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Earth & Space

Seeing: The Clearest Stars are above the Antarctic Sky

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The characteristics of an astronomical site limits the performance of telescopes. “Seeing”, the blurring of stellar images by atmospheric turbulence, is a key factor. Our measurements confirm that Dome A, the highest point on the Antarctic plateau, has the best seeing conditions on the earth. A telescope at Dome A could observe the universe both clearer and deeper than other ground telescopes.

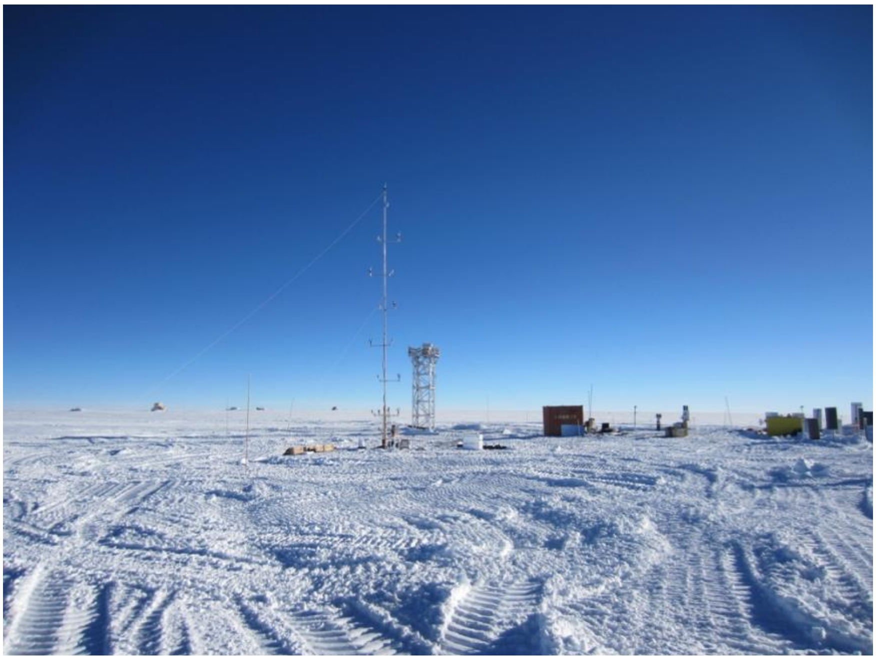

Image Credits: Zhaohui Shang

Twinkle, twinkle, little star.

Why do the stars twinkle? It is because of the turbulence in the atmosphere. You may hear turbulence from the airplane broadcast when the airplane is shaking. The turbulence shakes not only airplanes, but also the light from the stars, by altering the way the light bends around it. The stars are seen to jitter randomly hundreds of times per second. Images of the stars are therefore blurred, the same way views are distorted when seen through the air above a flame.

The level of such blurring is called seeing in astronomy. Seeing is measured as the angular distance smaller than which two stars cannot be distinguished from one another. Its unit is arcsecond (1 degree = 60 arcminutes = 3600 arcseconds). The seeing value depends on the location, and can span several arcseconds. This level of seeing is not perceptible to our eyes, with an angular resolution of about 1 arcminute, but is a disaster for a telescope.

Astronomers have therefore been seeking out sites with smaller seeing to host large telescopes. The ideal location is the space, where the Hubble space telescope is, but it costs 100s of times more than a ground-based telescope. Decades of efforts confirm several sites around the world with sub-arcsecond seeing, such as the mountains in Mauna Kea and Chile. Most large telescopes are built in these locations.

The Antarctic plateau has been thought to host promising sites on local summits of the ice sheet. While seeing is locally bad near the ground, it improves dramatically as the height increases. This is because that the majority of turbulence is concentrated near the ground in what is called the boundary layer. The boundary layer is hundreds of meters thick at mid-latitude sites, but less than one hundred meters at the South Pole, and only thirty meters at Dome C, a summit of the Antactic plateau. This means astronomers are able to put telescopes above the boundary layer to achieve excellent seeing, with values about two times better than that in Mauna Kea or Chile.

The highest point in Antarctic plateau, Dome A, is 4093 meters above the see level. It should be even better, but measuring seeing is challenging due to the harsh environment. The air temperature drops to -80°C in the winter, and it is only attended for 20 days in the year, during the relatively warm Summer. The telescope would therefore have to function with only yearly maintenance, at temperatures between -40 and -80°C.

We thus developed a small telescope to measure seeing at Dome A. To avoid the near-ground turbulence, we built an 8-meter tower. Although a higher tower would be better, this was logistically difficult. The team finished the construction and installation within two days, with temperatures at -30°C. A seeing telescope could then be installed, and, after installation and calibration, the seeing telescope worked fully automatically, 24 hours a day and 7 days a week, until August 2019, when the support platform ran out of power.

We used the telescope to take images of stars using very short exposure times – as short as one millisecond – and measured how much each star moved. We used these to calculate the seeing values.

From this data, we found that the seeing conditions 8 meters above Dome A is as good as those 20 meters above Dome C. 8 meters above Dome A, the boundary layer was only perceptible about two-thirds of the time, while 14 meters above the Dome A that value would decrease further to half the time. This is only half the height needed at Dome C. The thinner boundary layer would make it much less challenging and less expensive to construct a telescope above it, especially in Antarctica.

The thin boundary layer at Dome A is caused by a process called "temperature inversion", when the ground is cooler than the air above it. Unlike most places, the Antarctica's icy ground cools the air, producing the temperature inversion. This almost always occurs, and the air temperature at 8 meters high could be as much as 20°C higher than the ground. The warmer and lighter air lies above the colder and heavier air, preventing the generation of turbulence. The stronger temperature inversion corresponds to a thinner boundary layer, which helps make the boundary layer at Dome A so thin.

The superb seeing, in combination with dark and clean sky, make Dome A arguably the best site on Earth for astronomy. The study of the relationship between turbulence and weather can also improve the climate and weather forecast modelling.

[The authors would like to note the photograph used is a live record of the real work site. The photographer, Zhaohui Shang, would like to note that the site, although messy in the photograph, was later cleaned up well.]