ВАК 2024 MODERN ASTRONOMY: FROM THE EARLY UNIVERSE TO EXOPLANETS AND BLACK HOLES
300 years Russian Academy of Sciences

Study of the astroclimate at the Baikal Astrophysical Observatory

L. Bolbasova and V. Lukin

V. E. Zuev Institute of Atmospheric Optics of the Siberian Branch of the Russian Academy of Sciences, 1, Academician Zuev square, Tomsk, 634055 Russia

Abstract. The atmospheric conditions are crucial for an astronomical observatory. Earth's atmosphere limits image quality in ground-based optical telescopes. The knowledge of the atmospheric turbulence vertical distribution above an astronomical site is significant for the design and operation of adaptive optics systems as well as for scheduling the observing time. The Baikal Astrophysical Observatory (latitude 51°50′ north, longitude 104°55′ east) is the site of the 1-meter Large Solar Vacuum Telescope (LSVT). In this study we estimate the vertical distribution of optical turbulence C_n^2, which determines all the integrated parameters for adaptive optics. A 5-year dataset (2019–2023) of temperature and wind speed at pressure levels from the National Centers for Environmental Prediction (NCEP) / National Centers for Atmospheric Research (NCAR) Reanalysis are used for the research.

Keywords: atmospheric effects; site testing; instrumentation: adaptive optics

DOI: 10.26119/VAK2024.159

1 Introduction

The Baikal Astrophysical Observatory (BAO) is part of the Institute of Solar-Terrestrial Physics of the Siberian branch of the Russian Academy of Sciences. The main tool of BAO is the 1-meter Large Solar Vacuum Telescope (LSVT). It provides observations in the visible-light and infrared spectrum. In-depth understanding of Sun's physics requires optical observations of the Sun with higher and higher angular resolution. The optical image quality is limited by atmospheric turbulence. Adaptive optics (AO) is designed to achieve near-diffraction image quality. The knowledge of the wind speed and turbulence profiles above the observing site is significant for the design of an adaptive optics system and its operation as well as for scheduling the observing time. Currently, a program on multi-conjugated adaptive optics (MCAO) is underway for the LSVT. The MCAO are the next generation systems where each deformable mirror (DM) is conjugated to a plane at a height of a strong turbulent layer in the atmosphere. The MCAO design of the LSVT should be adapted to the turbulent layers above BAO. Therefore, the knowledge of turbulent layer positions to correctly select the conjugated plane is necessary. The aim of this work is to contribute to our knowledge of the profiles of the astroclimate parameters above BAO. We have estimated the profiles of the refractive index structure constant C_n^2 above the BAO site.

2 Methods and data

A 5-year dataset (2019–2023) of temperature and wind speed at pressure levels from the NCEP/NCAR Reanalysis is used for the study. The Reanalysis datasets are created by numerical simulation along with assimilation of remote sensing data and data in situ (e.g., radiosondes, satellites, weather stations) at grid points. The large differences in elevation in mountainous regions cause errors when averaging the Reanalysis data. BAO is not a high-altitude astronomical observatory. Consequently, the accuracy of the Reanalysis data on temperature and wind is expected to be very high.

The potential temperature θ is defined as

$$\theta(h) = T(h) \left(\frac{p(h)}{1000} \right)^{-0.288} \tag{1}$$

for temperature T in kelvins and pressure p in millibars. The gradient of wind speed is calculated as follows:

$$\frac{\partial V}{\partial h} = \sqrt{\left(\frac{\partial u}{\partial h} \right)^2 + \left(\frac{\partial v}{\partial h} \right)^2}, \tag{2}$$

where v and u are the components of wind speed. We use the following equation (Tatarskii 1961) to estimate the vertical profile of the refractive index structure constant from the Reanalysis data:

$$C_n^2 = aL^{4/3}M^2, \tag{3}$$

where L is the outer scale of the atmospheric turbulent flow, $a = 2.8$ is a constant, and M is the refractive index gradient provided by the equation

$$M = \frac{\partial N}{\partial h} = \frac{-79 \cdot 10^6\, P(h)}{\theta(h)\, T(h)} \frac{\partial \theta}{\partial h}, \tag{4}$$

where $\theta(h)$ is the profile of potential temperature, $T(h)$ is the profile of temperature in kelvins, and P is the pressure in hPa. The choice of a model for the L profile is very important. We estimate it as the largest energy scale of the atmospheric turbulent flow by the Masciadri & Jabouille (2001) model:

$$L = \sqrt{2\, E(h) \Big/ \left(\frac{g}{\theta(h)} \frac{\partial \theta}{\partial h} \right)}, \tag{5}$$

where $g = 9.8$ m/s^2 is the acceleration of gravity, and E is the turbulent kinetic energy. We determine E as the square of wind shear (Eq. 2) (Osborn & Sarazin 2018).

3 Vertical profiles of optical turbulence

Figure 1 shows, for each month, the median vertical optical turbulence profiles calculated by Eq. (3) from the NCEP/NCAR Reanalysis data for the BAO site over a period from 2019 to 2023.

According to the Reanalysis data for the period of 5 years, the BAO site has the lowest optical turbulence from May to September. Strong optical turbulence with significant turbulence at lower heights (less than 5 km) is detected from November to January. The optical turbulence is significant in the lower layers up to a hight of 3 km from February to April and in October. A turbulent layer is located between 10 and 15 km, its turbulence varies depending on the season. An additionally layer appears below 5 km in May, July–August, and April.

4 Summary

By the NCEP/NCAR Reanalysis data about wind speed and temperature at pressure levels, we have calculated the vertical profiles of C_n^2 above the BAO site. Strong

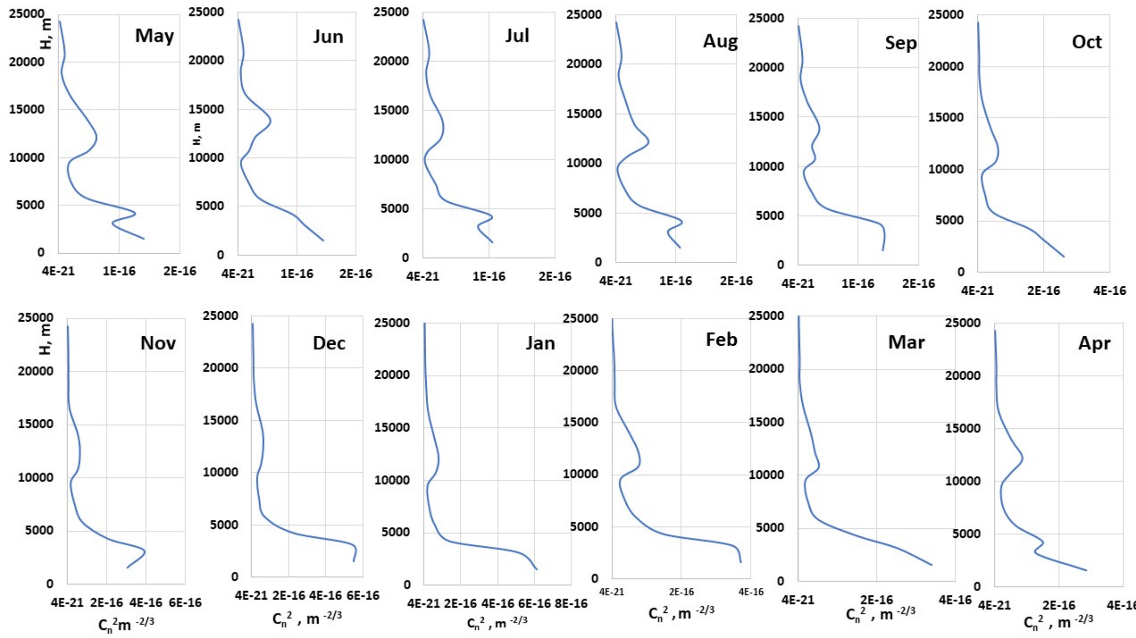

Fig. 1. Monthly median profiles of optical turbulence at the BAO site by the NCEP/NCAR Reanalysis data for the period of 2019–2023.

optical turbulence with significant turbulence at the lower heights (less than 5 km) is detected from November to January. The lowest optical turbulence is observed from May to September. Depending on the season, a layer lower 5 km and a more weaker layer between 10 and 15 km appear. The results indicate the feasibility of a ground-layer adaptive optics (GLAO) system whose DMs are conjugated with the heights less than 10 km as the most suitable for the BAO 1-m LSVT.

Funding

This study was funded by the Russian Science Foundation, grant No. 23-42-00043.

References

Masciadri E. and Jabouille P., 2001, Astronomy & Astrophysics, 376, p. 727
Osborn J. and Sarazin M., 2018, Monthly Notices of the Royal Astronomical Society, 480, p. 1278
Tatarskii V.I., 1961, Wave Propagation in a Turbulent Medium, McGraw-Hill Book Company