Novel polarimetric temperature radiometer for the middle atmosphere

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1 Project description

The dynamics in the middle atmosphere (∼12–80 km) are a substantial research topic to improve climatological models and long-term climate predictions. The global circulation in these layers of the atmosphere is driven by several types of atmospheric waves, which are generated in the troposphere (∼0–12 km) and stratosphere (∼12–50 km) and propagate vertically, where they grow in amplitude due to the barometric pressure decrease. These waves alter the energy and momentum balance and, as a result, force the global circulation into patterns that differ from a purely radiation-driven atmosphere. Implementing wave activity in numerical models is crucial for modeling the circulation of the middle atmosphere. On the other hand, models with a poor representation of the upper atmospheric layers will deviate from the real atmospheric state in long-term predictions.

Continuous monitoring of parameters like temperature and wind is of great importance to improve our understanding of the wave-driven dynamics in the middle atmosphere. Most of the temperature observations in these altitudes are derived from data from satellite missions, for example, (Forbes et al. 2006). However, space-born datasets are limited by the orbital geometry, so the time resolution for temperature profiles at specific locations is several hours. This low time resolution limits the ability to detect higher-frequency waves such as gravity waves and tides.

In contrast, ground-based microwave radiometry is a robust passive remote sensing technique that provides continuous measurements with a comparably high time resolution of one hour or better and is more resilient to tropospheric weather conditions during day and night. Currently, the Microwave group is developing a new temperature radiometer tailored to perform continuous temperature soundings for the middle atmosphere shown in Figure 1 as breadboard setup Sphinx observatory.

Figure 1: TEMPERA-C setup in the Sphinx-laboratory. The microwave signal is observed through the (microwave transparent) window on the left-hand side.

1.1 TEMPERA-C

TEMPERA-C is a newly developed, fully polarimetric ground-based radiometer, designed for continuous temperature monitoring in the middle atmosphere. It measures the fine structure emission lines of atmospheric oxygen at 53.07 GHz and 53.6 GHz with a high-resolution digital correlator. The innovation is that the new instrument splits the polarization of the incoming microwave radiation into the 4 Stokes parameters. Compared to single-polarization instruments, the fully polarimetric technique improves the altitude coverage for temperature retrievals. In addition, the Zeeman split of the emission spectra allows the retrieval of features of the Earth's magnetic field.

1.2 The advantage of operating at a high altitude

Microwave radiometry is a passive remote sensing technique where the atmosphere's microwave emission is measured. Microwave emitters in the atmosphere are oxygen, ozone, and water vapour. Signals emitted in the middle atmosphere and received on the ground have to propagate through the lowest atmospheric layers with the highest density and highest concentration of water vapour. To observe the middle atmospheric signal, it has to be corrected for the influence from the lowest layers, leading to a high error. At the altitude of the Sphinx-observatory (3570 m asl), the air is comparably dry (Figure 2a) and the water vapour contribution is about a factor of 7 lower compared to Bern (550 m asl). Also, the contribution from tropospheric oxygen is lower by roughly a factor of 2 (Figure 2b), and the signal of the very weak V-Stokes component (Figure 2c) is higher by roughly 20 %. Such a low tropospheric influence is unique in ground-based radiometry.

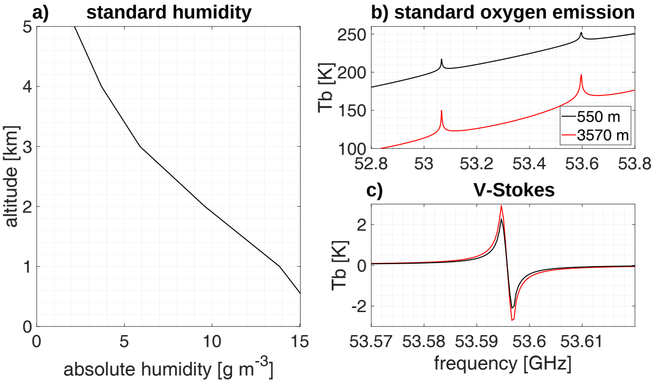

Figure 2: a) Standard mid-latitude summer absolute humidity profile. b) Standard mid-latitude summer O_2 simulated microwave emission spectra, as observed on the surface for Bern (550 m asl) and the Sphinx-observatory (3570 m asl). c) Simulations of the V-Stokes component of the fine-structure emission line at 53.6 GHz. Same conditions as in b).

1.3 Calibrated data

The lineshape of the measured emission lines (Figure 3) is formed by Zeeman broadening as a consequence of the Zeeman effect. This is because the oxygen molecule has a magnetic dipole moment and couples to the Earth's magnetic field. A non-vanishing V-Stokes component can only be observed in the presence of a magnetic field. Although this band is widely used for temperature sounding, this is the first time the V-Stokes component of these lines is measured. The calibrated dataset has a time resolution of 30 min with interruptions due to electricity cut-offs and precipitation.

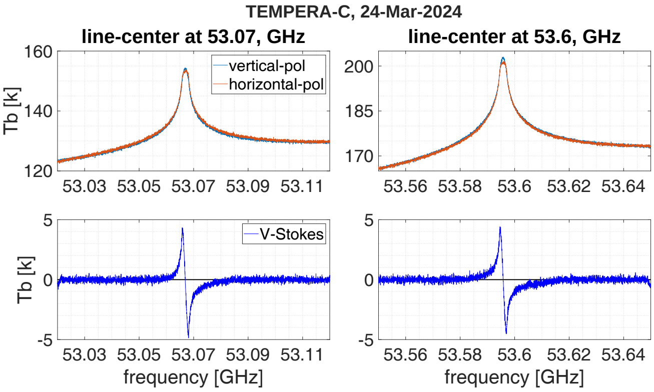

Figure 3: TEMPERA-C measurements after calibration. The illustration shows the vertical and horizontal polarized components of the two fine-structure emission lines as well as the V-Stokes components.

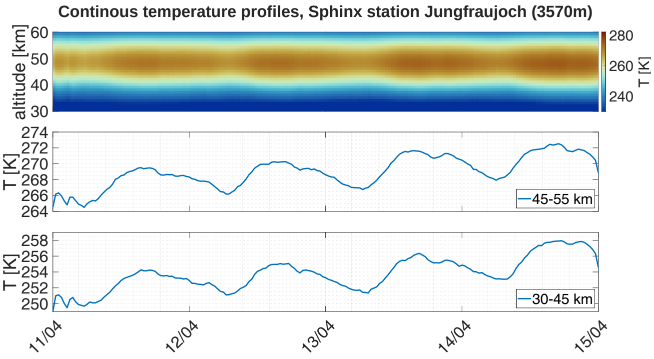

Figure 4: Continuous profiles of atmospheric temperature retrieved from TEMPERA-C measurements. The averages over the altitudes of 30–45 km and 45–55 km show thermal tide signatures.

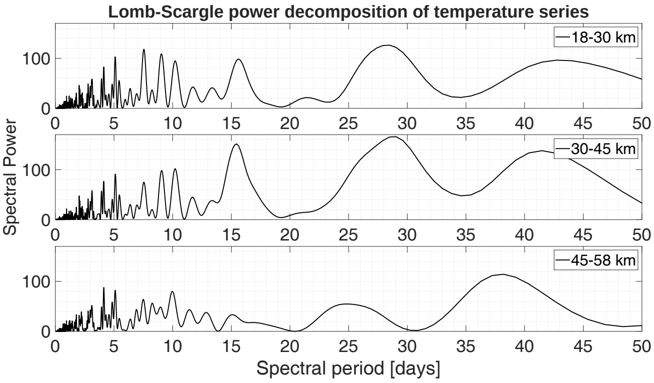

Figure 5: Lom-Scargle power decomposition of atmospheric temperatures retrieved from the TEMPERA-C dataset for different altitude regions. Significant periods were found at 25–30 days, 15–16 days, and 7–11 days.

1.4 Thermal Tides

Thermal tides are planetary-scale gravity waves generated by the absorption of solar radiation by water vapour in the troposphere and ozone in the stratosphere. These waves are known to propagate vertically and force the dynamics of the middle atmosphere. For the TEMPERA-C test campaign, 8 months of continuous temperature profiles were measured, allowing to derive the non-migrating tidal modes. Figure 4 shows results obtained from a test campaign at the Sphinx observatory demonstrating the increased altitude coverage (Krochin et al. 2024).

1.5 Higher period atmospheric oscillations

Next to thermal tides, higher-period atmospheric oscillations are present in the middle atmosphere. A power decomposition of the temperature series averaged over a certain altitude region reveals, for example, the planetary Rossby-modes with a period of 25–30 days and 15–16 days (Figure 5) in the two layers 18–30 km and 30–40 km. Other significant periods are around 7–11 days. Also, significant differences are visible between the upper and the lower two layers. Thermal tides are not visible in Figure 5 because the spectral power for periods below 5 days is suppressed due to noise.

References

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Collaborating partners / networks

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