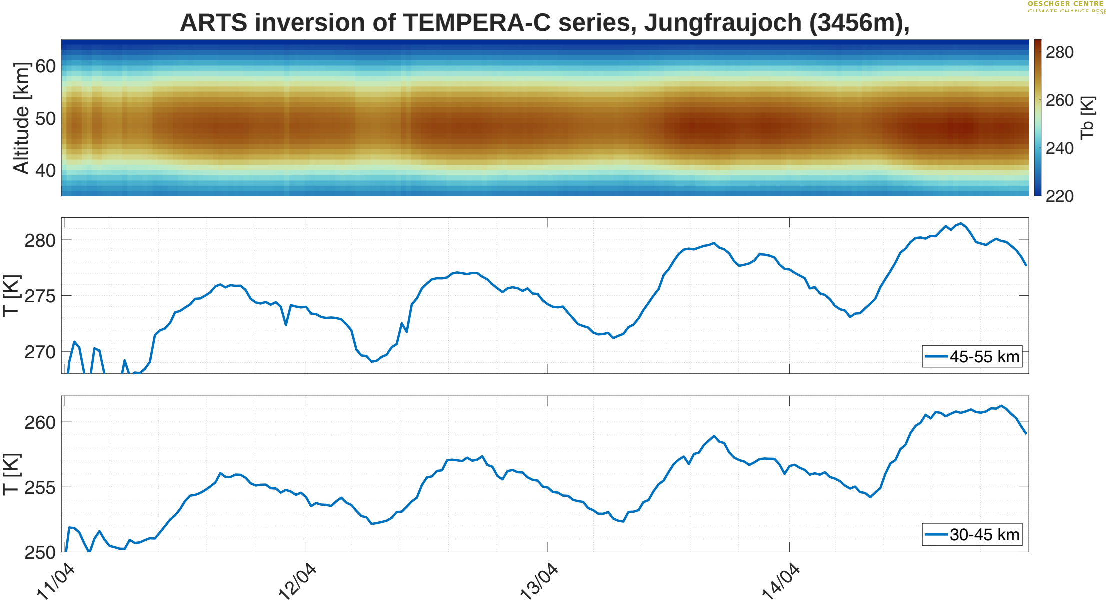
TEMPERA-C atmospheric time series



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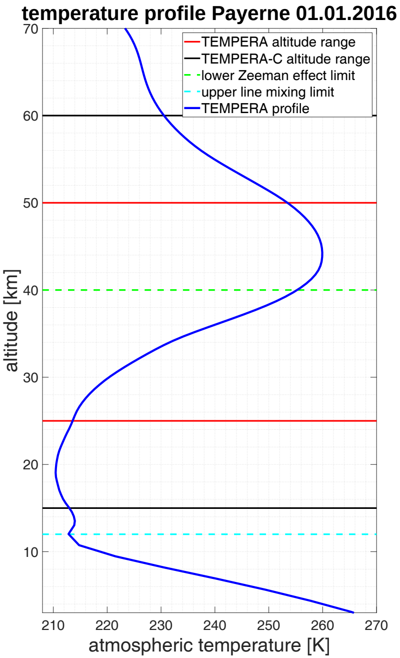
Summary

- Ground based radiometry provides continuous atmospheric measurements with a high time resolution.
- Zeeman broadening dominates temperature inversion in the mesosphere by broadening the line shape.
- Line mixing affects tropospheric emission spectra.
- Fully polarimetric observations increases the altitude range for temperature inversions.



Thank you for your attention
Please feel free to ask questions

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