

SNODAR II: PROBING THE ATMOSPHERIC BOUNDARY LAYER ON THE ANTARCTIC PLATEAU

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The height of the atmospheric boundary layer on the Antarctic plateau is of particular interest to meteorologists and designers of optical telescopes for Antarctica. “Snodar” was developed at the University of New South Wales to measure the height of the boundary layer at Dome A and Dome C on the Antarctic plateau. Snodar operates between 3 kHz and 14 kHz and has a vertical resolution of 1 m or better. Snodar was deployed to Dome A in 2008 and was found to have sufficient sensitivity to be able to measure the height of the atmospheric boundary layer with a single pulse. We present here the technical details of a second-generation Snodar, which will be deployed to Dome A in 2009.

1. Introduction

Acoustic radars have been used by meteorologists to probe the lower atmosphere for decades. Acoustic radars transmit an intense pulse of sound into the atmosphere and listen for the very small portion of energy scattered by temperature and velocity inhomogeneities[1]. The intensity of the scattered pulse is proportional to the intensity of the atmospheric turbulence and the Doppler shift of the scattered pulse provides information about wind velocity. The remote sensing nature of acoustic radars have made them an invaluable tool in exploring the nature of the atmospheric boundary layer (ABL)[2,3,4,5]. The ABL over the Antarctic plateau is of interest to meteorologists, atmospheric chemists, and astronomers alike. In recent years acoustic radars have been used by astronomers for site testing and characterisation[6,7]. Travouillon[7] has shown that data from acoustic radars can be used to directly estimate the ground-layer contribution to astronomical “seeing” (i.e., image degradation due to the earth’s atmosphere).

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1.1. Instrument background

At Dome C, the turbulence in the free atmosphere above the ABL has been found to be exceptionally calm and stable[8,9]. However, the winter-time ABL, which is typically tens of metres thick, was found to be very turbulent, contributing up to 87% of the winter-time astronomical “seeing” at ground level[9]. The PLATeau Observatory (PLATO) was developed at the University of New South Wales and deployed to Dome A[10] in January 2008 as part of the Polar Research Institute of China PANDA traverse. At an altitude of 4093 m, Dome A is the highest point on the Antarctic plateau as shown in Figure 1. One of the motivations for PLATO was to investigate the ABL at Dome A. Unfortunately, no commercially available acoustic radars could probe the first few tens of meters of the atmosphere with the required resolution of 1 m or better. “Snodar” is an acoustic radar designed specifically to autonomously measure the height, strength, and variability of the ABL on the Antarctic plateau. The original design of Snodar is presented by Bonner *et al.*[11]. We present here technical details of the second-generation Snodar.

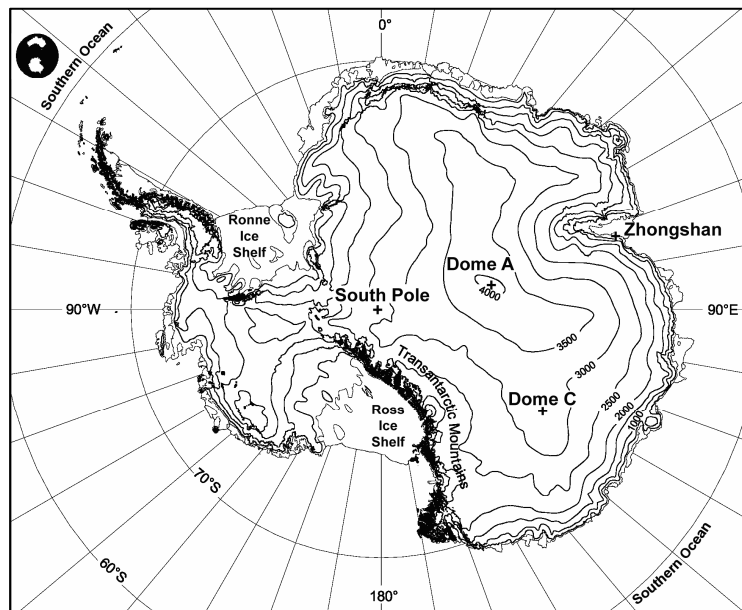


Figure 1 Map of Antarctica showing the Chinese coastal station Zhongshan and the high plateau stations South Pole, Dome C and Dome A. Basic map courtesy of the Australian Antarctic Data Centre.

2. Instrument design

Snodar was the first acoustic radar deployed to Dome A in February 2008. Snodar successfully operated fully autonomously and was able to determine the height of the atmospheric boundary-layer (ABL) from a single pulse. Data were collected for a short period before the failure of an electromechanical relay crippled the instrument. Parts of the instrument were redesigned in 2008 to expand its capabilities and increase its reliability.

The original Snodar used a fixed-gain low-noise preamplifier and a 60 W Class-AB power amplifier. A USB sound card provided high-speed analog IO. All signal processing was performed in real time on a PC/104 running GNU/Linux (Debian etch, with a read-only filesystem). On-site data reduction reduces the 2.7 MB of raw data by a factor of approximately 600 to 4.5 KB. Data files are then compressed using bzip2 before being written to disk. The final turbulence profile is reconstructed by post processing the data to correct for temperature gradients, noise and atmospheric attenuation.

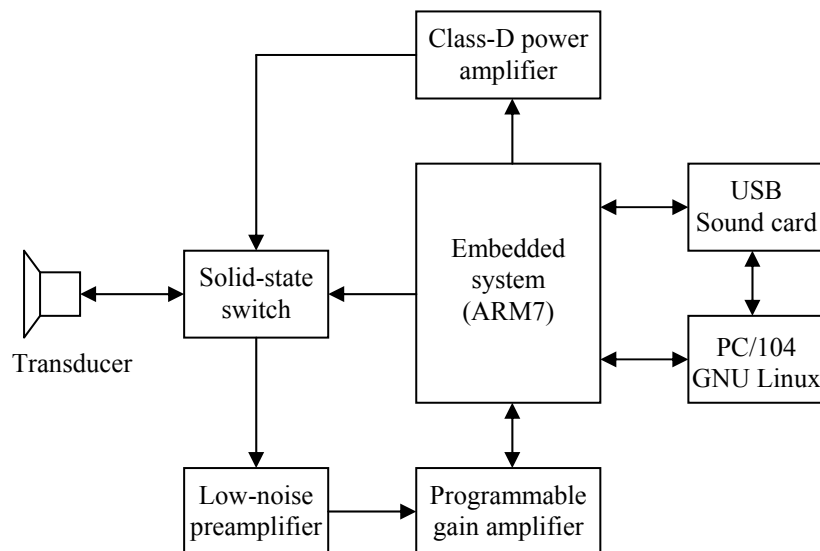


Figure 2 System overview of the second-generation Snodar.

The second-generation Snodar incorporates several enhancements including a 12-bit programmable gain amplifier following the low-noise preamplifier, a 150 W Class-D power amplifier and an embedded system as shown in Figure 2.

The programmable gain amplifier has a software selectable gain between 1 and 4095 which increases the dynamic range of the instrument. The electrical efficiency of the instrument is significantly increased by using a Class-D power amplifier. The embedded system is based on a 40 MHz ARM7TDMI microprocessor and has the ability to perform all IO and digital signal processing. A USB sound card and a PC/104 running GNU/Linux (Debian etch, with a read-only root filesystem) will be used at Dome A to expand the system's capabilities and increase maintainability through the PLATO facility.

The PC/104 communicates with the embedded system via RS-232C while the USB sound card is connected to the embedded system via two 3.5 mm stereo sockets. Snodar can be turned into a low-cost, low-power instrument for remote installation by removing the PC/104 and solely relying on the embedded system. In such a case a radio modem, Iridium modem or Ethernet-based RS-232 device server can be used for communication with the instrument. A secondary RS-232C interface has been added to the embedded system to facilitate the connection of auxiliary devices such as weather stations or a secondary Snodar.

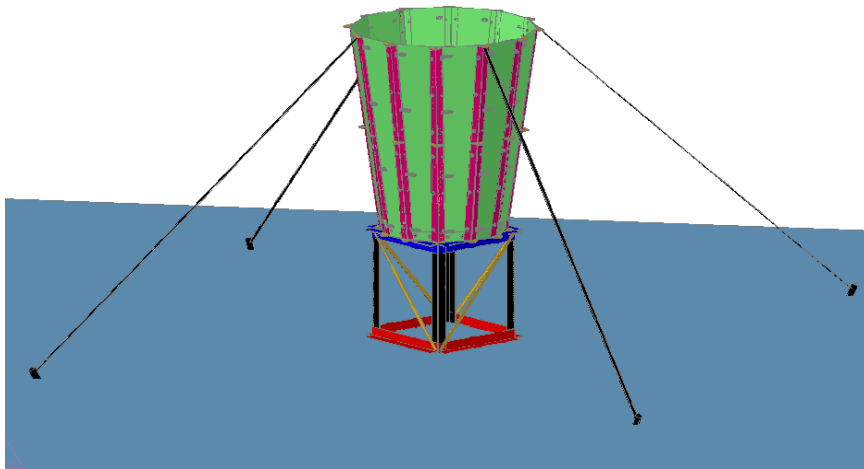


Figure 3 A CAD rendering of Snodar installed in Antarctica. The 1.6 m tall sound cone sits on a 0.8 m open air frame. Four guide wires are used to secure the structure. A 0.95 m off-axis parabolic reflector is located at the bottom of the sound cone.

2.1. *Acoustic design*

The second generation of Snodar uses a 0.95 m $f/0.6$ off-axis parabolic reflector housed in a 1.6 m tall aluminium sound cone and operates between 3 kHz and 14 kHz. A rock-wool based sound absorber is used to reduce the reverberation

time and provide acoustic isolation. Heaters have been installed on the back of the parabolic reflector and covered with several inches of insulation. The heaters have enough power to sublime small portions of snow and prevent frost formation. A low emissivity coating has been applied to the top surface of the parabolic reflector to passively hinder frost formation and increase heating efficiency. As shown in Figure 3, Snodar has been placed on a 0.8 m tall open-air frame to reduce snow drift. Guide wires are used to secure the structure.

2.2. Calibration

Although it is straightforward to accurately derive the height of the turbulence layer for an acoustic radar, deriving accurate estimates of the turbulence intensity is more difficult[12]. As the height of the ABL can be defined through relative changes in the temperature structure function constant (C_T^2), absolute calibration of the scattering coefficient is seldom required. However, if the temperature, pressure and C_T^2 profiles are known then the refractive index structure function constant (C_N^2) can be derived and its contribution to the astronomical “seeing” calculated[7]. For this reason it is desirable, but not essential, to calibrate the intensity data from Snodar. The fact that Snodar must operate over a 40° C temperature range, unmanned for a year poses an issue with the stability of the instrumental sensitivity. To address this, we suspended a sphere of 50 mm diameter made from solid phenolic resin over the aperture of the sound cone as shown in Figure 4. The sphere is referred to as the “calibration sphere” and has two purposes. Firstly, as the height of the calibration sphere above the ice surface is accurately known the echo can be used to remove any systematic offset errors in the scattering heights. Secondly, at any given wavelength the magnitude of the echo from the calibration sphere should be constant throughout the year. This will allow the efficiency of the system to be monitored and the transducer sensitivity to be corrected during post processing.

2.3. Diagnostics

The accumulation of snow and ice on exposed surfaces poses the largest issue for autonomous operation of Snodar in Antarctica. If ice forms on the transducer or parabolic reflector the gain of the system will be reduced. This can have a significant impact on the signal to noise ratio of data. During 2008 the echo from the calibration sphere allowed the gain of the system to be monitored and any changes corrected for. A WiFi based camera will be installed inside Snodar’s antenna for 2009. The camera will transmit images through the

PLATO facility allowing snow and ice accumulation to be monitored and the heating of the dish optimised.

An array of analog and digital IO has been added to the embedded system to provide a simple system control and data acquisition (SCADA) system. Several of the digital outputs drive high-current high-side switches that are used to control heaters, fans and power to the WiFi camera. The analog inputs allow bus voltages and currents to be monitored.

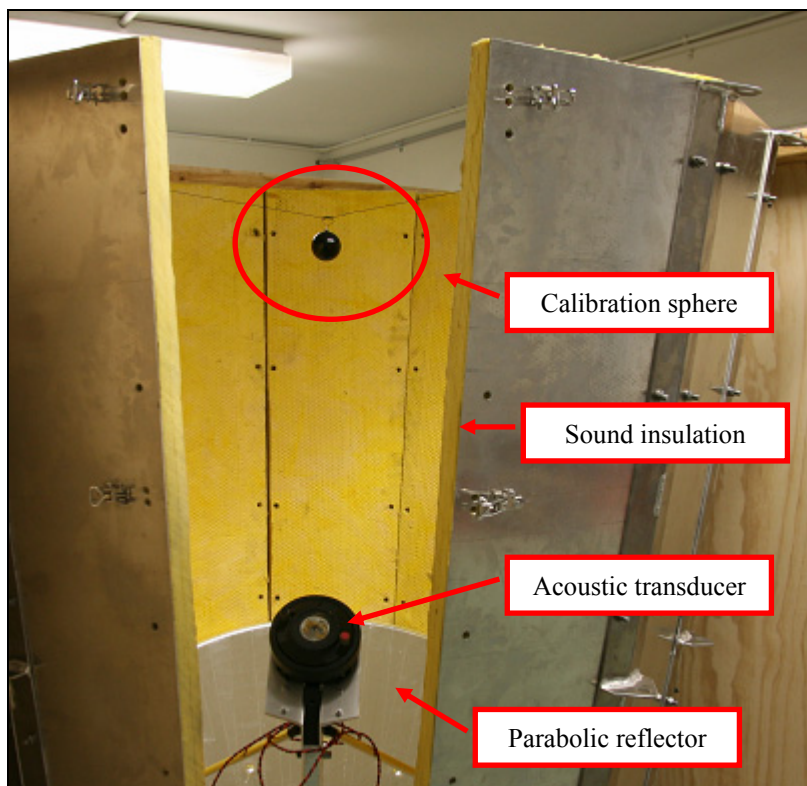


Figure 4 View of the aluminium sound cone, parabolic reflector and calibration sphere. The calibration sphere is suspended by thin wires. Image credit Xuefei Gong.

3. Future work

The second-generation Snodar will be installed at Dome A in January 2009 by the Chinese PANDA traverse. The electronics of the original Snodar will also be upgraded at the same time. Operating two Snodars side-by-side will allow the different antenna designs to be compared. This will be used to optimise the

antenna design for a third generation of Snodar in terms of acoustic performance and sensitivity to snow and ice. The design goal for the third-generation Snodar is that it can be installed in remote locations with a nominal power consumption of only a few hundred milliwatts. A large bank of batteries and solar panels will be used to provide power to the instrument.

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References

1. C. G. Little, *Proc. IEEE*, **57**, 571 (1969)
2. M.A. Kallistratova, *IOP Conference Series: Earth and Environmental Science* **1**, 012001 (2008).
3. A.D. Culf, *Antarctic Science*, **1**, 363 (1989).
4. S. Argentini, G. Mastrantonio, A. Viola¹, P. Pettre and G. Dargaud, *Boundary-Layer Meteorology* **81**, 75 (1996)
5. W.D. Neff, *PhD Thesis*, Wave Propagation Laboratory, Boulder Colorado, USA, (1981).
6. T. Travouillon, M.C.B. Ashley, M.G. Burton, J.W.V. Storey, and R.F. Loewenstein, *Astron. & Astrophys.* **400**, 1163 (2003).
7. T. Travouillon, *Proc. SPIE*, **6267**, 626720 (2006);
8. J.S. Lawrence, M.C.B. Ashley, A. Tokovinin, T. Travouillon, *Nature* **431**, 278 (2004).
9. A. Agabi, E. Aristidi, M. Azouit, E. Fossat, F. Martin, T. Sadibekova, J. Vernin, A. Ziad, *The Publications of the Astronomical Society of the Pacific* **118**, 344 (2006).
10. J.S. Lawrence, G.R. Allen, M.C.B. Ashley, C. Bonner, S. Bradley, X. Cui, J.R. Everett, X. Feng, S. Hengst, J. Hu, Z. Jian, C.A. Kulesa, Y. Li, D. Luong-Van, A.M. Moore, C. Pennypacker, W. Qin, R. Riddle, Z. Shang, J.W.V. Storey, B. Sun, N. Suntzeff, N.F.H Tothill, T. Travouillon, C.K. Walker, L. Wang, J. Yan, J. Yang, H. Yang, D. York, X. Yuan, X. Zhang, Z. Zhang, X. Zhou, Z. Zhu, *Proc SPIE* **7012**, 701227 (2008).
11. C.S. Bonner, M.C.B. Ashley, J.S. Lawrence, J.W.V. Storey, D.M. Luong-Van and S.G. Bradley, *Proc. SPIE* **7014**, 70146I (2008).
12. S.D. Danilov, A.E. Gur'yanov, M.A. Kallistratova, I.V. Petenko, S.P. Singal, D.R. Pahwa, B.S. Gera, *Meas. Sci. Technol* **3**, 1001 (1992).