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ABSTRACT

Snodar is a high resolution acoustic radar designed specifically for profiling the atmospheric boundary layer on the high Antarctic plateau. Snodar profiles the atmospheric temperature structure function constant to a vertical resolution of 1 m or better with a minimum sample height of 8 m. The maximum sampling height is dependent on atmospheric conditions but is typically at least 100 m. Snodar uses a unique in-situ intensity calibration method that allows the instrument to be autonomously recalibrated throughout the year. The instrument is initially intensity calibrated against tower-mounted differential microthermal sensors. A calibration sphere is located in the near-field of the antenna to provide a fixed echo of known intensity, allowing the instrument to be continuously re-calibrated once deployed. This allows snow accumulation, transducer wear and system changes due to temperature to be monitored. Year-round power and communications are provided by the PLATO facility. This allows processed data to be downloaded every 6 hours while raw data is stored on-site for collection the following summer. Over 4 million processed samples have been downloaded through PLATO to date. We present signal attenuation from accumulation of snow and ice on Snodar's parabolic reflector during the 2009 at Dome A.

Keywords: atmosphere, boundary layer, SODAR, Antarctica, Antarctic plateau, astronomy, site-testing

1. INTRODUCTION

Atmospheric turbulence is of interest to astronomers as optical turbulence limits the spatial resolution of ground based optical astronomical observations. The atmospheric boundary layer on the Antarctica plateau is unique in that over 90% of the total atmospheric turbulence can be confined to within the first few tens of meters of the atmosphere[1,2]. Such an environment provides a unique opportunity as it is technically feasible to build and operate a 2 m class telescope on a 30 m tower[3,4] where it can take advantage of the excellent free-atmosphere seeing of 0.27 arcsec[5]. The height, distribution and variability of the atmospheric boundary layer is critical knowledge when designing an optical telescope for the Antarctic plateau. While there are several methods to profile atmospheric turbulence[6], a SODAR is the ideal instrument for profiling the first few hundred meters of the atmosphere with high spatial and temporal resolution. Snodar is a monostatic SODAR designed specifically to profile atmospheric turbulence within the first 100 m of the atmosphere

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to a vertical resolution of 1 m with the aim of characterising the height of the Atmospheric boundary layer on the Antarctic plateau.

Snodar was deployed to Dome A, Antarctica in 2009 as part of PLATO (the PLATeau Observatory)[7,8,9] as pictured in Figure 1. Snodar operated throughout 2009 at Dome A with 77% data availability. The results of the 2009 campaign are presented in Bonner et al. (2010)[2]. Snodar was serviced in January 2010 and in still operating as of May 2010 when this paper was submitted. Signal attenuation due to snow and ice accumulation within Snodar's antenna is critical information for obtaining calibrated turbulence profiles. We present signal attenuation from accumulation of snow and ice on Snodar's parabolic reflector during the 2009 at Dome A.

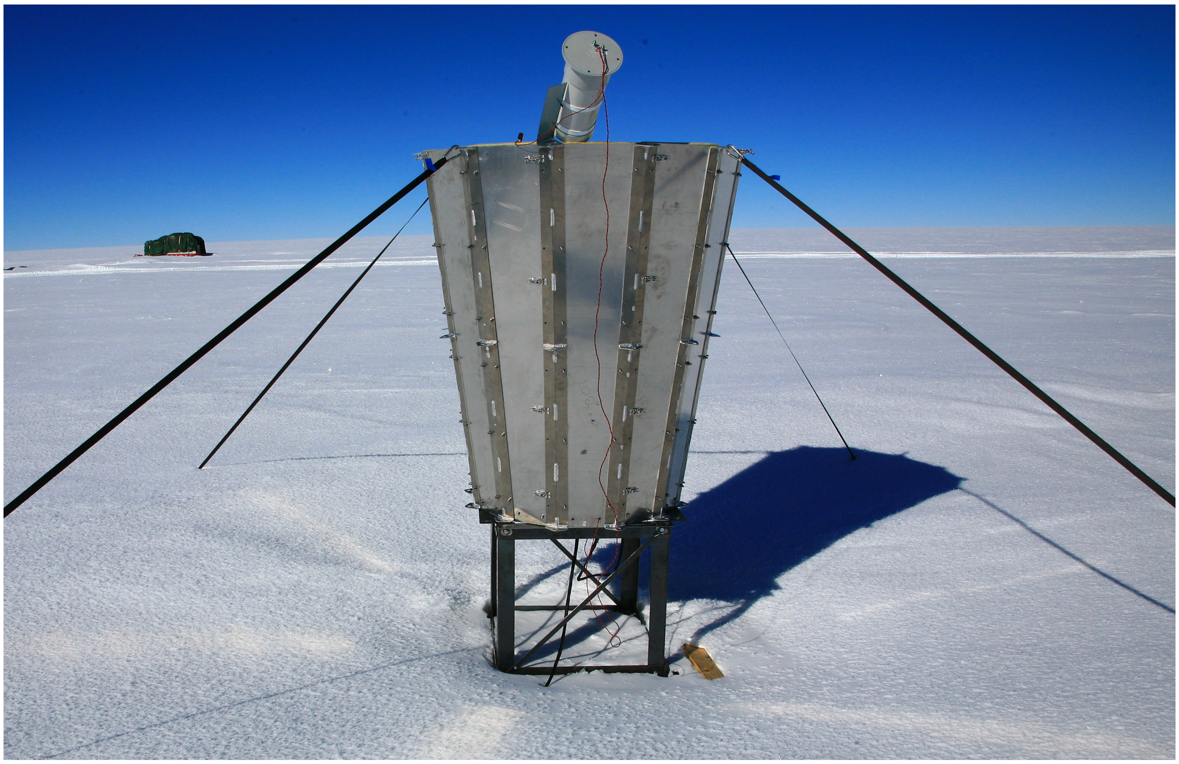

Figure 1 Snodar installed at Dome A, Antarctica 2010. The tube at the top of the 1.6 m tall sound cone is a WiFi webcam to monitor snow accumulation on the parabolic reflector.

2. SNODAR

The acoustic design of Snodar is given in [10], and an overview of the electrical system is given in [11]. Snodar uses a single horn loaded compression driver (JBL2404H) as a transducer to transmit an intense pulse of acoustic energy vertically into the atmosphere and receive the faint backscatter from atmospheric turbulence. A 0.9 m f/0.6 off-axis parabolic reflector is used to collimate the acoustic energy, the transducer and reflector are housed in a 1.6 m tall sound cone to shield it from ambient noise and reduce acoustic scattering from ground clutter. The cross section of Snodar's antenna is shown in Figure 2. The front surface of the dish has been aluminised to reduce its emissivity and increase the effectiveness of electrical heating pads mounted on the back side of the reflector. The back of the reflector has also been insulated with polyurethane foam to increase the efficiency of the heaters. The heating pads apply almost continuous 200W of heat directly to the parabolic reflector to inhibit frost formation and sublime small portions of snow and ice. A 50 m diameter sphere of solid phenolic resin is suspended in the aperture of Snodar's sound cone, the echo from which provides a fixed echo at a known height with a known intensity; we refer to this sphere as the calibration sphere. The intensity of the echo from the calibration sphere can be used to compensate for variations in the system gain due to snow and ice on Snodar's parabolic reflector. While the intensity of the calibration sphere can be calculated theoretically, we measure it experimentally by first calibrating Snodar against microthermal sensors[12].

Snodar is largely software defined and runs under Linux on a PC/104 form-factor computer. A *Sound Blaster Live! 24-bit* external USB sound card is used for all analog signal IO and an ARM7TDMI embedded system is used for system control and data acquisition. A high level overview of Snodar's electrical system is shown in Figure 3. The USB soundcard allows stereo signal capture at 24-bit resolution while sampling at 96 kHz with a USB 2.0 connection. Snodar uses both channels of the stereo output: one channel generates the waveform to be amplified and energise the transducer while the other controls a solid-state transmit-receive switch. The output channel that controls the transmit-receive switch is also connected to one of the input channels to form a hardware loop back allowing the audio output and input to be synchronized in software. The transmit-receive switch connects the transducer to a 1nV/√Hz preamplifer via an impedance matching network and 30 m of cable while in the receiving position. The preamplifier has a fixed gain of 60dB followed by a 12-bit programmable gain amplifier that can be varied from 0dB to 72dB; a gain of 38dB is generally used while profiling turbulence up to 100 m. The signal is them sampled by the USB sound card and processed in software. The embedded system allows the PC/104 to control the gain of the programmable gain amplifier, measure bus voltages and current consumption and control auxiliary devices, such a heaters and webcams.

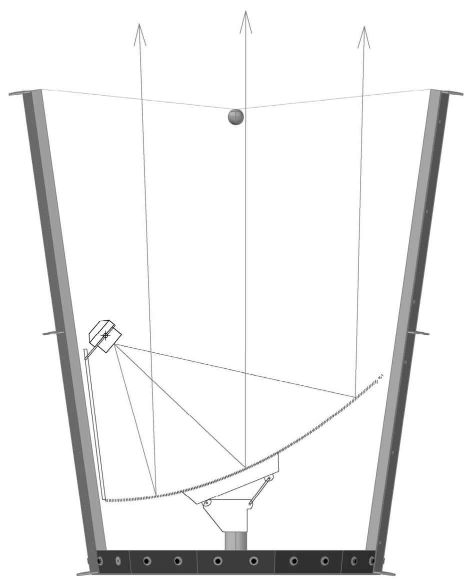

Figure 2 Cross section of Snodar's antenna[10]: the acoustic transducer is near the focal point of a 0.9 m f/0.6 off-axis parabolic reflector housed in a 1.6 m tall sound cone. The calibration sphere is suspended in the middle of the sound cone's aperture.

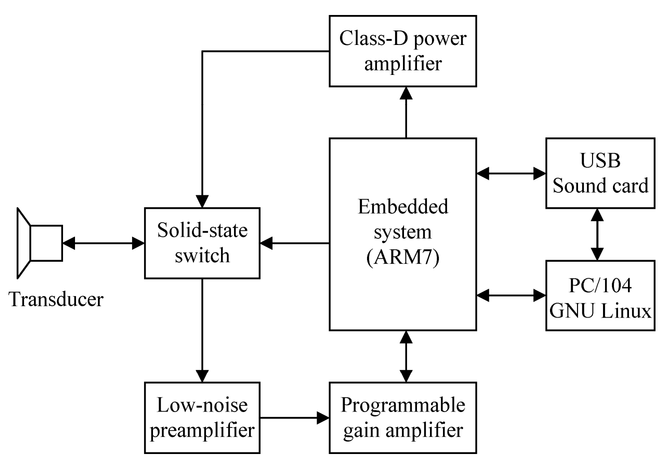

Figure 3 High level overview of Snodars electrical system[11]. A PC/104 computer running Linux performs all the signal processing and control tasks in real time. A USB sound card provides 24-bit analogue signal acquisition at a sampling frequency of 96kHz. The ARM7TDMI embedded system provides system control and data acquisition.

The radar equation can be rewritten for acoustics[13]. The power received by a SODAR can therefore be written as

$$P_r = \eta P_t \sigma(\theta) \frac{1}{h^2} e^{-2\alpha h} + P_n \tag{1}$$

where P_r and P_t are the power received and transmitted respectively, P_n is the noise power, α is the atmospheric attenuation coefficient, η is the system gain and h is the height of scattering volume. The accumulation of snow and ice in Snodar's antenna directly affects the system gain. The height of the scattering volume can be calculated from the time of flight of the initial acoustic pulse and the known speed of sound. The $1/h^2$ term is due to $1/r^2$-spreading from the scattering volume towards the receiver, while the $e^{-2\alpha h}$ accounts for atmospheric attenuation. For an acoustic wave propagating in a turbulent atmosphere, the scattering cross section as a function of scattering angle, θ, is given by[14]

$$\sigma(\theta) = 0.03\kappa^{1/3} \cos^2\theta \left[\frac{C_V^2}{c^2} \cos^2\frac{\theta}{2} + 0.13\frac{C_T^2}{T^2} \right] \sin\left(\frac{\theta}{2}\right)^{-11/3} \tag{2}$$

where κ if the wave vector, and C_T^2 and C_V^2 are the temperature and velocity structure function constants respectively. By collocating the transmitter and receiver, or making the instrument monostatic, the scattering angle becomes π and equation (2) simplifies to

$$\sigma_\pi = 0.0039\kappa^{1/3} \left[\frac{C_T^2}{T^2} \right] \tag{3}$$

Equation 1 and 3 therefore allow the power received by a SODAR to be related to the intensity of the atmospheric turbulence of a scattering volume as a function of height. The signal to noise ratio for a SODAR can be written as

$$SNR = \frac{\eta P_t \sigma(\theta) \frac{1}{h^2} e^{-2\alpha h}}{P_n}$$

The effective range of a SODAR is the height where the returned signal can no longer be differentiated from the noise. This is dependent on the signal processing algorithms and the characteristics of the noise. High frequencies propagate well on the Antarctic plateau due to the extreme cold, as such $1/r^2$-spreading and the extremely low atmospheric turbulence is the limiting factor for the maximum range of Snodar. The minimum range of a SODAR is limited by antenna reverberation and electrical transients within the receiver circuitry from the intense pulse transmitted. The antenna reverberation and electrical transients reduce to the noise floor by 8 m in the case of Snodar. Snodar measures the in-band noise power immediately before transmitting each pulse to allow the noise to be characterised. Data are processed on site before being compressed and sent off site for detailed analysis. Calibration pulses, which record the scattered power from the calibration sphere, require more in-depth analysis of the saved raw data.

3. RESULTS AND DISCUSSION

Calibration pulses were recorded every 30 minutes while Snodar was operating at Dome A during 2009. Figure 4 shows the scattered power from the calibration sphere referenced to the preamplifer input (crosses), and data availability (thin horizontal broken line towards the top of the plot indicates invalid data). Data are deemed valid when a sharp transition at the top of the atmospheric boundary layer can be observed as described by Bonner et al. 2010[2].

The power scattered from the calibration sphere can be broken into three piece-wise approximately linear regimes during 2009. Linear regression was performed on these three regimes to build a simple model of attenuation on Snodar's dish over the year. The fitted model is shown as the thick solid line in Figure 4. This model indicates that the majority of the snow that accumulated on Snodar during 2009 occurred between mid March to late April 2009. Further work is required to compute calibrated turbulence profiles from these data.

The accumulation of snow within Snodar's antenna reduces the SNR of the measurements and hence reduces the effective range of the instrument. The top of the boundary layer could no longer be identified from Snodar pulses after 18th August 2009 as the height of the boundary layer increased above the effective range of Snodar as the Antarctic plateau entered the Austral Spring. Data was available for 77% of the time between 4th February and 18th August 2009. A webcam has been installed within the sound cone of Snodar for the 2010 campaign to further investigate the problem of snow accumulation within Snodar's antenna. A mechanical sweeper will be installed on future deployments of Snodars.

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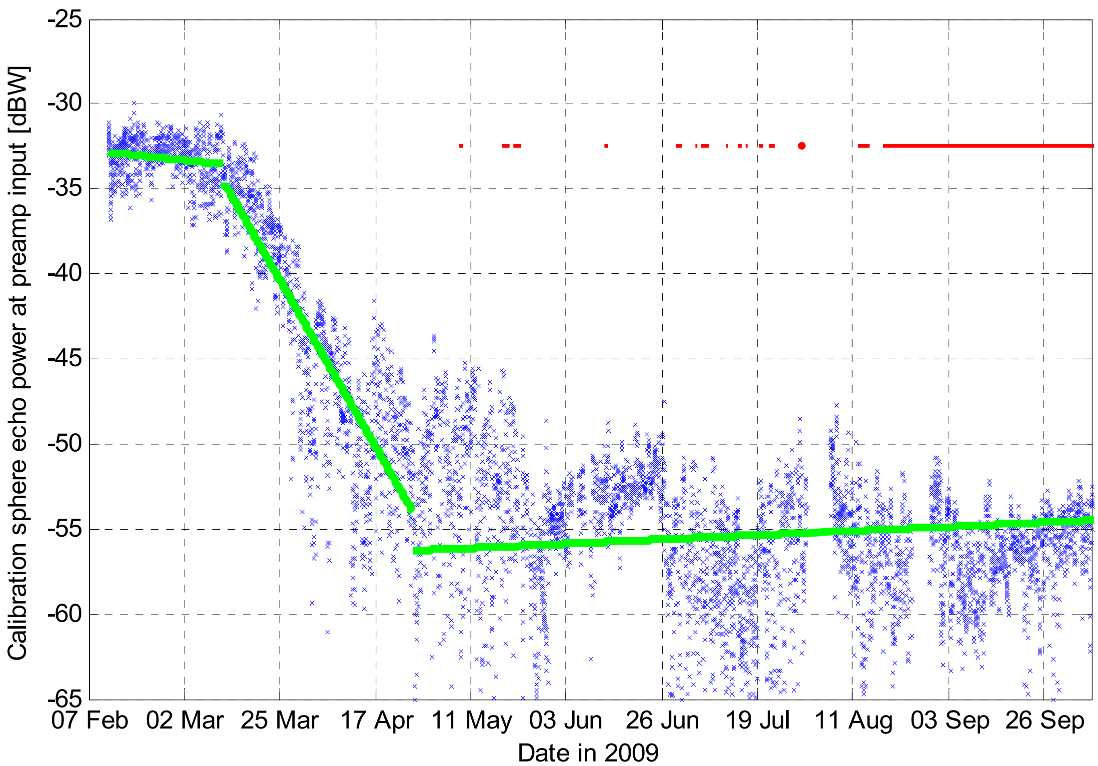

Figure 4 Crosses indicate the echo power from Snodar's calibration sphere referred to the transducer terminals during 2009. The thick lines indicates the piece-wise linear fit and the thin horizontal broken line towards the top of the plot indicates those regions where no sharp transition at the top of the boundary layer was observed, and hence the data were deemed to be invalid.

REFERENCES

[1] Trinquet, H., Agabi, A., Vernin, J., Azouit, M., Aristidi, E., Fossat, E., "Nighttime Optical Turbulence Vertical Structure above Dome C in Antarctica", Publications of the Astronomical Society of the Pacific 120, 203-211 (2008).

[2] Bonner, C. S., et al., "Height of the Atmospheric Boundary Layer Above Dome A, Antarctica, during 2009", Submitted to PASP May 2010.

[3] Hammerschlag, R. H., Bettonvil, F. C. M., Jaegers, A. P. L., "Towers for telescopes with extreme stability: active or passive?", Proc. SPIE 6273, 62731O (2006).

[4] Saunders, W., Gillingham, P. R., McGrath, A. J., Storey, J. W. V., Lawrence, J. S., "PILOT: design and capabilities", Proc. from the 2nd ARENA conference on The Astrophysical Science Cases at Dome C (Eds. H. Zinnecker, H. Rauer, N. Epchtein). EAS Publications Series 33, 285-288 (2008).

[5] Lawrence, J.S., Ashley, M.C.B., Tokovinin, A., Travouillon, T., "Exceptional astronomical seeing conditions above Dome C in Antarctica", Nature 431, 278-281 (2004).

[6] Storey, J. W. V., Ashley, M. C. B., Lawrence, J. S., "How can we understand the Antarctic Atmosphere?.", Proc. International Conference Optical Turbulence Astronomy meets Meteorology (Eds. E. Masciadri, M. Sarazin). Imperial College PressWorld Scientific, 82-89 (2009).

[7] Lawrence, J. S., et al, "The PLATO Antarctic site testing observatory", Proc. SPIE 7012, 701227-1 (2008).

[8] Lawrence, J. S., et al., "The PLATO Dome A site testing observatory: power generation and control systems", Review of Scientific Instruments 80, 064501-1-064501-10 (2009).

[9] Yang, H., et al., "The PLATO Dome A Site-Testing Observatory: Instrumentation and First Results", Publications of the Astronomical Society of the Pacific 121, 174-184 (2008).

[10] Bonner, C. S., Ashley, M. C. B., Lawrence, J. S., Luong-Van, D. M., & Storey, J.W. V., "Snodar: An acoustic radar for atmospheric turbulence profiling with 1m resolution", Acoustics Australia 37(2), 47-51 (2009).

[11] Bonner, C. S., Ashley, M. C. B., Lawrence, J. S., Luong-Van, D. M., Storey, J. W. V., "Snodar II: Probing the atmospheric boundary layer on the Antarctic Plateau", Proc. International Conference Optical Turbulence Astronomy meets Meteorology (Eds. E. Masciadri, M. Sarazin). Imperial College PressWorld Scientific, 264-270 (2008).

[12] Bonner, C. S., Ashley, M. C. B., Lawrence, J. S., Storey, J. W. V., Luong-Van, D. M., & Bradley, S.G., "Snodar: a new instrument to measure the height of the atmospheric boundary layer on the Antarctic plateau", Proc. SPIE 7014, 70146I (2008).

[13] Little, C.G., "Acoustic methods for the remote probing of the lower atmosphere", Proceedings of the IEEE 57, 571-578 (1969).

[14] Tatarskii, V., [The effects of the turbulent atmosphere on wave propagation], Keter Press, Jerusalem (1971).