# A NEW LIDAR FACILITY TO INVESTIGATE THE MIDDLE ATMOSPHERE OVER BUCKLAND PARK, AUSTRALIA, 35° S

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## ABSTRACT

This article reports the ongoing development of the lidar facility at Buckland Park (35°S, 138°E), the first of its kind in Australia. Within The University of Adelaide, the Atmospheric Physics Group, in collaboration with the Optics and Photonics Group, is setting up a facility with the potential to host three lidar systems. The aim of this facility is to measure atmospheric temperature and dynamical processes with high spatial and temporal resolution from 15 to 110 km altitude. In addition, this project provides students with the unique opportunity to participate in a real world experiment and to benefit from the education and training gained by access to these instruments. The current work focuses on the development of a Rayleigh/Mie/Raman (RMR) backscatter lidar for temperature measurements in the altitude range from approximately 15 to 75 km. The derived temperature profiles will be used to establish a climatology and to study dynamical processes such as gravity waves at this unique geographic location. Although the RMR lidar technique is well established, most of these lidars are predominantly situated in the northern hemisphere. There are very few lidar stations in the southern hemisphere with the capability to investigate the middle atmosphere. The scientific outcomes of this project will greatly enhance our understanding of the middle atmosphere and will contribute to the evaluation of meteorological satellites and models in this southern subtropical region.

## 1. INTRODUCTION

One of the most fundamental parameters to describe our Earth's atmosphere is temperature. The knowledge of its temporal and spatial structure over a large vertical range is essential to understand dynamical and chemical processes. Numerous methods and instruments are used to investigate the thermal and dynamical state of the atmosphere. This includes in-situ measurements, active and passive remote sensing from the ground, as well as from space. The exploration of the middle atmosphere is particularly difficult since it is not accessible by aeroplanes or meteorological balloons, while sporadic rocket-borne measurements are too infrequent to produce adequate climatological data. The middle atmosphere is a key link to understand dynamical processes such as tidal, planetary and gravity waves because they change their characteristics (e.g. wavelength, amplitude) when propagating through the atmosphere from their source regions in the lower atmosphere to their breaking altitudes. The characteristics of these waves are still under scientific discussion as they vary significantly with geographical location, season and altitude [e.g. review by 1]. With ground based lidar measurements, various wave characteristics can be observed directly e.g., vertical wavelength, amplitude of temperature variation, potential energy and spectral power density. Nowadays investigating the middle atmosphere by lidar is a well established experimental method and utilised at many sites around the world. However, these sites are predominately in the northern hemisphere and there are very few lidar stations in the southern hemisphere. The southern subtropics is in particularly important as there is significant demand for temperature measurement with high spatial and temporal resolution in this area. To our knowledge there is only one lidar site in the southern subtropics with the capability to measure atmospheric temperatures similar to this proposal. The Durban lidar is situated in South Africa (30°S, 31°E) and is capable of measuring temperatures from 20 up to 74 km altitude [2]. The Buckland Park lidar (BP) facility will deliver high quality data from a geographically isolated location (35°S, 138°E) compared to existing lidar sites. The BP field site is already a unique atmospheric research location due to the co-location of a number of radars and passive optical instruments which have been in operation for decades [e.g. 3; 4; 5].

A broader outline of the Buckland Park lidar facility, scientific objectives and co-located instruments is presented in the next section. The anticipated performance of the RMR lidar and a detailed instrument description is presented in Section 3. The last section gives a status report of the project as of February 2010.

## 2. LIDAR FACILITY AND CO-LOCATED INSTRUMENTS

The lidar building has been recently finished and it is anticipated that installation and commissioning of the lidar will begin in March 2010. It is planned that this facility will incorporate 3 lidar systems: a) Coherent laser radar to measure wind fields and air turbulence up to altitudes of around 3 km [6], b) RMR lidar for measuring temperature and dynamical processes from 15 up to 75 km altitude and c) Sodium resonance lidar (Na lidar) which measures temperature and dynamical processes in the altitude range from 75–110 km. In combination, the latter two lidars facilitate investigation of the atmosphere



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Table 1: Anticipated characteristics of the RMR lidar at Buckland Park (35°S, 138°E)

| | | | |
|---|---|---|---|
| **Transmitter** | | | |
| Laser | | | |
| Type and wavelength | diode-pumped Nd:YAG; 532 nm | | |
| Average Power and pulse rate | 20 W at 200 Hz | | |
| Beam expander | | | |
| Geometry and beam expanding | Galilean; 20 times | | |
| Beam diameter and divergence | 65 mm; 10 $\mu$rad | | |
| **Receiver** | | | |
| Telescope | | | |
| Geometry and mirror diameter | Newtonian; 1 m | | |
| Field of view | 450 $\mu$rad | | |
| Detection bench | | | |
| Channels | Raman 608 nm | Rayleigh 532 nm low | Rayleigh 532 nm high |
| Interference filter (FWHM) | 1 nm | 1 nm | 1 nm |
| Altitude coverage | 10–40 km | 15–60 km | 40–80 km |
| Data acquisition | | | |
| Manufacturer and Model | Licel; 250 MHz photon counting recorder | | |
| Max. summation and repetition rate | 4094 shots; up to 435 Hz | | |
| Height range and resolution | 250 km; 50 m | | |

from the lower stratosphere to the lower thermosphere [e.g. 7; 8]. With this large vertical coverage from 15 up to 110 km it will be possible to investigate dynamical processes through the atmosphere and to establish an exceptional temperature climatology at this southern subtropical site. The lidar facility completes the Buckland Park site as a unique atmospheric research location as radar and airglow imaging instruments are already installed. The altitude region from 20 to 60 km is especially difficult for radar instruments to investigate due to the weak signal strength in these altitudes. The co-located Stratospheric-Tropospheric (ST) and Medium-Frequency (MF) radars can measure winds and dynamical processes up to 20 km and upwards of 60 km, respectively [e.g. 9]. The lidar will close this observational gap between 20 and 60 km, and it will also contribute to the analysis of co-located airglow imager instruments [e.g. 4]. In particular the Na lidar will contribute to the analysis of airglow imagers as it determines temperatures in the same altitude region. Furthermore the temporal high resolution measurements of chemical and dynamical properties of the Na layer will be compared with all-sky airglow images. With a comprehensive annual data set, intercomparison of these local observations with meteorological satellites and models will be conducted. Overall the scientific outcomes will greatly advance our understanding of the middle atmosphere and will contribute to the needs for observations in this southern subtropical region.

## 3. PROPOSED RMR LIDAR

The proposed lidar utilises backscattered light from Rayleigh, Mie and Raman scattering and is therefore called RMR lidar for brevity. For temperature soundings in the upper stratosphere and mesosphere, Rayleigh scatter signals can be used to derive the relative atmospheric density and temperature as demonstrated by many lidars [e.g. 10]. To use the so called ”top-to-bottom temperature integration” method, a temperature start value at the upper end of the profile is needed. Ideally this start value is taken from a simultaneous and co-located temperature measurement [11]. Until the Na lidar is developed this temperature value will be taken from the NRLMSISE-00 model [12]. The Rayleigh method is only applicable in the absence of particle and resonance scattering which thereby defines the limit of the achievable altitude coverage with this RMR lidar. Whereas the upper limit of $\sim$75 km is mainly given by instrumental parameters, the lowest height is determined by the influence of aerosol scattering. With increasing Mie scattering on aerosols at altitudes below $\sim$30 km, pure Rayleigh scattering can no longer be assured. Below this altitude the vibration-shifted $N_2$ Raman signals can be used to derive a pure molecular signal that is free of any aerosol background. By assuming that the particle extinction of the signal is negligible compared with the molecular extinction, temperature profiles down to $\sim$15 km can be derived [e.g. 11; 13; 14].

The atmospheric density decreases by about 5 orders of magnitude over the altitude up to $\sim$75 km, while the backscattered signal decreases by about 7 orders of magnitude due to the lidar's observational geometry. Such a high dynamic range can not be covered by just one PMT. To achieve this large dynamic range, two Rayleigh detection channels with different height coverage and a separate Raman detection channel will be installed. In order to obtain high quality data over the whole altitude range, and to achieve the scientific objectives, the lidar needs to meet high technical standards. The main components of the lidar are an in-house developed transmitter, receiving telescope, detection bench and a commercially available data acquisition system. The transmitter and the detection



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bench will be placed inside temperature stabilised laboratories. The receiving telescope will be placed outside under a movable roof next to the laboratories. The details of the RMR lidar are described in the following two subsections and summarized in Table 1.

## 3.1. Transmitter

The laser source for the RMR lidar is a frequency doubled, diode-pumped Nd:YAG laser. In recent years, diode-pumped Nd:YAG laser technologies have became increasingly mature and advanced. Compared to flash lamp pumped lasers they give great opportunities to simplify a lidar in terms of operational procedure, maintenance, reliability and robustness. Furthermore, the beam quality, divergence and jitter are far superior to that of a flash lamp pumped laser. The optical setup of the transmitter is shown in Figure 1. It consists of the diode-pumped Nd:YAG laser, frequency doubling crystal and beam widening telescope. The in-house developed Nd:YAG laser is based on the zig-zag slab architecture which is known to minimise thermal birefringence and thermal lensing issues. The combination of this architecture with diode pumping will minimise beam wander and jitter to provide a very stable beam geometry. The zig-zag slab is pumped at 808 nm by four quasi continuous wave diodes (LD) with 5 kW peak power and a lifetime of around one billion shots. This setup requires only minimal cooling power (~0.7 kW) as the diodes and the zig-zag slab operate at room temperature. The laser setup is designed for injection seeding, however, the seeder laser itself will be implemented at a later stage. The laser pulse at 1064 nm will exit the laser resonator through the thin film polarizer (TFP) and is then frequency doubled to 532 nm. It is anticipated that this laser system will provide 100 mJ per pulse of nearly diffraction limited output at 532 nm with a repetition rate of 200 Hz. The maximum repetition rate of the laser is limited by the speed of the data acquisition system, however, the system is laid out for repetition rates of up to 435 Hz. For beam diagnostics, a harmonic separator (HS 1) reflects the 532 nm and transmits the 1064 nm into the beam diagnostics. After the second separator (HS 2), a fraction of the 532 nm light is coupled onto a energy meter (EM) for continuous monitoring of the output energy during operation. The beam is then passed through a Galilean beam expander (BWT) which expands the beam diameter to 65 mm with a divergence of $\sim$10 $\mu$rad. This corresponds to a beam diameter of 1 m at 100 km altitude. Finally, a motorised beam guiding mirror (BGM) directs the beam vertically and coaxially to the receiving telescope into the sky. This motorised mirror allows the alignment of the emitted beam to the field of view of the receiving telescope.

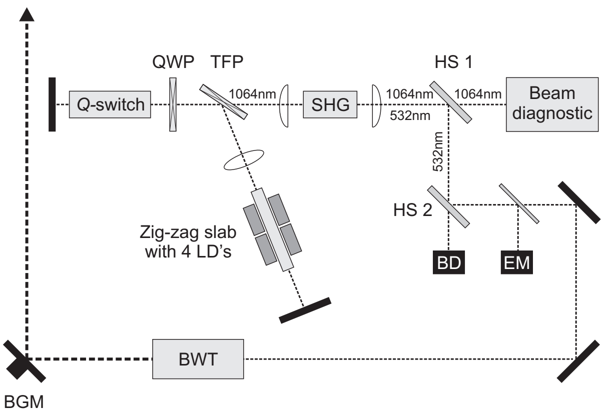


Figure 1: Schematic of the transmitter. The laser pulse exits the laser resonator through a thin film polarizer (TFP) and is then frequency doubled to 532 nm. A beam widening telescope (BWT) expands the beam to 65 mm with $\sim$10 $\mu$rad divergence. See text for more details.

## 3.2. Receiver

The backscattered light from the atmosphere is collected by a Newtonian telescope which has a mirror of 1 m diameter and a focal length of 4 m. The field of view of the telescope is determined by the focal length of the mirror and the diameter of the optical fiber which guides the light to the detection bench. The diameter of the optical fiber has been chosen to match a field of view of 450 $\mu$rad. To generate a parallel beam on the detection bench, the lens L1 is placed near the optical fiber output. Following the lens, a notch filter (NF) separates the vibration-shifted $N_2$ Raman light at 608 nm from the Rayleigh backscattered light at 532 nm. The light at 532 nm then passes through an interference filter ($IF_{532}$) with a 1 nm FWHM bandwidth, before it is separated into two Rayleigh detection channels. Both Rayleigh channels are blocked by a rotating chopper wheel (CP) to avoid saturating PMT 1 and 2 due to high intensity backscatter from lower altitudes. To increase the total dynamic range the signals below 15 km and 40 km are blocked in the 532-low and 532-

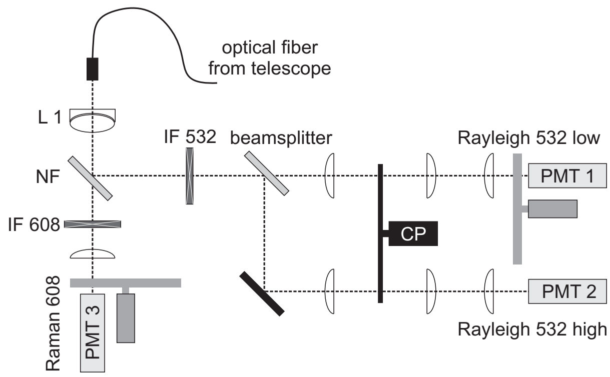


Figure 2: Schematic of the detection bench. The light from the telescope is separated by a notch filter (NF) into a $N_2$ Raman detection channel and a Rayleigh detection section with two channels. Detector PMT 1 (532-low) and PMT 2 (532-high) are used for lower and higher altitude Rayleigh measurements, respectively. Whereas PMT 1 and PMT 2 are protected by a mechanical chopper (CP), PMT 3 has a electro-optical shutter. In addition, filter wheels with neutral density filters are installed in front of PMT 1 and PMT 3. See text for more details.



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high channels, respectively. PMT 3 detects the vibration-shifted $N_2$ Raman signal at 608 nm and is protected by a electro-optical shutter. A schematic of the detection bench is shown in Figure 2.

Atmospheric return signals are recorded with a data acquisition system from Licel GbR, Germany. It has a height resolution of 50 m and can summarize up to 4094 shots with repetition rates as high as 435 Hz. Each PMT has its own photon counting unit and all three record simultaneously. For future extension of the receiver, the Licel system is already laid out for up to six receiving channels. It is also used for synchronising the laser to the rotating chopper wheel for both timing and producing the diode fire and *Q*-switch trigger pulses for the laser.

## 4. CURRENT STATE

The installation and commissioning of the lidar systems will start as soon as the lidar building is handed over in March 2010. With the handover all necessary laboratory fitout including optical tables, cabinets etc. will be completed. The Coherent laser radar is already assembled and will be reinstalled at BP during 2010. The installation of the Na lidar is not expected before 2011 as both, the transmitter and receiver are still under development. The main emphasis is currently on the installation of the RMR lidar. The capabilities of the diode-pumped laser system have been demonstrated for a different purpose. However there will be improvements to the laser system for the RMR lidar which is currently under development. It is expected that the improved laser setup will be operational in late March and installed at Buckland Park soon after. Other components for the transmitter, like beam guiding mirrors, have been purchased. The properties of the receiving mirror have been determined and even though the parts for the telescope frame have not yet been ordered, the lay out of the telescope frame is completed and a supplier selected. All parts for the Rayleigh detection section have been purchased along with the Licel data acquisition. The Raman detection section will be added later in 2010. It is expected that the RMR lidar will be operational in June 2010.

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