Site Testing Antarctica for Astronomy

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Abstract.

The Antarctic Plateau provides the pre-eminent sites on the surface of the Earth for many types of astronomical observation. We have embarked on a site testing programme to quantify the ultimate sensitivity levels achievable. The programme is now in operation at the South Pole, where an infrared sky brightness monitor and micro-thermal temperature sensors have been deployed. We plan to extend these measurements, first at the Pole, and then to the highest parts of the Plateau, Domes Argus and Circe. The latter will involve adapting an 'Automated Geophysical Observatory', a mobile laboratory designed for autonomous operation on the Plateau, for astrophysical purposes.

1. Introduction

The Antarctic Plateau offers the promise of the best site conditions on the surface of the Earth for a wide range of astronomical observations. This is a result of the unique combination of cold, dry and tenuous air that is only found there. The Plateau reaches an elevation of nearly 4,300m, has average wintertime temperatures of -60°C , dropping below -90°C at times, and has columns of precipitable water vapour which can fall below 100μm at times. Winds are generally light, with the katabatic wind, originating on the highest parts of the Plateau, not reaching its full fury till near the coast. Weather conditions are stable, with minimal diurnal temperature fluctuations. This environment provides superlative conditions for measurement of the photon fluxes incident on the Earth from space, particularly in the near-infrared and sub-millimetre regimes.

In the near–IR, at 2.4μm, the background thermal flux from sky and telescope is reduced by a factor of 200 between Mauna Kea (0°C) and the South Pole (-60°C) (Harper 1989). From 2.27-2.45μm there is no airglow emission and the zodiacal flux is near its minimum, at the transition from scattered sunlight to thermal emission. Thus a window exists through which unprecedently deep observations can be made, only limited by the natural background of the inner solar system.

The low water vapour content will open up the sub-millimetre windows, partly accessible from Mauna Kea, for virtually continuous viewing (Bally 1989). This cannot be achieved from any other ground based site. Existing atmospheric windows will be cleaner, the mid–IR windows extended towards $50\,\mu$m, and a window at $200\,\mu$m opened for viewing at times.

The stable atmospheric conditions, tenuous air and absence of jet streams combine to produce conditions of superb clarity, or super-seeing (Gillingham 1993). The micro-thermal fluctuations in air temperature, which degrade spatial resolution from the diffraction limit, are minimised in this environment. Mitigating against these positive attributes, however, is the presence of a strong inversion layer which can occur during the most stable days of winter, where the air temperature can rise by 10 degrees in a few metres. It necessitates placing a telescope on a raised platform, whose height has to be determined.

Such are the conditions of the Antarctic Plateau. Their unique properties offer the potential of our making the most sensitive observations, with the greatest clarity, over a wide wavelength range, that are possible from the Earth. Ultimately, a telescope borne upon an aerostat above the tropopause might provide space-telescope image quality, with water columns similar to the KAO and negligible near–IR thermal background, all for a cost more akin to a large ground-based project than a space-based one. The scientific potential is immense (*e.g.* Burton *et al.*, 1994). It is, however, necessary to quantify these statements before they can form the basis of a drive to construct a major observatory on the high Plateau. A site testing programme is first necessary. In the remainder of this article we discuss the activity which is now underway towards this goal.

2. Current Programmes

The NSF has funded the Center for Astrophysical Research in Antarctica (CARA) to establish the first astronomical observatory at the South Pole. Building upon a series of isolated experiments, construction of the observatory is now well underway. Two experiments have been operating over the past Antarctic winter, an infrared camera (SPIREX, Hereld 1994) and a microwave background anisotropy experiment (Ruhl *et al.*, 1993). The first new scientific results have been recorded, for instance with the spectacular images of the comet Shoemaker-Levy 9 encounter with Jupiter, as recorded by SPIREX. Next year a sub-millimetre telescope will be installed (AST/RO, Stark 1989).

The University of New South Wales is conducting a site testing programme at the South Pole in collaboration with CARA. We are operating two experiments during this current winter, a near–IR sky brightness monitor and a set of micro-thermal turbulence sensors. The latter experiment also involves the Université de Nice. Both experiments have returned data, and we will report full results at a later date.

The IR sky brightness monitor uses the original IR photometer of the Anglo Australian Observatory, the 'Infrared Photometer Spectrometer' (IRPS), which has been modified for operation through the Antarctic winter. It operates in D.C. mode, measuring the incident sky flux on the detector through a 4° beam in the broad band J, H, K, L' and M filters, and through two 1% resolution CVF's (1.5-$2.5\,\mu$m and 3-$4\,\mu$m). The instrument is not attached to a telescope, but receives the sky radiation via a small mirror whose angle can be adjusted along a meridian from zenith to either horizon. While the experiment has been operated this year from the Pole, it is capable of being remotely controlled over the internet through use of electronic mail. The IRPS is being used to measure not only the sky background level, but also sky fluctuation noise, from instabilities in the the background signal. Early results show the expected low thermal background levels at wavelengths longer than 2.3 μm, with the airglow dominating at shorter wavelengths. They also show cleaner atmospheric windows, with non-zero transmission between H and K.

The second experiment uses small resistive sensors to measure micro-thermal fluctuations in the air temperature at three heights, 7-m, 17-m and 27-m, up a mast above the ice level. Their resistance is responsive to small changes in temperature in less than 1 second, whose magnitude depends on the level of air turbulence. Readings from two pairs of sensors are taken at each level and compared to check for consistency. The results clearly show the increase in turbulence in the lowest layer during times when a strong inversion layer is present, and periods when all layers show similar, sustained levels of low turbulence when it is not.

3. Future Plans

These experiments will continue during the the 1995 Antarctic winter. The IRPS will undergo some small modifications to improve its performance, and obtain a second seasons data. The micro-thermal temperature measurements will be extended to balloon-borne sensors, enabling the contribution over the entire atmospheric column to be determined. A mid–IR monitor will be installed to measure sky emissivity and thus infer levels of winter time cloud cover.

In the long term, however, we do not believe the South Pole will provide the optimal site for astronomy. It is directly under the auroral circle, and thus suffers regularly from a bright optical background (albeit only in specific frequencies). It also experiences a steady katabatic wind of 5-10 m/s. Though low compared to many observatory sites it contributes to seeing degradation. The best observing sites are expected to lie at the high points of the Plateau, Domes Argus (82S, 80E) and Circe (73S, 127E). Dome Circe is close to the center of the auroral circle and the site of a planned French / Italian base. Dome Argus is the highest point on the Plateau. Communications would also be simplified as equatorial satellites can always be sighted.

It is essential to site test these uninhabited locations before a major observatory project can be initiated. It is desirable to do so without need for the prior construction of a new inland station. Fortunately the NSF sponsored 'Automated Geophysical Observatories' (AGOs), constructed by Lockheed, provide a means by which this programme can be achieved. The AGO is a mobile laboratory which can be deployed on the ice by an LC-130 aircraft, and left to run unattended in an autonomous manner for a year (Doolittle 1986). The interior provides a warm enclosure to control and power a series of attached experiments, and a data acquisition system to store the data. The AGO is deployed during the summer months and retrieved, with data, the following summer. It essentially provides a low cost means with which essential site data can be obtained rapidly and with minimal environmental impact. Australia is now committed to the purchase and equipping of an AGO, and with the USA have formed the 'Automated Astronomical Site Testing Observatory Working Group' (AASTOWG) to achieve this end.

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