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Antarctic Site Testing

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Abstract. We review the results obtained to date by various groups site-testing on the Antarctic plateau. To further these studies, we have developed a suite of self-contained instruments for year-long site testing on the Antarctic plateau. These instruments include a UV/visible sky brightness and stellar spectrometer, a near-infrared sky-brightness monitor, and a mid-infrared sky brightness monitor. To these we have added a Remtech acoustic radar and a low-power version of the sub-millimeter tipper originally developed by NRAO and CMU. The complete suite of instruments operates within a total power of 50 watts. These instruments have operated at the South Pole as part of the Automated Astrophysical Site-Testing Observatory (AASTO). We have already shown that the infrared sky brightness at the Pole can be up to 100 times lower than at temperate sites, and further data are being acquired. The AASTO will soon be deployed to other, more remote sites on the Antarctic plateau.

1. Introduction

The Antarctic plateau offers unique opportunities for astronomers (see, for example, the review by Burton et al. 1994). No other region on earth is as cold or as dry. With an elevation that ranges from 2850 m at South Pole to above 4100 m at Dome A, the Antarctic plateau offers an atmospheric transmission at infrared and sub-millimeter wavelengths that is unsurpassed. Because the sky is both extremely transparent and exceptionally cold, the infrared sky background is correspondingly reduced—at some wavelengths by up to a factor of 100 over even the best temperate sites. In addition, the absence of a high-altitude jet stream within the polar vortex combines with an exceptionally stable middle atmosphere to offer the promise of remarkably good seeing, compromised only by a very thin turbulent layer just above the ground.

Contrary to popular belief, observing conditions on the plateau are not particularly difficult. It never rains, there is very little wind (an average of just 2 m/s at Dome C; Valenziano & Dall'Oglio 1999) and there are no polar bears. Once equipment has been designed to cope with the extreme cold, the operating constraints are largely those of the difficulty of access and of isolation—constraints that apply to a greater or lesser extent at all observatories.

2. Site Testing Results

In this section we review the progress made to date in characterizing the properties of the sky above the Antarctic plateau. While site testing on the plateau is an on-going exercise, results to date are sufficiently encouraging to justify the construction of facilities of at least modest size—facilities which, because of the favorable conditions under which they operate, can outperform very much larger facilities at temperate sites (Burton, Storey & Ashley 2001).

2.1. Weather Statistics

There has been a continuous record of the basic atmospheric conditions at the South Pole since 1957. At other sites on the plateau, data are far more sparse. Most of the information available comes from the Automated Weather Stations (AWS) that are dotted around the plateau. In addition, each of the six Automated Geophysical Observatories and the Automated Astrophysical Site Testing Observatory (see section 3) are themselves complete weather stations. Some additional summer data are also available for Dome C, where a permanent French/Italian station is currently under construction.

2.2. Seeing

For optical astronomers, seeing is the most important site parameter after cloud cover. Unfortunately it is also probably the most difficult to characterize at a remote site, as it requires the ability to point at, and track, a specific star using a telescope of at least 30 cm aperture. In addition, simple measurements of seeing made for example, with a basic Differential Image Motion Monitor (DIMM) reveal little about the actual structure of the atmosphere. In particular, little or no information is derived on the heights of the turbulent layers. For this reason, indirect measurements of seeing are often preferred—either in combination with a DIMM or on their own.

Direct measurements of the seeing at the South Pole using a DIMM (Loewenstein et al. 1998) show a median value at ground level of $1.7''$. While this is considerably inferior to typical values at the best optical sites, there is compelling evidence from microthermal measurements (Marks et al. 1996; Marks et al. 1999) that almost all of this seeing degradation occurs in the lowest 200 meters of the atmosphere. Above this thin, turbulent surface layer the atmosphere is exceptionally stable and there is no jet stream—in contrast to the situation at other observatories. At the South Pole, an adaptive optics (AO) system could be very effective, as only a single turbulent layer needs to be corrected. The result should be a simple and effective AO system and a wide isoplanatic angle. This is anticipated to be ~ 30 times larger than at temperate latitude sites (Marks, 2000).

Furthermore, it is to be expected that at other sites on the Antarctic plateau where the wind speed is lower the turbulent surface layer will be correspondingly thinner, leading to the possibility of placing the telescope on a small tower above 90% of the seeing disturbance.

2.3. UV/optical

Early optical astronomy at the South Pole was directed towards the measurement of solar oscillations (Grec, Fossat, & Pomerantz 1980). In these studies advantage was taken of the ability to make continuous observations of an astronomical source over many days. These observations were made only in the summer, and the atmospheric conditions then do not necessarily relate to winter time (or "night") conditions.

2.4. Near-IR

The first measurements of the sky brightness at 2.4 microns (Ashley et al. 1996; Ngyuen et al. 1996) showed that the South Pole could be up to 100 times darker than temperate sites at this wavelength. A more comprehensive study (Phillips et al. 1999) confirmed these results, extending the wavelength coverage to 5 microns and analyzing data from a full Antarctic winter.

2.5. Mid-IR

The low temperatures and improved atmospheric transparency at the South Pole lead to significant reduction in sky brightness across the 10 μm window (Smith & Harper 1998). A year-long study by Chamberlain et al. (2000) has shown that mid-infrared sky is consistently darker at the South Pole by about one order of magnitude relative to temperate sites.

2.6. Sub-millimeter

Most of the data on the sub-millimeter properties of the South Pole come from the AST/RO telescope (Antarctic Sub-millimeter Telescope/Remote Observatory), Stark et al. 1997. These results (for example, Chamberlin, Lane, & Stark 1997) show a remarkably transparent sky. Lane (1998) has summarized these results and used them to predict behavior at other sub-mm wavelengths.

2.7. Radio

The Antarctic plateau is expected to have a very low level of radio interference—a consequence not only of the exceptionally low population density but also the complete absence of local industry. All of the research stations operating in Antarctica closely control their own radio emissions, maintaining an almost pristine "radio quiet" environment. The low level of absolute humidity can also be expected to lead to particularly good phase stability, promising exceptional conditions for millimeter wave interferometry. However, few data on this are yet available apart from those obtained indirectly as a result of Cosmic Microwave Background experiments (Platt et al. 1997; Sironi 1998; Valenziano et al. 1998).

3. The Automated Astrophysical Site Testing Observatory (AASTO)

Beginning in 1987, the NSF funded a program with Lockheed to develop a self-powered, self-heated field station to enable geophysical data to be obtained from the remote Antarctic interior. This station, of which six were built, is called an Automated Geophysical Observatory (Doolittle 1986). However, the basic station is equally suited to astronomical site testing and hence we have dubbed the seventh "AGO", which we have had built for this specific purpose, the Automated Astrophysical Site Testing Observatory, or AASTO (Storey, Ashley, & Burton 1996; Storey, 1998).

The AASTO is an insulated, portable laboratory. Short-term accommodation is provided for up to four people. The AASTO is designed to fit exactly into the cargo hold of a ski-equipped LC-130 ("Hercules") transport plane. Deployment to a remote site will require an initial "put-in" flight, in which the AASTO will be placed on the snow, together with the science team of three or four persons and enough fuel for three weeks. Approximately one week later the Hercules will return with a year's supply of fuel and retrieve the science team. The AASTO can then remain on the ice for the next twelve months, gathering data in an autonomous mode very similar to that of a deep-space spacecraft.

3.1. Power Generation

A major challenge in operating any remote station in Antarctica is how to provide heat and electrical power for a full twelve months in sub-zero temperatures. There is little wind on the plateau, it is dark for six months of the year, and environmental and cost considerations rule out radioisotope generators. The solution chosen for the AGOs (and subsequently for the AASTO) is a propane-fueled catalytic oxidizer that produces 2.5 kW of heat, plus 50 watts of electrical power via a thermoelectric generator.

3.2. Power Management

The AASTO thermoelectric generator produces a nominal 50 watts at 28 volts; this power bus is available for housekeeping power and for the instrumentation. Each instrument uses an independent, galvanically isolated DC-DC converter to charge a 24 volt sealed lead-acid battery. Each battery charger is set so that it cannot draw more than 7 watts from the bus. As the instrument battery approaches a fully charged state, the battery charger reduces its drain on the bus to negligible values.

For most of the time the instruments, including their control computers, are powered down. The only activity is that of each instrument's "wakey-wakey board", which counts 1 Hz clock pulses generated by a common clock in the AASTO housekeeping system. The wakey-wakey boards draw just 40 microamps each from the bus. Every two hours the board switches on power to the control computer of the instrument to which it is attached. The computer then consults an internal clock and other information, and decides whether or not to initiate a full power-up sequence for the instrument, or simply to allow itself to be shut down again. If it decides to switch the instrument on and take data, it then does so for a pre-determined time before allowing itself to be switched off. To remain on the computer must toggle a line to the wakey-wakey board every few seconds, otherwise it will automatically be shut down after 60 seconds. In this way a "watchdog" function is implemented, automatically resetting the computer in the event of a software crash.

The computer monitors the battery voltage and can tell when the state of charge is starting to fall. It can then adjust the duty cycle of the instrument to ensure that the instrument is taking data for as much time as possible consistent with not exceeding its share of the available power.

3.3. Instrument Control and Data Management

Each instrument is controlled by its own, independent computer running under the real-time multitasking operating system RTKernel. Each computer is built around a set of cards conforming to the PC/104 standard and typically uses a 486 processor plus flash memory. The observing software is written within a scriptable language called ERIC (Ashley, Brooks, & Lloyd 1996). Although operating independently, each computer also communicates via the RS-232 protocol with a central "supervisor" computer.

3.4. Communications

While the AASTO is still at the South Pole we have regular Internet access available. Communication from the University of NSW is made first to the supervisor computer, then through it to the individual instruments.

4. AASTO Instruments

Each instrument in the AASTO is designed to measure a particular property of the sky. Together they constitute a suite of instruments capable of making a comprehensive study of any Antarctic site at wavelengths from 280 nm to 350 μm and to measure both the seeing and atmospheric turbulence. The instrument suite has been described by Storey, Ashley, & Burton (2000), and in individual instrument papers. In the following a brief summary of each instrument is given.

4.1. SODAR

The SODAR (SOnic raDAR) is an acoustic radar model PA1 manufactured by Remtech. Fifty-two piezoelectric transducers operate together as a phased-array antenna, generating electrically steerable acoustic beams that propagate into the atmosphere and are reflected back to the antenna by small density fluctuations in the air. These fluctuations, which originate from the turbulent mixing of layers of air at different temperature, are also responsible for the refractive index variations that give rise to seeing. The Remtech PA1 can measure these inhomogeneities up to a height of 900 m with 30 m resolution.

Figure 1 provides an illustrative image summarising SODAR data obtained over a week during mid-winter in 2000 at the South Pole. In particular, notice how the turbulence (measured by C_T^2) is confined to the lowest part of the boundary layer for extensive periods.

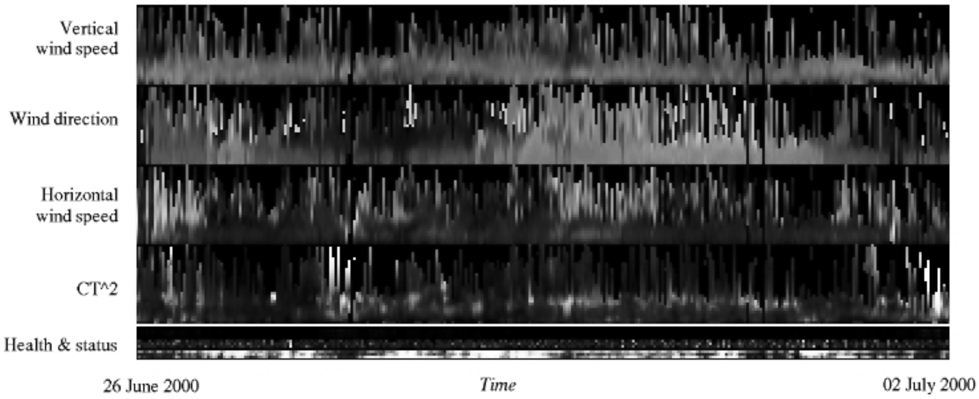

Figure 1. Illustrative data from the SODAR, obtained at the South Pole from 26 June to 2 July, 2000. Time is along the horizontal axis. The vertical axis shows, respectively, the vertical wind speed, the wind direction, the horizontal wind speed and the temperature structure coefficient, C_T^2, all as a function of height over the lowest 890 m of the atmosphere, plus some health and status information on the instrument. The degree of shading represents the strength of a particular parameter.

4.2. ADIMM

The ADIMM (Antarctic Differential Image-Motion Monitor) has been developed by the Australian National University to directly measure the seeing (Dopita, Wood, & Hovey 1996). It uses a 35 cm telescope masked into sub-apertures, and is intended for fully autonomous operation.

4.3. AFOS

The AFOS (Antarctic Fiber Optic Spectrometer) is designed to measure the atmospheric transmission and sky brightness at 2.4 nm resolution from 280 nm to 800 nm (Boccas et al. 1998). It consists of a 30 cm telescope feeding a bundle of six fibers that bring the light back to the AASTO, where a Jobin Yvon CP200 fixed-grating spectrometer and Andor Technology cooled CCD.

4.4. NISM

The NISM (Near Infrared Sky Monitor) measures the sky brightness at a fixed wavelength of 2.35 μm (Storey et al. 1999). It observes the sky through two 4° beams 45° apart on the sky, which it chops between at 77 Hz. The instrument uses an InSb detector cooled to 80 K by a low-power Stirling cooler.

4.5. MISM

The MISM (Mid-Infrared Sky Monitor) is similar to the NISM but measures the sky brightness from 4 to 14 μm (Storey et al. 1999). The detector is a HgCdTe photoconductor cooled to 77 K by a miniature Stirling cooler. Two Circular

Variable Filters (CVF) plus two fixed filters allow measurements across the "N" window and into the atmospheric absorption bands either side.

4.6. SUMMIT

SUMMIT (the SUb MilliMeter Tipper) is based on a set of similar instruments designed by Simon Radford and Jeff Peterson. These instruments use a room-temperature pyroelectric detector and metal-mesh filter to measure sky brightness and atmospheric temperature at a wavelength of 350 μm. One such instrument is deployed at South Pole, one at Mauna Kea (Hawaii), and two at Chajnantor (Chile). SUMMIT differs from its sister instruments in that it has been extensively modified to reduce its power consumption to just a few watts. This has been done by passively heating and cooling the hot and cold loads, installing a low-power chopper based on the NISM/MISM design, and using a PC/104 computer.

5. Future Plans

The AASTO has operated at the South Pole since January 1997. During this time it has accumulated a wealth of site-testing data, and is now ready for deployment to other sites on the Antarctic plateau. At the present time the tentative schedule is to move the AASTO to Dome C at the beginning of 2002. Once that site has been fully characterized, the AASTO can be deployed to higher sites—ultimately to Dome A, the highest point on the Antarctic plateau and quite possibly the best astronomical site on Earth.

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