

An innovative rotational Raman lidar to measure the temperature profile from the surface to 30 km altitude

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Motivations

The temperature is a fundamental parameter for meteorology and climatology. A concept of innovative rotational Raman lidar with daylight measurement capability is proposed to measure continuously the vertical profile of temperature from the ground to the middle stratosphere. Our goal is to achieve a time resolution permitting the observation of small-scale atmospheric processes playing a role in the troposphere-stratosphere interaction as gravity waves. If successful, this project will open the possibility to consider the Raman rotational lidar for weather and climate monitoring from ground, airborne and space applications.

Principle and methodology

Rayleigh lidars [1] [2] and vibrational Raman lidars [3] measure the atmospheric density profile and the temperature profile is computed by a downward integration of the hydrostatic equation. This requires a good knowledge of the atmospheric transmission which is generally not the case in the troposphere due to the possible presence of thin cloud and aerosol layers. The Rotational Raman spectrum of a diatomic molecule (N_2 or O_2) comprises the Stokes and anti-Stokes branches. Each branch is composed of a series of lines with an intensity depending on temperature. The measurement of the ratio between two lines with opposite dependence in temperature allows to obtain a direct determination of the atmospheric temperature down to the surface without any assumption on the atmospheric transmission. This is generally done with two interference filters placed in anti-Stokes lines around 529 nm and 530.5 nm [4] [5] [6][7].

We propose a new concept based on the observation of the full rotational Raman spectrum of N_2 as suggested by [8]. The optical filtering will be made using a Fabry-Pérot Interferometer (FPI) with line spacing exactly equal that of the N_2 spectrum (7.958 cm^{-1}) with two advantages:

- the very intense Rayleigh line corresponds to a minimum of transmission of the FPI and is then strongly attenuated, depending on the finesse of the FPI;
- the sky background is also highly attenuated, allowing daytime measurement up to the middle stratosphere (see Figure 2).

A spectrometer will be used to disperse the rotational Raman spectrum and the detection will be made using a linear array detector with fast reading rate (PMT array, APD array or ICCD) operated in photon counting mode.

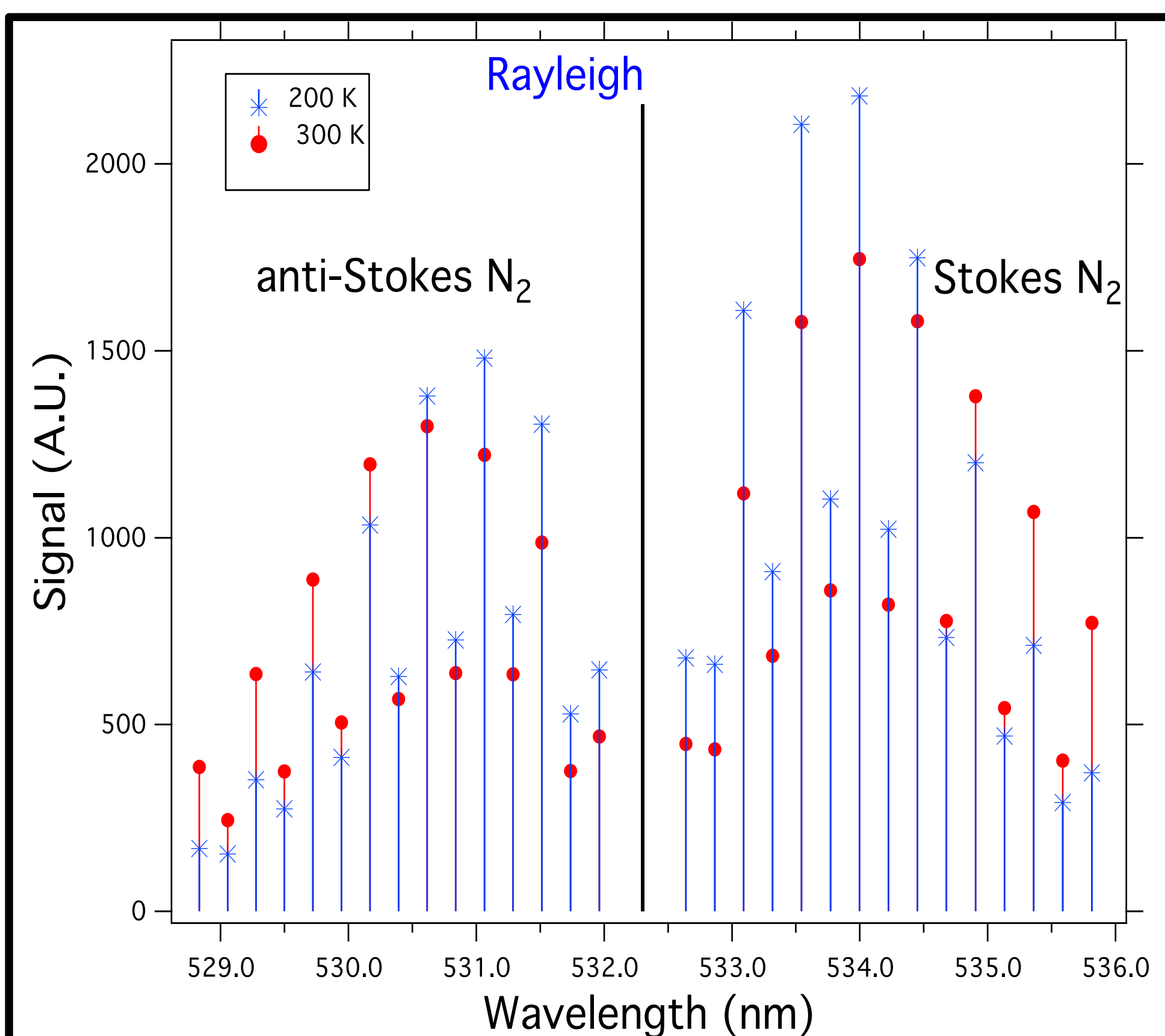


Figure 1: Night-time simulated N_2 Raman signal for 30 km altitude (atmos. density), 100 m thickness and 1 hour integration for 2 temperatures 200 K and 300 K. It shows the sensitivity of the spectrum shape to temperature.

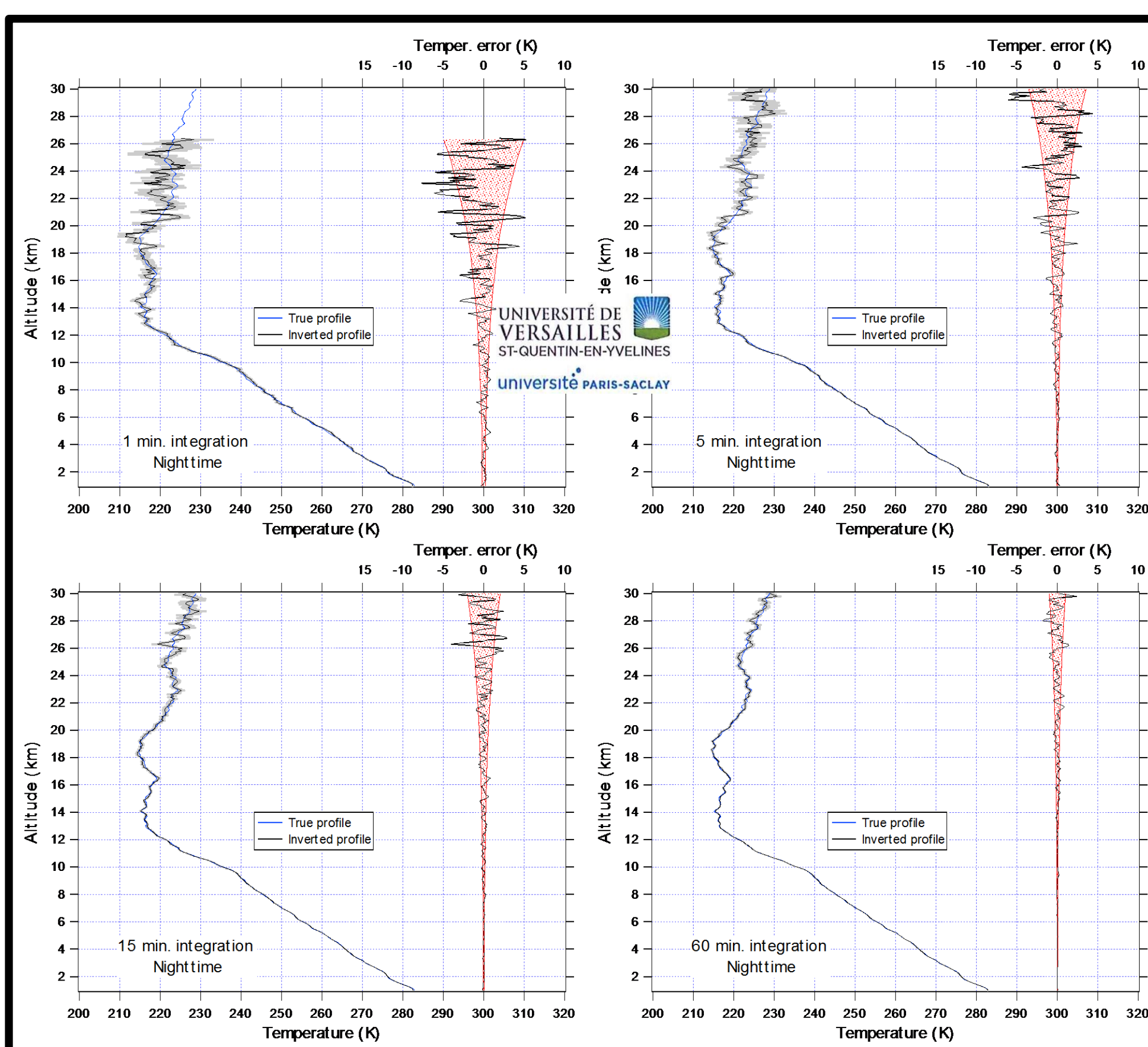


Figure 2: Night-time (left) and daytime (right) simulated temperature profiles for 4 integration duration: 1 min., 5 min., 15 min. and 1 hour. For each case the initial profile is in blue the and inverted profile in black with its 1- σ uncertainty (grey area). The right part represents the deviation from the initial profile (black) and its 1- σ uncertainty (red area). Vertical profiles have been represented up to the altitude for which the 1- σ uncertainty reaches 5K.

Results and discussion

For night-time conditions the altitude reached with a better than 5 K uncertainty is 26 km for 1-min time integration and higher than 30 km for a longer time integration. The accuracy is better than 1 K in the whole troposphere even for the shortest integration time showing the potential of the rotational Raman technique for accurate temperature profiling from the surface to the middle stratosphere and for detailed studies of the atmospheric dynamics including gravity

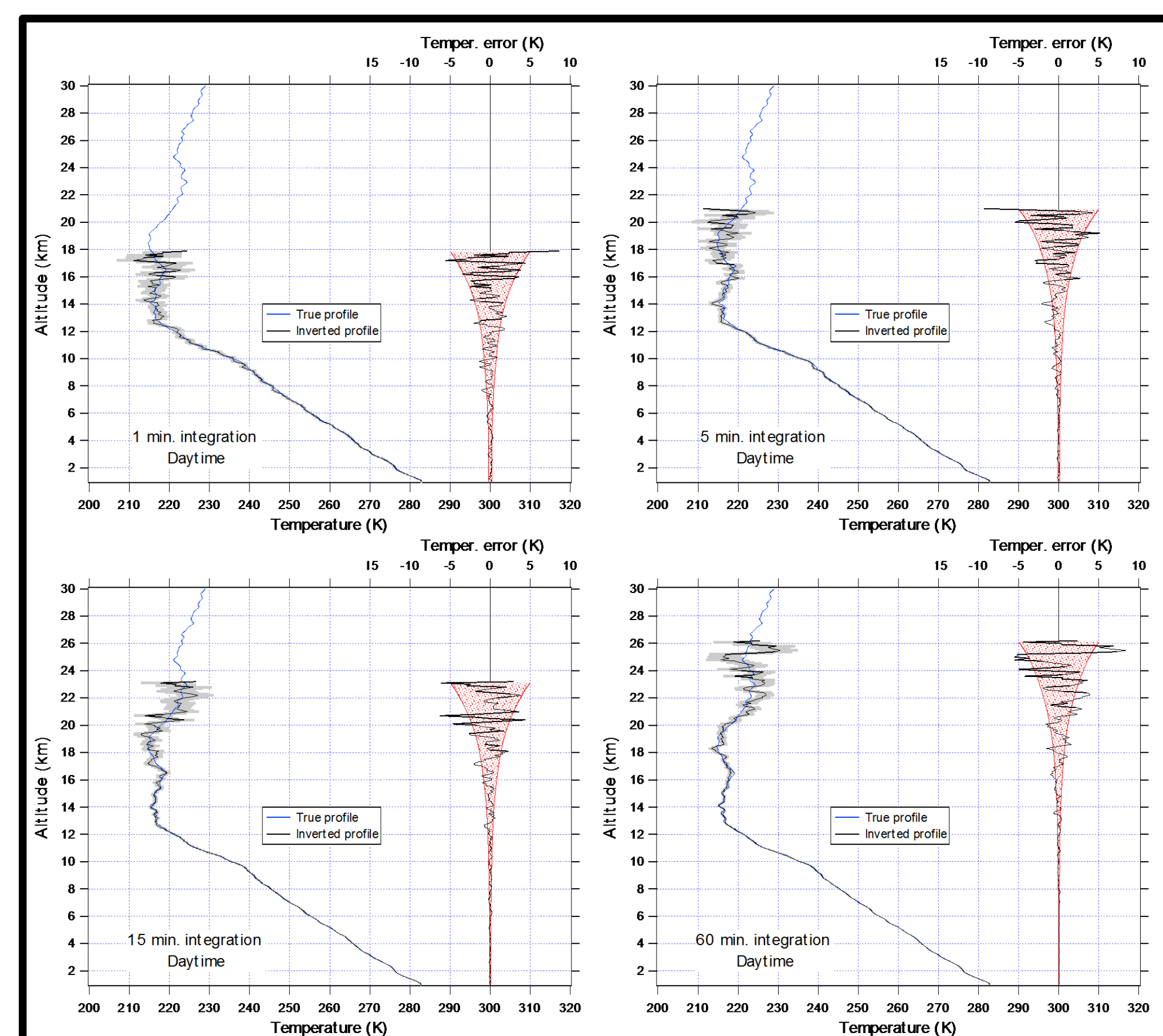
Simulation

A simulation has been performed to estimate the expected performances of the new concept. It is based on existing equipment at Observatoire Haute-Provence (OHP, 43.9°N, 5.7°E) for the laser and the optical emission-reception system. The N_2 rotational Raman spectrum intensity is computed from [9], see Figure 1.

Characteristics of the simulation

• Laser	Nd-YAG 800mJ @ 30 Hz – 532.3 nm
• Telescope	50 cm diameter, 0.133 mrad FOV
• Detector quant. Eff.	18%
• Detector noise	1000 counts s^{-1}
• Overall opt. transm.	30%
• FPI finesse	20
• Atmosph. transm.	80%
• Daytime sky radiance	0.06 $Wm^{-2}sr^{-1}nm^{-1}$
• Night-time sky radiance	0
• Vertical resolution	300 m

Figure 2 presents the results of randomly generated temperature profiles for night-time (left) and daytime (right) conditions for 1-min., 5-min., 15-min. and 1-hour time integration.



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waves and stratosphere troposphere coupling. The accuracy remains very good up to the lower stratosphere for daytime conditions, showing that this technique can be very useful for applications that need a 24-hour monitoring of the temperature profile as for instance weather monitoring and forecasting.

We are planning to develop a prototype lidar based on the concept presented in this study and to test it at OHP where comparisons with Rayleigh and vibrational lidar temperature profiles can be made.

Future works will be also oriented toward the evaluation of the potential of the rotational Raman technique for airborne and spaceborne lidars.