Performance Simulation of a Space-borne Raman Lidar for ATLAS

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01 - Space-borne lidar missions, instruments and science

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ATLAS - Atmospheric Thermodynamics LidAr in Space

- ATLAS is mission concept aimed at developing the first Raman Lidar in space, capable to measure simultaneously atmospheric temperature (T) and water vapour mixing ratio (WVMR) with high temporal and spatial resolutions.

- Accurate observations of thermodynamic profiles in the lower troposphere from the surface to the interfacial layer at the top of the planetary boundary layer (PBL) are critically essential for improving weather forecasting and re-analyses, and for understanding the Earth system.

- Global scale measurements of 3D thermodynamic profiles would have a great impact in several research areas [Wulfmeyer et al., 2015]:
    - Radiative transfer, as well as regional and global water and energy budgets,
    - Land-atmosphere feedback including the surface energy balance and its dependence on soil properties and land cover,
    - Mesoscale circulations and convection initiation
    - Data assimilation

Experimental setup

The space-borne Raman Lidar considered in ATLAS collects six lidar signals:

- The Elastic backscattered signal at the laser wavelength
- The WV roto-vibrational Raman signal
- The high- and low-quantum number O2-N2 rotational Raman signals both in the anti-Stokes and Stokes branches

As reference signal will be used a temperature-independent weighted sum of rotational Raman signal.

LIDAR TRANSMITTER	
Source	Injection-seeded frequency tripled, diode-laser pumped Nd:YAG
Laser Wavelength	354.7 nm
Single-shot pulse energy	1 J
Repetition rate	200 Hz
LIDAR RECEIVER	
Telescope	f/5 a-focal Cassegrain
Telescope diameter	2 m
Field-of-View (FWHM)	25 µrad
SPECTRAL SELECTION AND DETECTION	
Spectral selection devices	Interference Filters (IFs)
Detection Devices	Photodiodes or Photomultipliers
Quantum efficiences	85 %

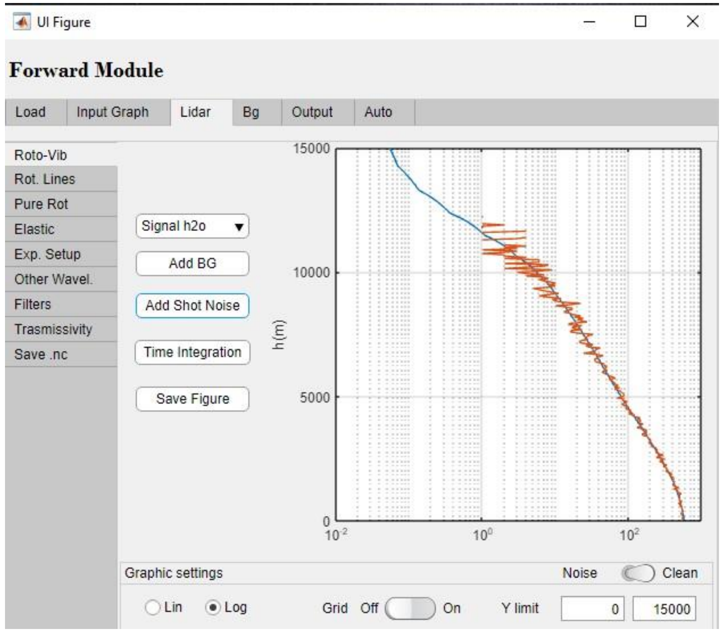
The end-to-end simulator

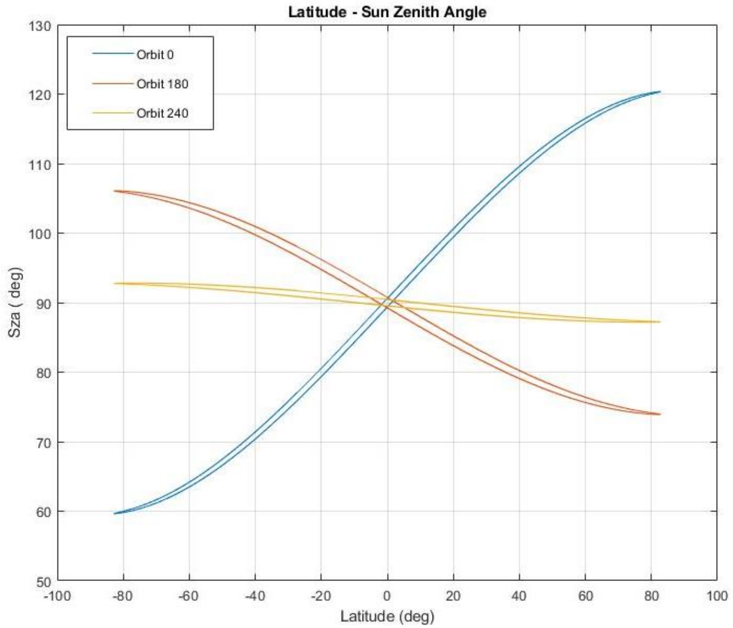
An assessment of the specifications of the different lidar sub-systems has been performed with an analytical simulation model for space-borne Raman lidar systems [Di Girolamo et al., 2018] and verified through an end-to-end numerical simulation model.

The simulator consists of two separate modules:

- The forward module simulates the Raman signals collected by the receiver, considering the behavior of all the devices in the experimental system. The simulated signals include the solar background contribution and, eventually, the presence of clouds.
- The retrieval module analyses the simulated signals to obtain the vertical profiles of temperature and water vapour mixing ratio, together with the statistical and systematic uncertainties.

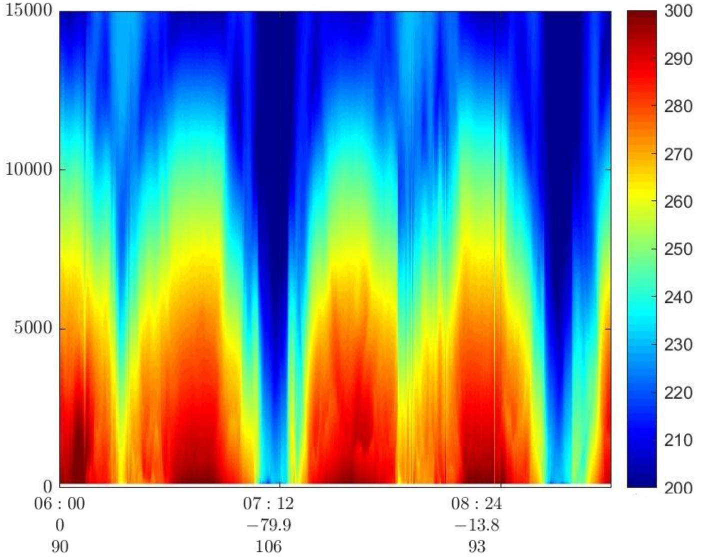
To verify the capabilities of ATLAS, simulations along several orbits around the Earth were performed, using data extracted from NASA's Goddard Earth Observing System Model (GEOS-5) analysis to simulate a dawn-dusk orbit around the Earth.



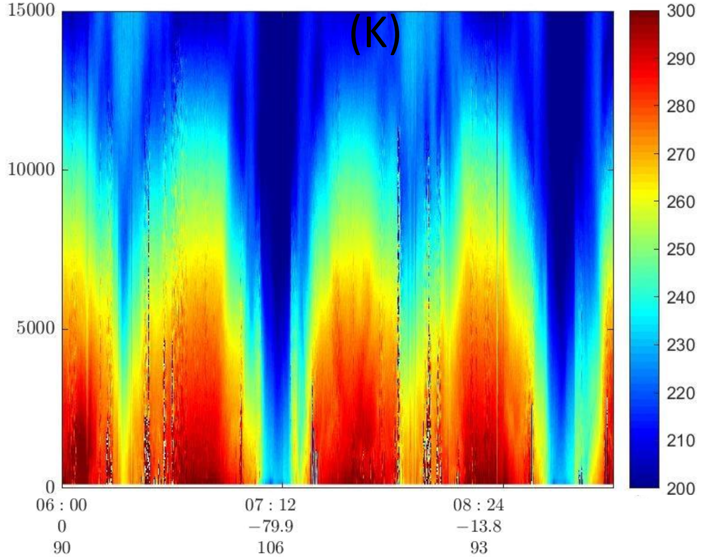


Results: temperature

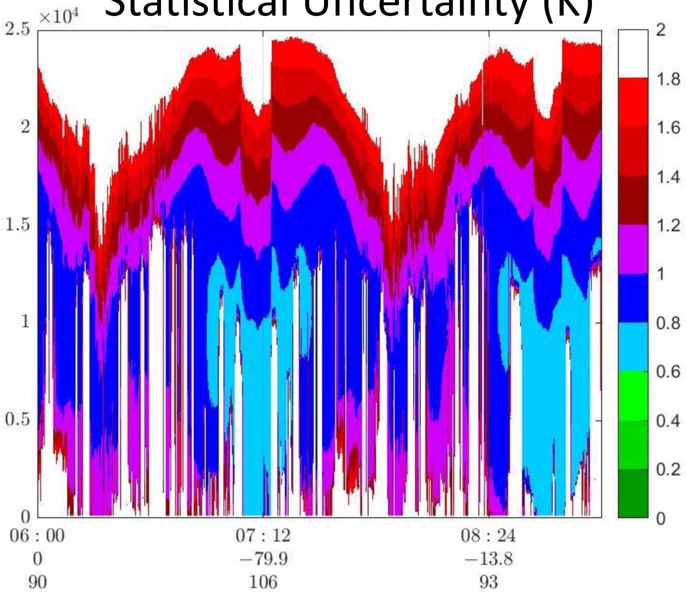
Input Temperature (K)



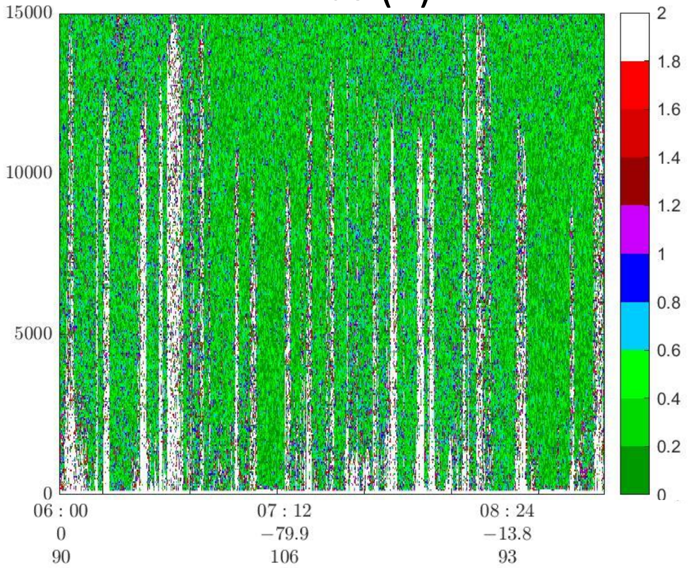
Retrieved Temperature (K)



Statistical Uncertainty (K)



Bias (K)

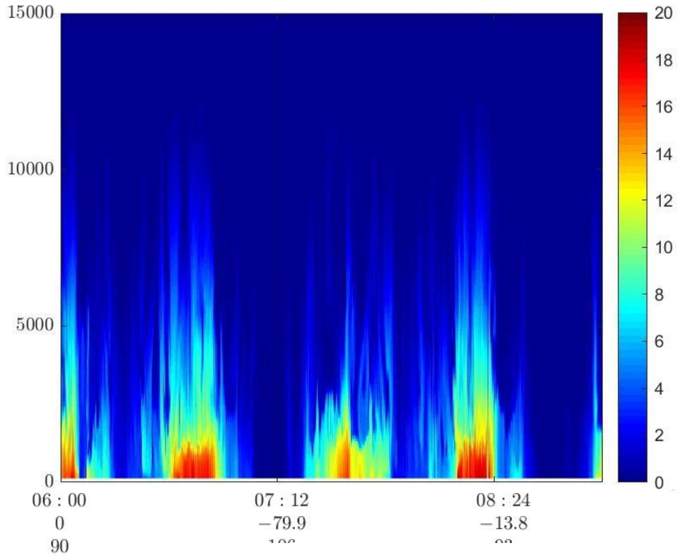


All the obtained results are compatible with the observational requirements to be fulfilled for applications in monitoring, verification, data assimilation and process studies.

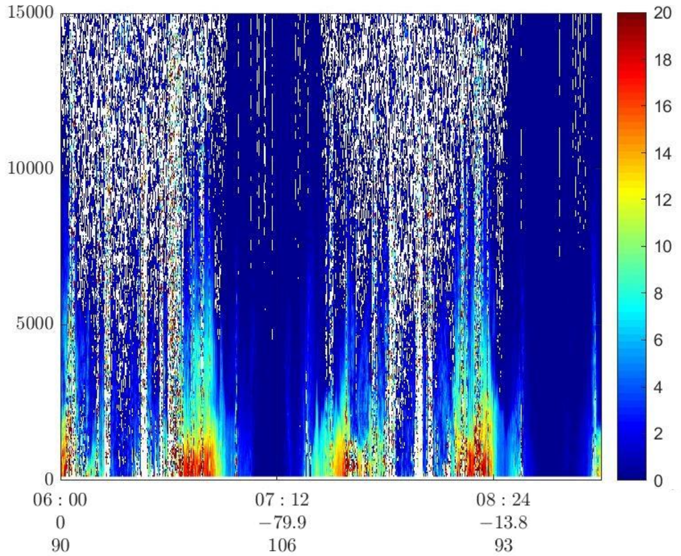
The bias obtained comparing the input and retrieved temperature profiles is below 0.6 K and the statistical uncertainty is less than
1-1.2 K up to 15 km along almost the entire orbit, except on those areas where the cloud cover is too thick.

Results: water vapour mixing ratio

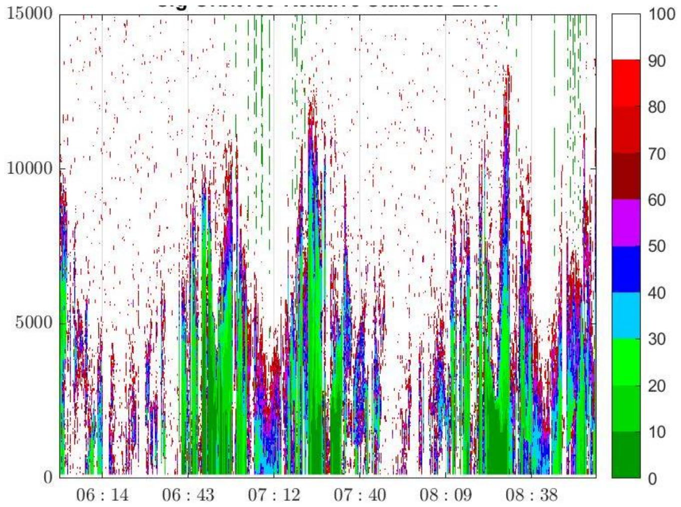
Input WVMR (g/kg)



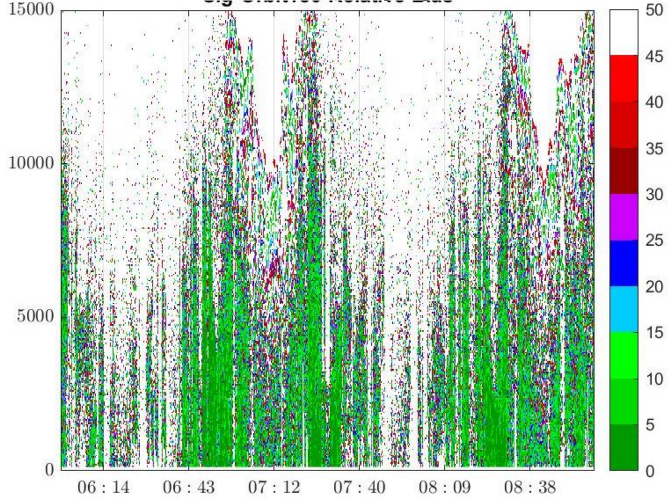
Retrieved WVMR (g/kg)



Statistical Uncertainty (K)



Bias (K)



The water vapour mixing ratio measurement shows a higher variability in terms of performance. In the tropical belt, the bias is below 5 % and the percentage statistical uncertainty is below 10 % up to 3 km, but they keep below respectively 15 % and 30 % up to 7 km. In the mid latitudes the uncertainty is below 30 % up to 5 km and reaches 7 km with low background conditions, while the bias is 5-10 %. The presence of clouds severely influences the performance, that appears more degraded in the boreal hemisphere, where their effect is combined with higher background conditions.