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TAKING THE PULSE OF OUR PLANET FROM SPACE

THERMODYNAMIC PROFILING OF THE ATMOSPHERE WITH A SPACEBORNE RAMAN LIDAR FOR ATLAS

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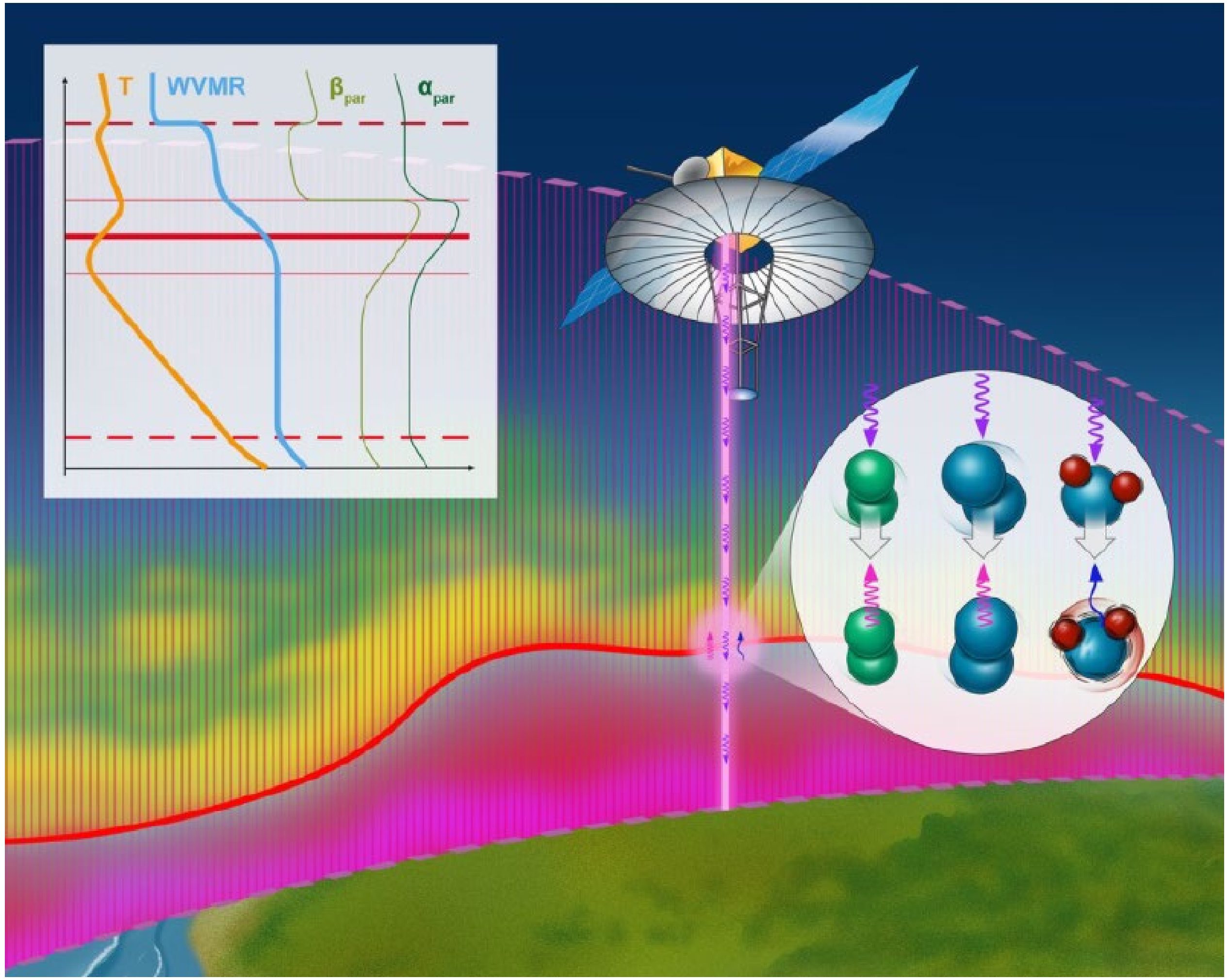
The mission concept

ATLAS

Atmospheric Thermodynamic LidAr in Space

The mission concept aims to develop 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.

Further data products comprise relative humidity profiles, the particle extinction and backscatter coefficient profiles at 354.7 nm and the PBL depth over land and the oceans.



Impact of the mission

Accurate, high temporal and spatial resolution 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

The mission concept

The core element of the proposed Earth Explorer mission is a nadir-viewing water vapour and temperature Raman lidar system.

Range-resolved rotational and vibrational Raman scattering measurements of laser radiation represents a selective and sensitive method for measuring vertical profiles that can be obtained from specific ratios of the Raman backscattered signals.

Raman Lidar technique

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

$$WVMR(z) = k\,\Delta Trs(z)\,\frac{P_{WV}(z)}{P_{ref}(z)}$$

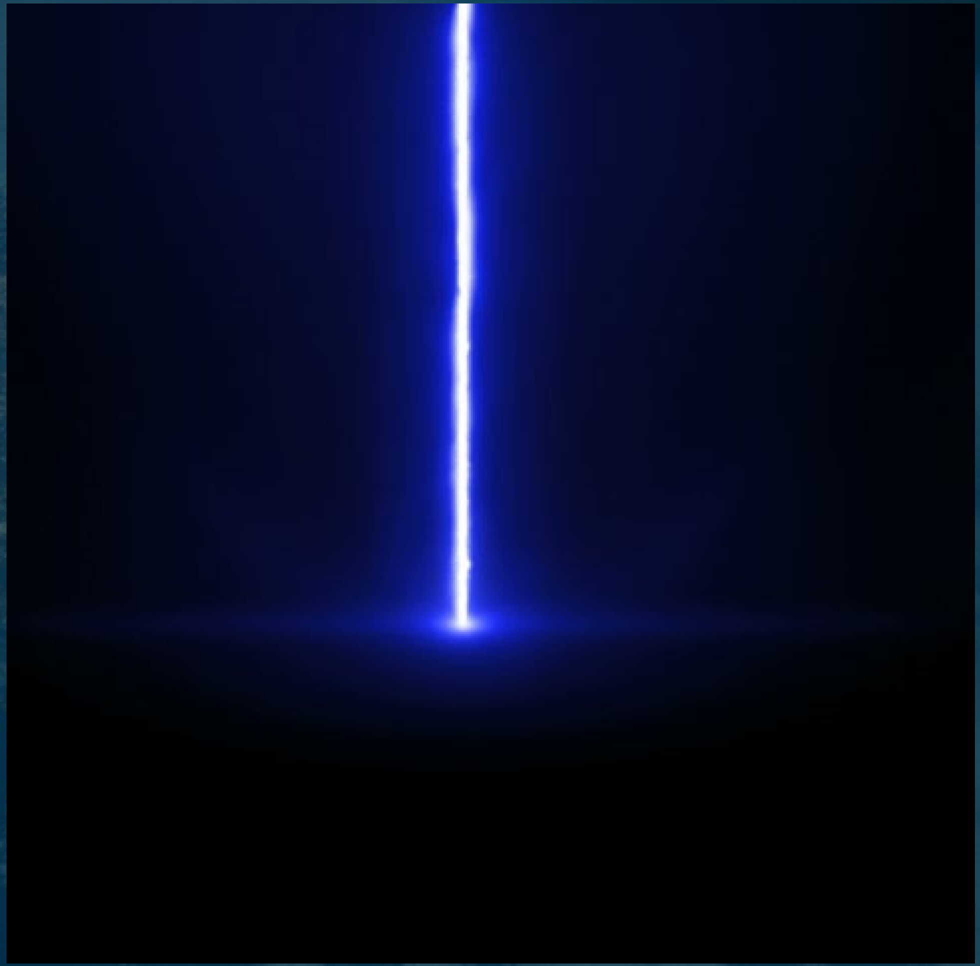
$$T(z) = \frac{a}{\ln\left(\frac{P_{HiJ,S}(z) + P_{HiJ,AS}(z)}{P_{LoJ,S}(z) + P_{LoJ,AS}(z)}\right) - b}$$

$$\beta_{\lambda_0}^{par}(z) = \beta_{\lambda_0}^{mol}(z)\left[\frac{P_{\lambda_0}(z)}{c\,P_{ref}(z)} - 1\right]$$

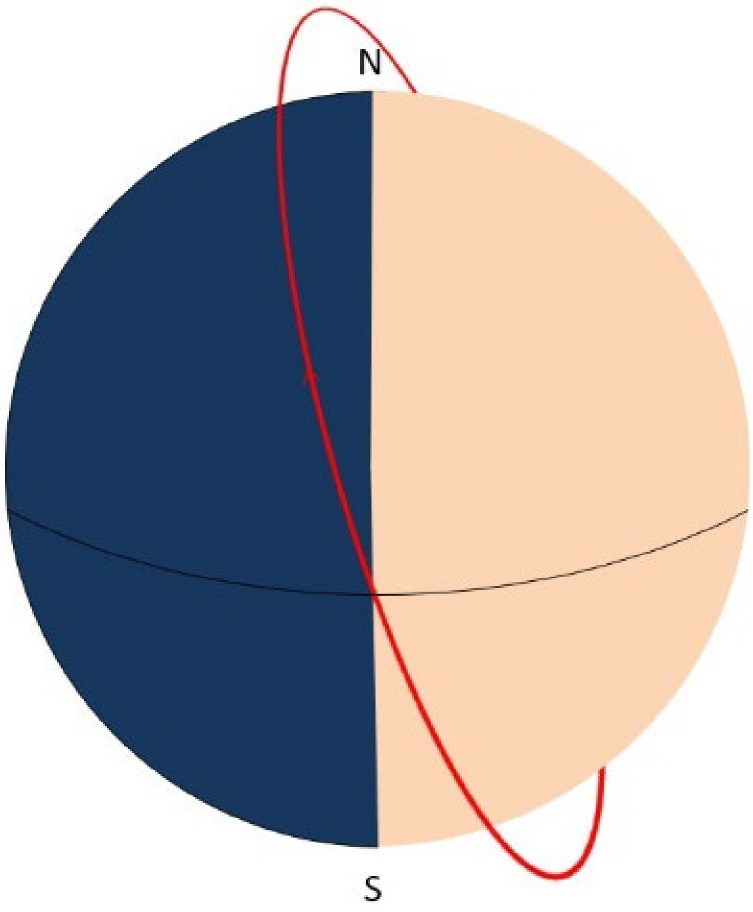
$$\alpha_{\lambda_0}^{par}(z) = \frac{1}{2}\frac{d}{dz}\ln\left(\frac{n(z)}{P_{ref}(z)z^2}\right) - \alpha_{\lambda_0}^{mol}(z)$$

Instrumental Concept

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 %



Orbit selection

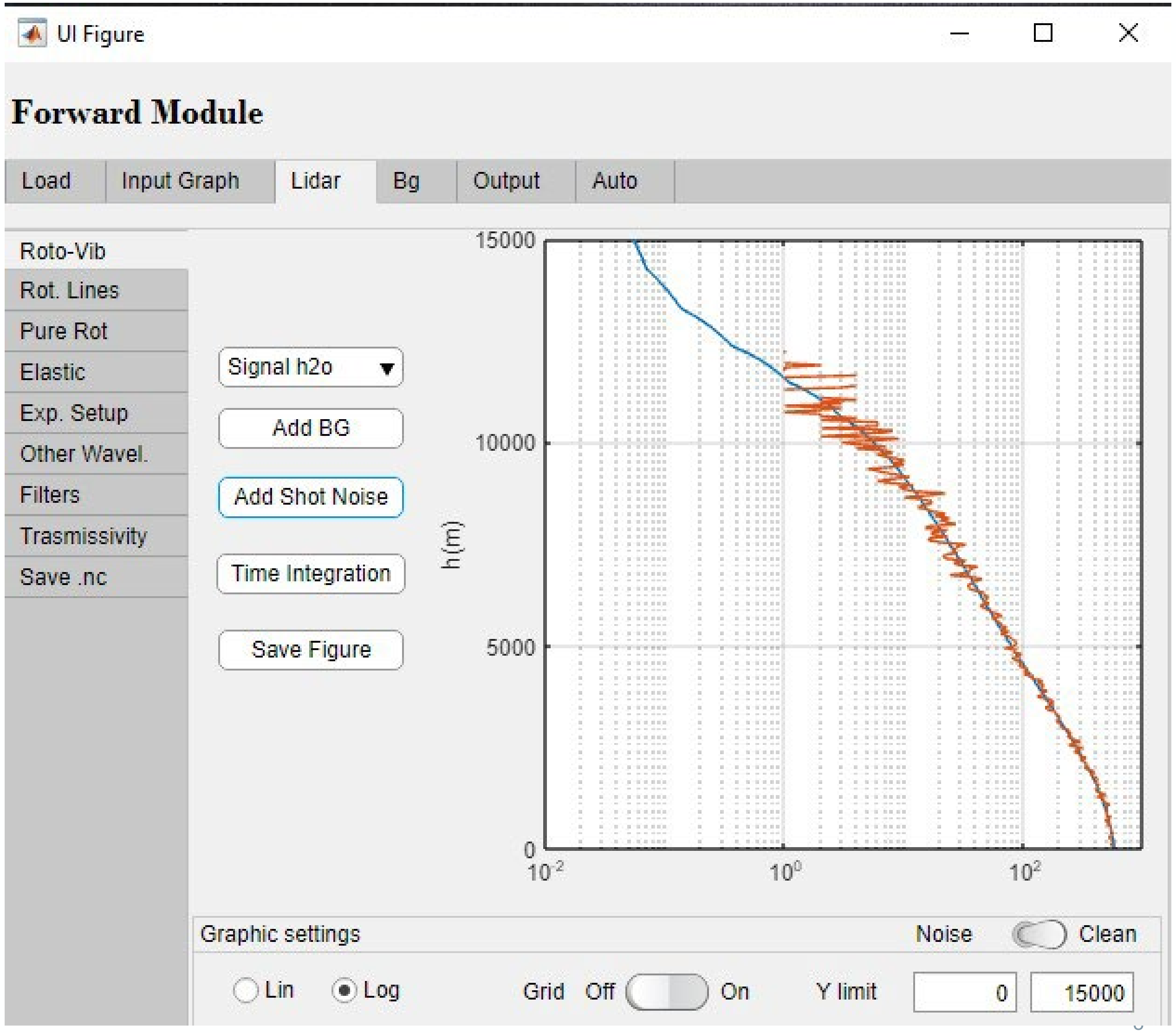


The selected orbit for the satellite is a sun synchronous polar orbit with a local time descending node at 06:00 (dawn-dusk orbit) and an orbital height of 450 km.

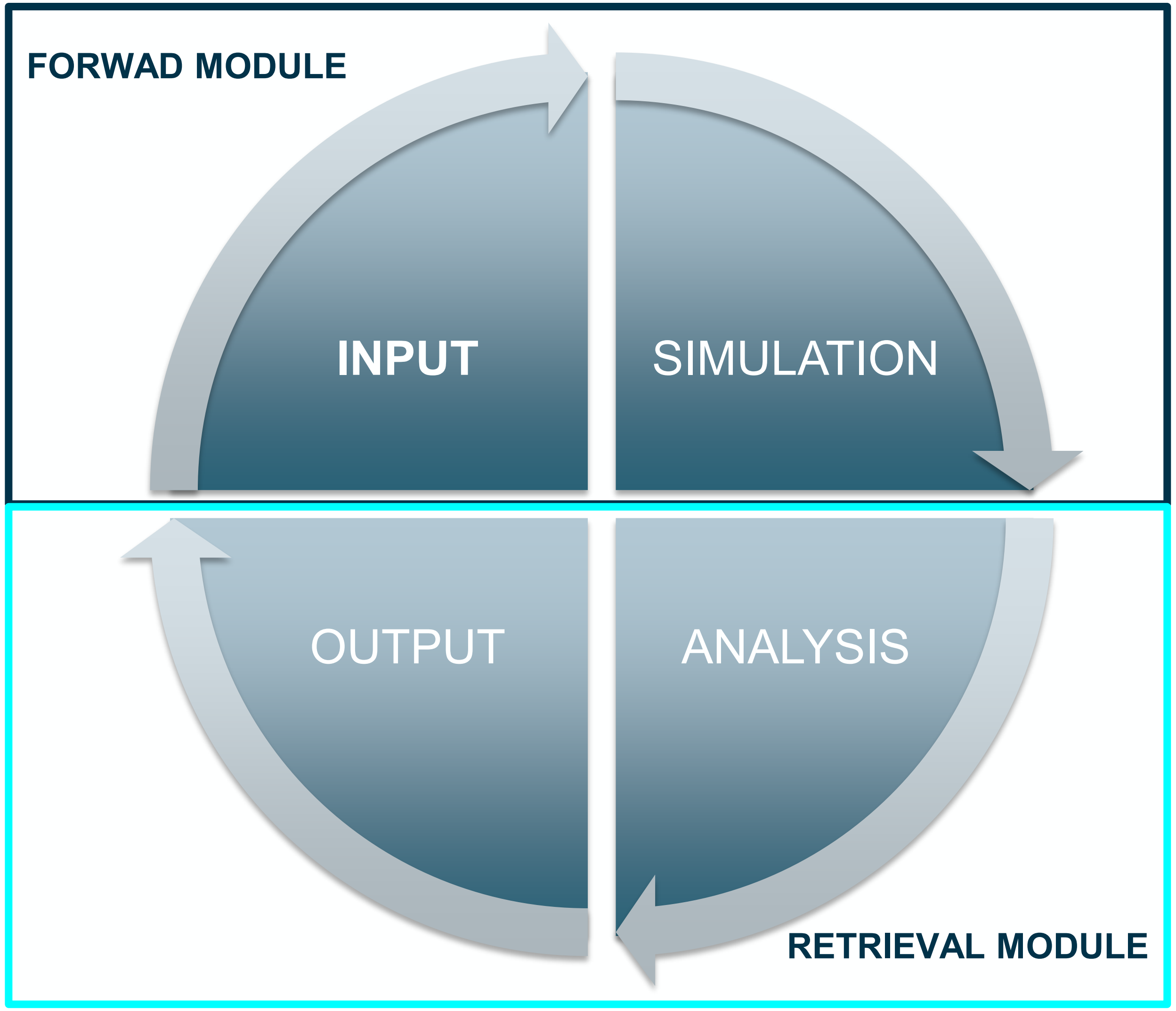
This kind of orbit guarantees a sun zenith angle on the sub-satellite point close to 90°

Specification assessment

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.



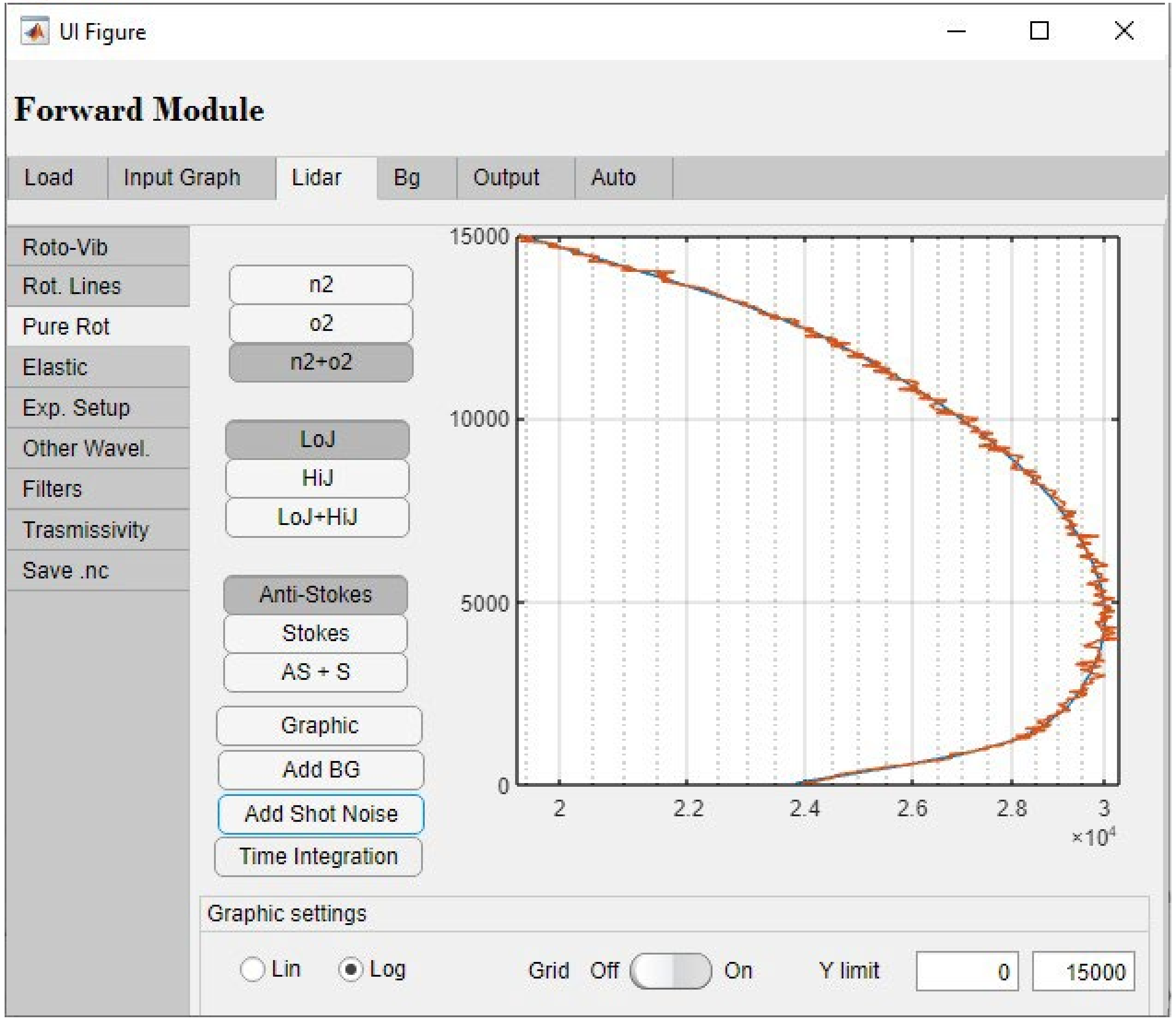
End-to-end simulation scheme



INPUT DATA:

- Thermodynamic profiles (temperature, pressure, air density)
- Optical properties (backscatter and extinction coefficient)
- Surface albedo, clouds …

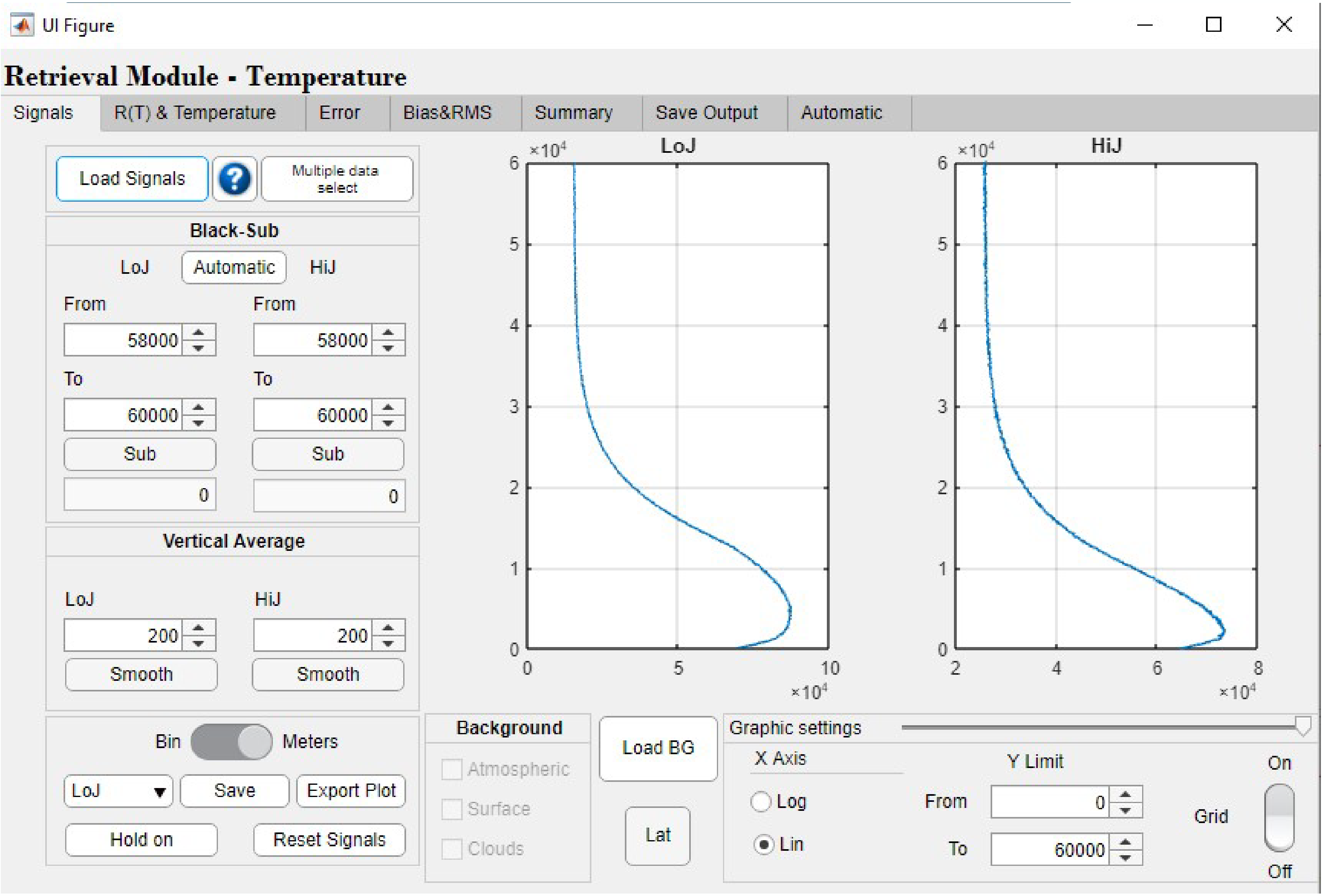
End-to-end simulation scheme



SIMULATION:

- Behavior of all the devices in the experimental system
- Simulation of the signals
- Background contribution
- Shot-noise contribution

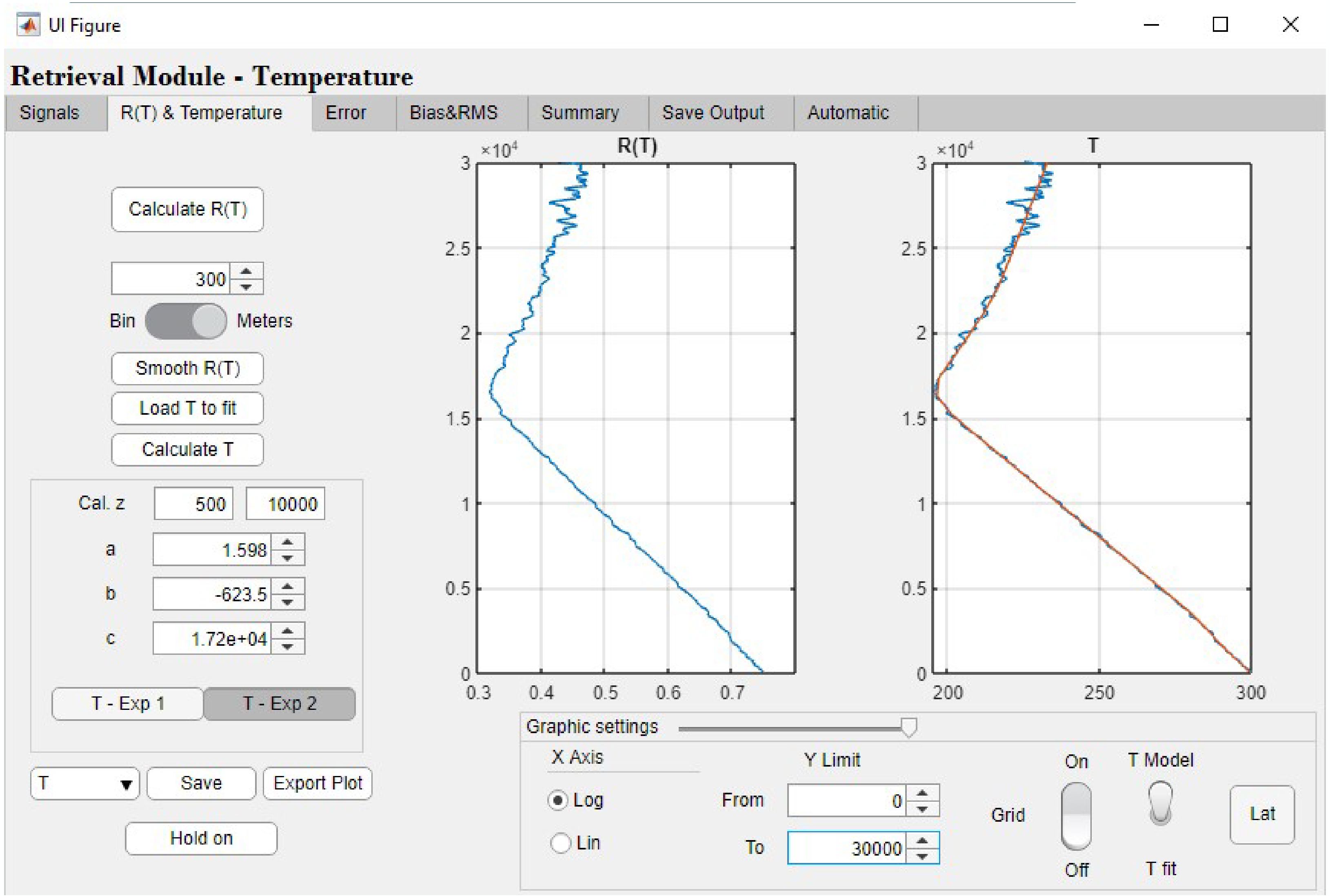
End-to-end simulation scheme



SIGNAL ANALYSIS

- Background subtraction
- Vertical average
- Application of Raman Lidar techniques

End-to-end simulation scheme



OUPUT:

- Retrieval of water vapour mixing ratio and atmospheric temperature profiles
- Statistical uncertainties for temperature (K) and WVMR (g/kg; %)
- Bias for temperature (K) and WVMR (g/kg; %)

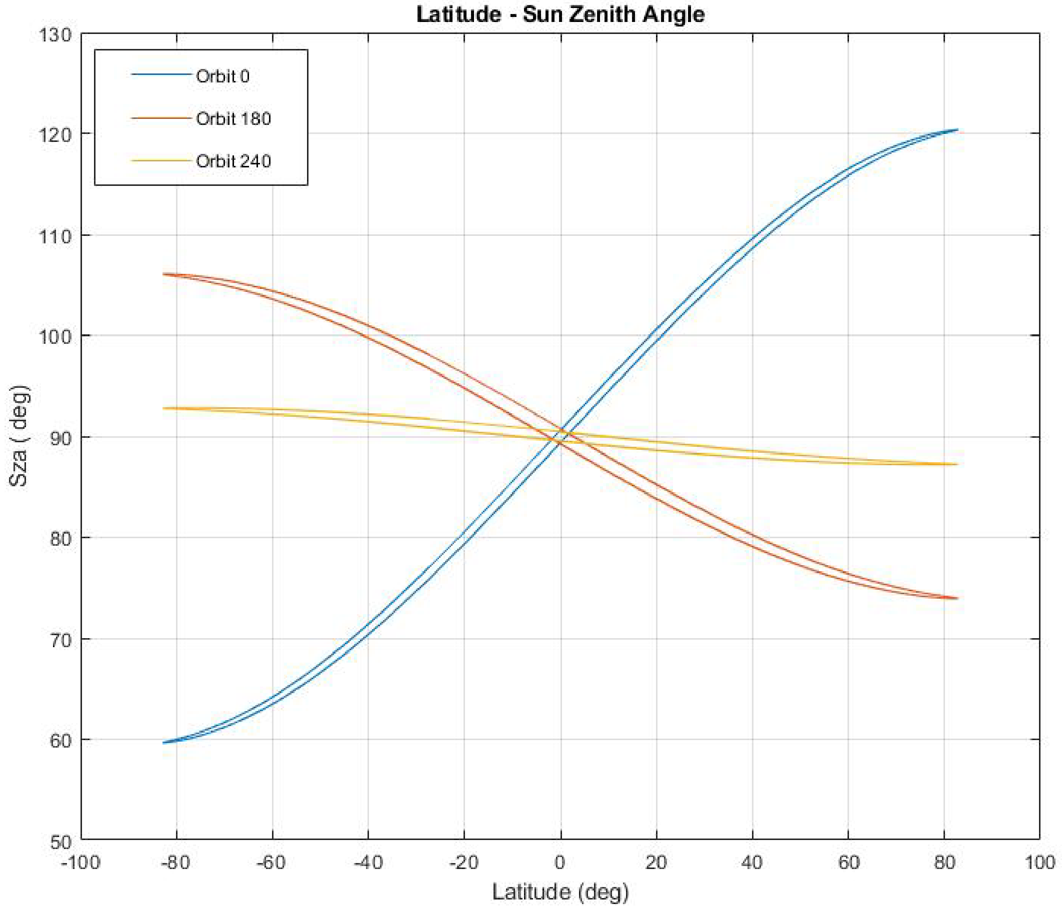
Orbit Simulation

To verify the capabilities of ATLAS, simulations along several orbits around the Earth were performed.

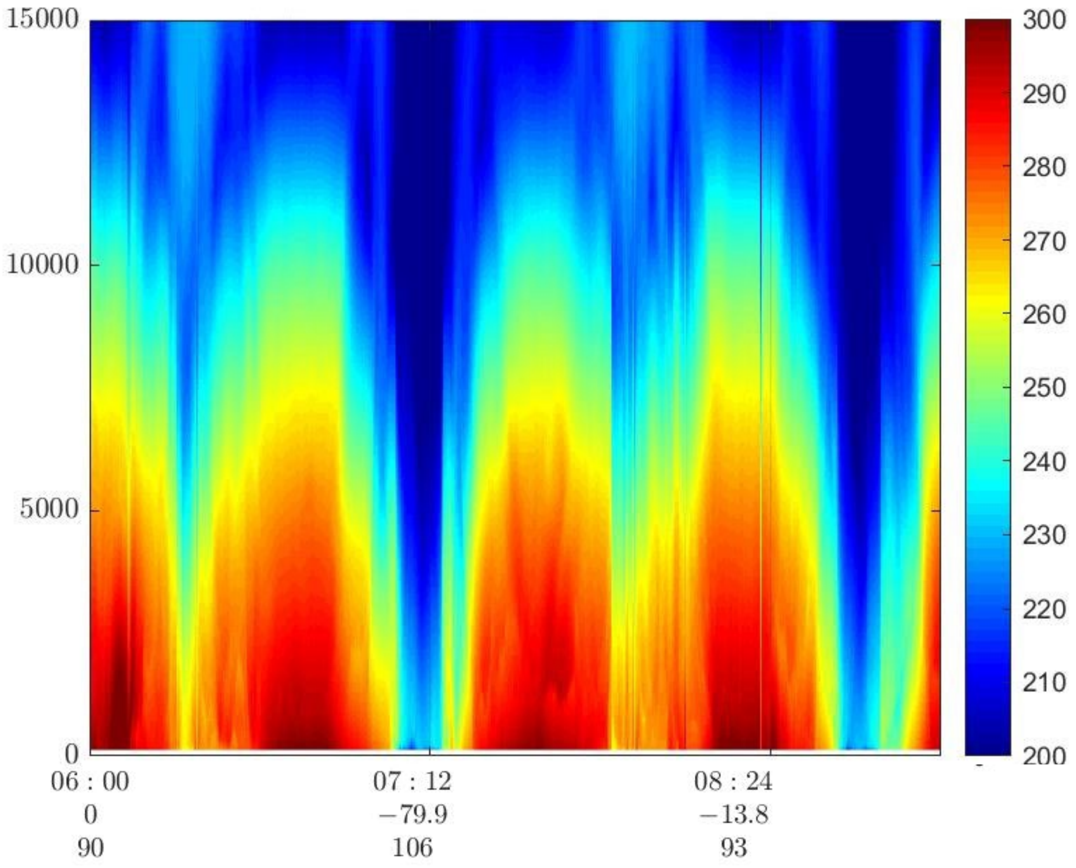
The orbit were selected to consider the different variability of the sza during the year:

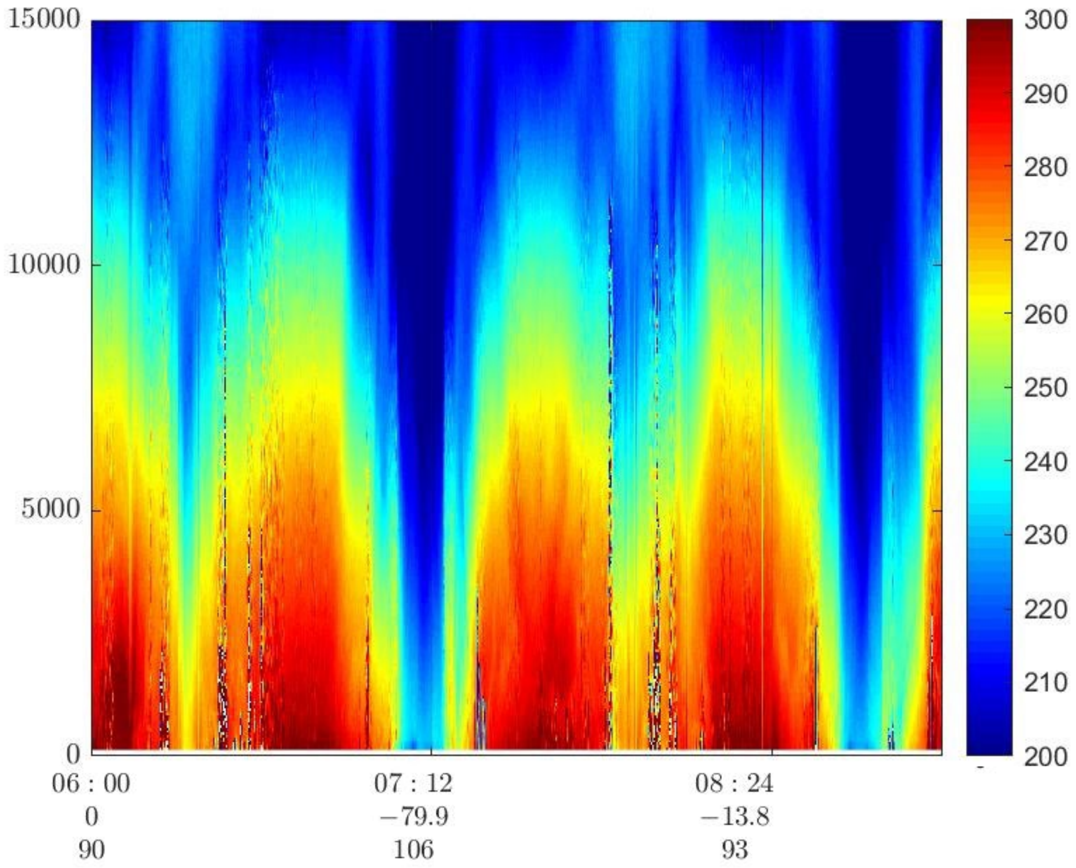
- Day 0: 90° ± 30° (High background)
- Day 180: 90° ± 15° (Mean background)
- Day 240: 90° ± 3 ° (Low background)

The data are extracted from NASA's Goddard Earth Observing System Model (GEOS-5) analysis

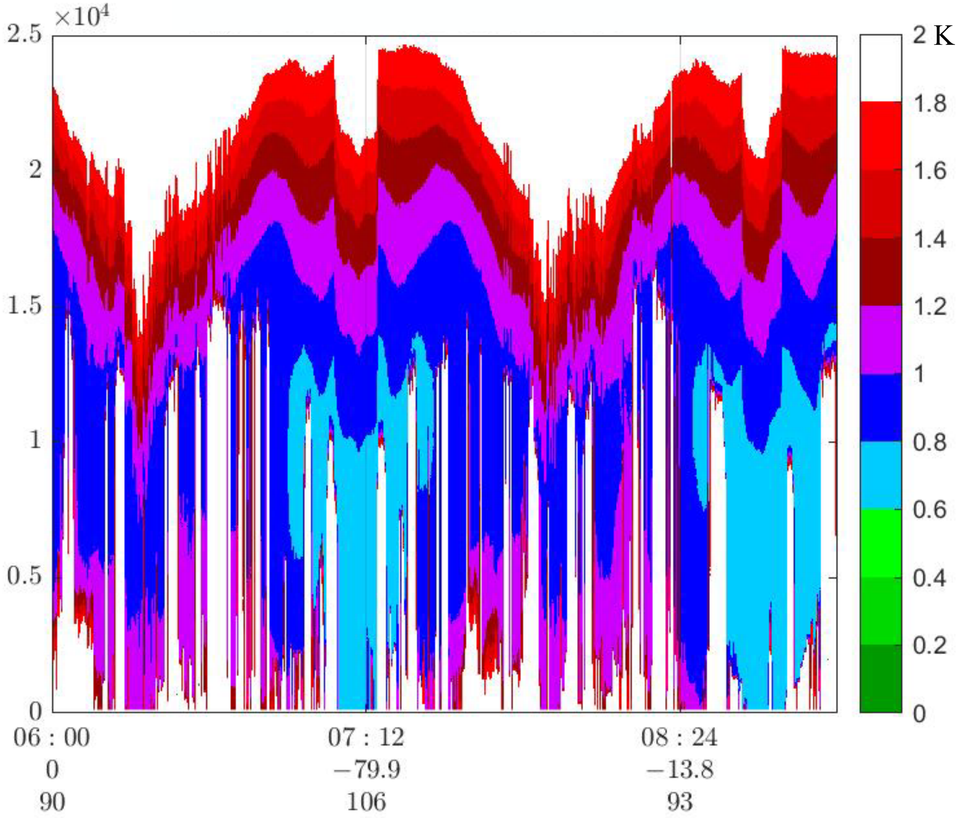


Input and Retrieved Temperature (K)

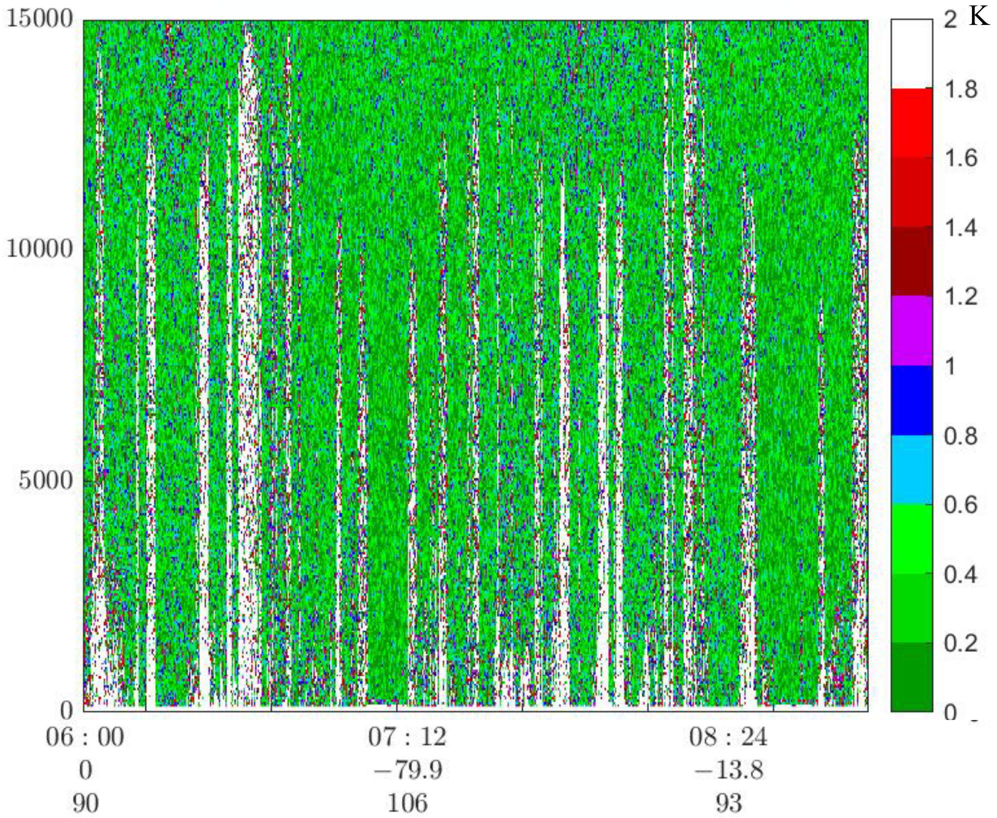




Statistical uncertainty (K) and bias (K)

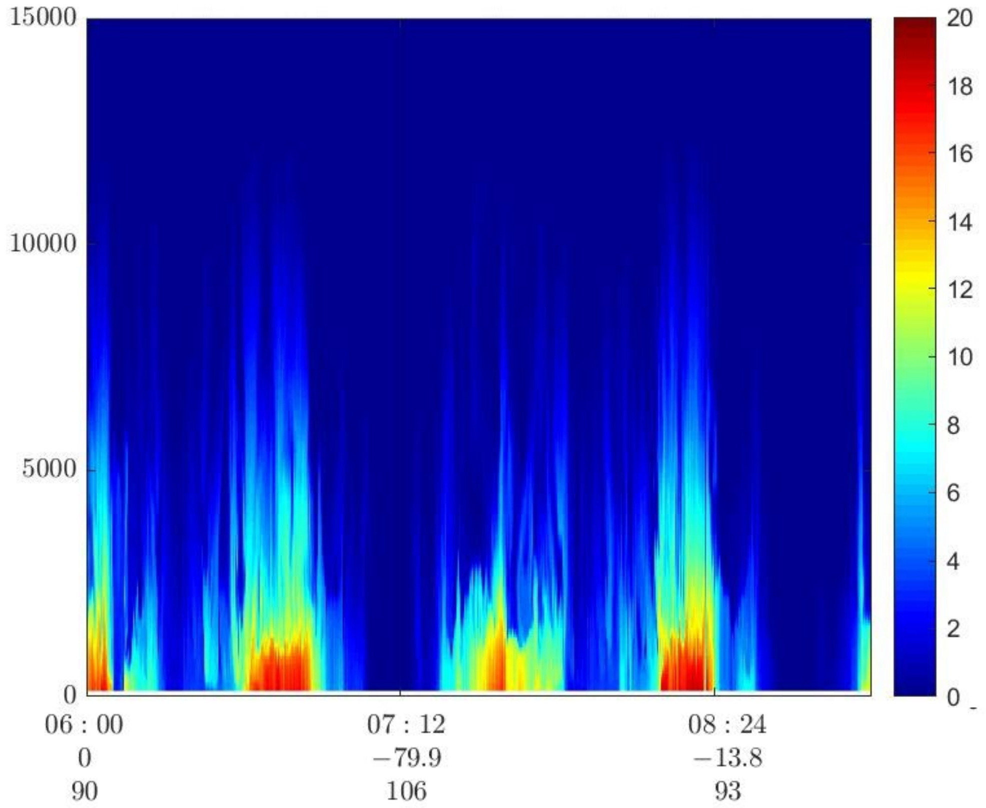


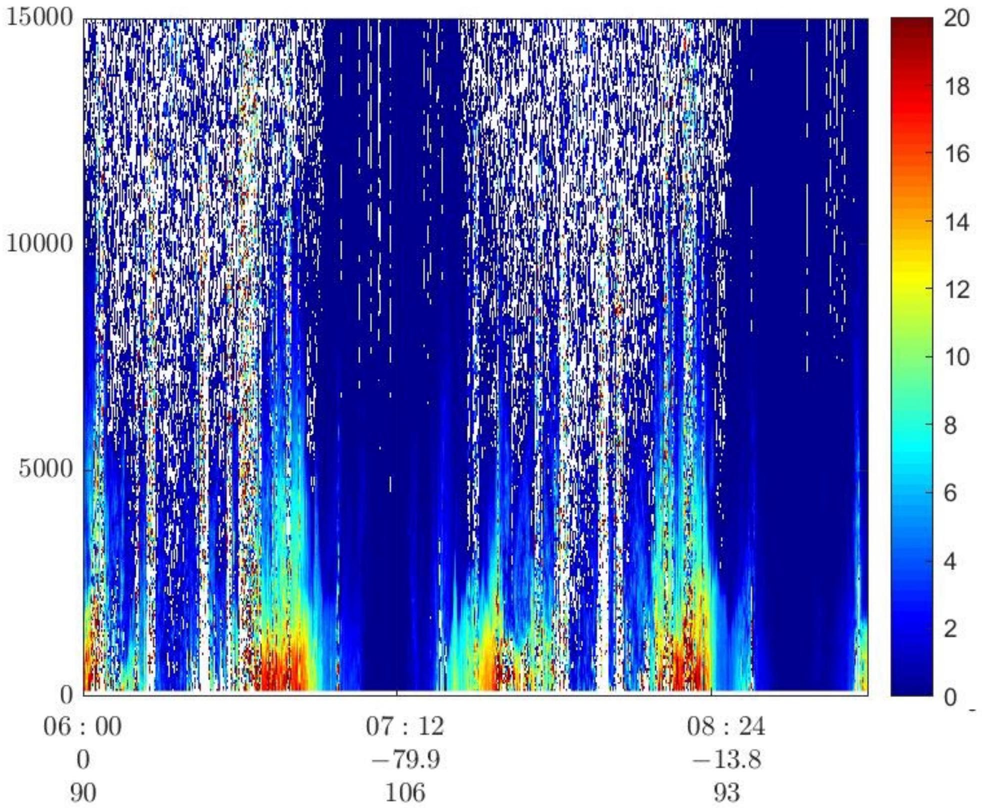
$$\Delta T(z) = \frac{\partial T(z)}{\partial R} R(z) \sqrt{\frac{N_{LoJ}(z) + bg_{LoJ}}{N_{LoJ}^2(z)} + \frac{N_{HiJ}(z) + bg_{HiJ}}{N_{HiJ}^2(z)}}$$



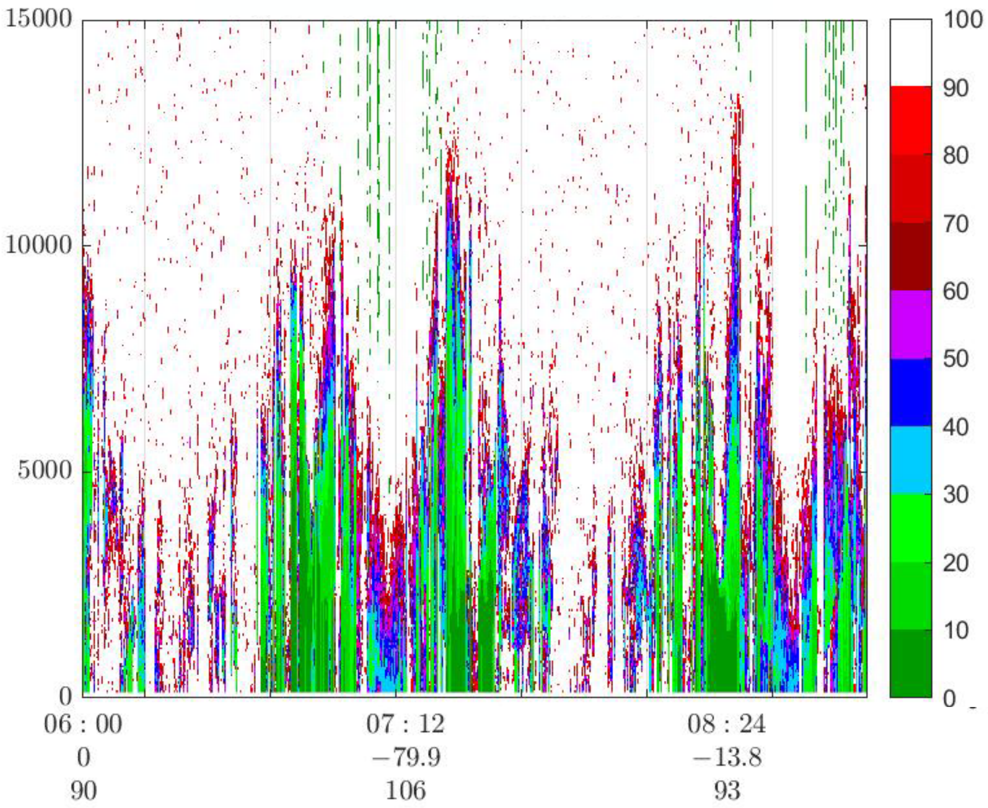
$$\Delta T = |T_{inp} - T_{ret}|$$

Input and Retrieved Water Vapour Mixing Ratio (g/kg)

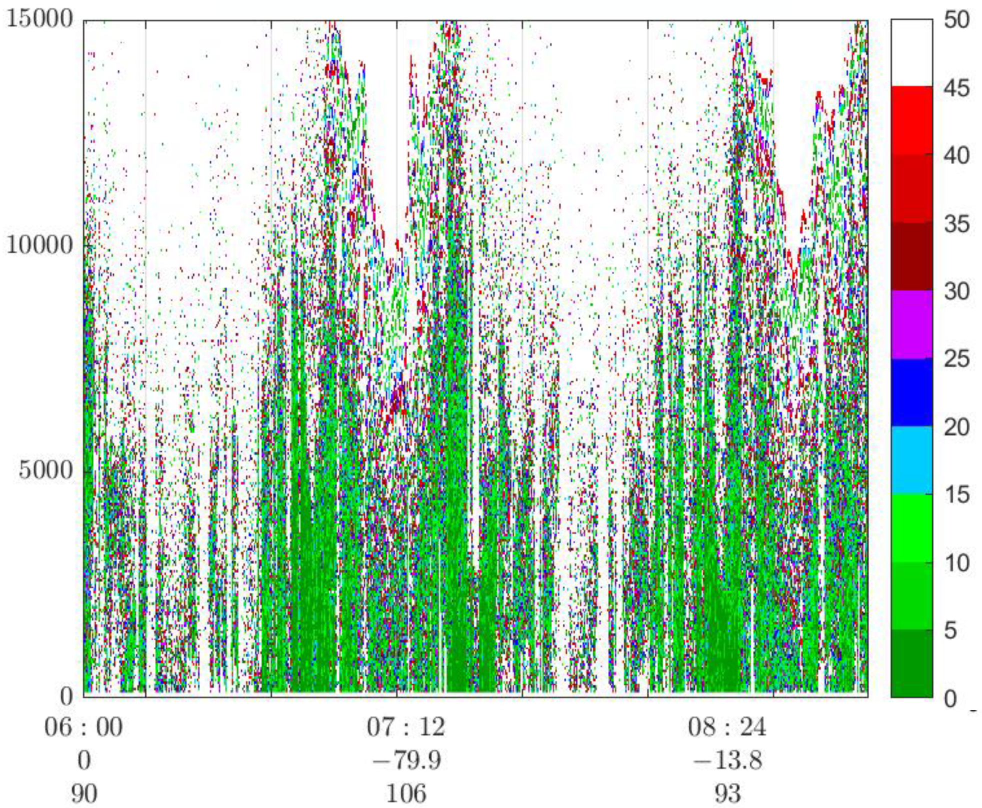




Relative Statistical Uncertainty (%) and relative Bias (%)



$$\frac{\Delta\chi_{H_2O}(z)}{\chi_{H_2O}(z)} = 100 \times \sqrt{\frac{N_{H_2O}(z) + bg_{H_2O}}{N^2_{H_2O}(z)} + \frac{N_{ref}(z) + bg_{ref}}{N^2_{ref}(z)}}$$



$$\frac{\Delta\chi_{H_2O}}{\chi_{H_2O}} = 100 \times \frac{|\chi_{inp} - \chi_{ret}|}{\chi_{inp}}$$