Astronomical seeing forecast for the Thai National Observatory

Ronald Macatangay* **and Somsawat Rattanasoon**

National Astronomical Research Institute of Thailand, Mae Rim, Chiang Mai, 50180, Thailand

*Corresponding author's Email: ronald@narit.or.th

Abstract. Forecasting the astronomical seeing above an observatory can assist astronomers plan their observations. In this study, the astronomical seeing above the Thai National Observatory (TNO) in Doi Inthanon, Chiang Mai, Thailand was simulated using the Weather Research and Forecasting (WRF) model. The model outputs were then compared to Polaris seeing observations and using the Differential Image Motion Monitor (DIMM). Results showed that the forecasts capture the variation of the astronomical seeing fairly well. However, bias correction is needed on the simulations due to lack of data from meteorological balloons to constrain the model.

1. Introduction

Ground-based astronomical observations are limited by two factors – diffraction and turbulence. Diffraction-limited point images have a point-spread function than can have a full-width at half maximum of 1.22λ/D at its best (when there is no effect from the atmosphere of the earth), where λ is the wavelength and D is the aperture size of the observing system, Considering the effects of the atmosphere of the earth, particularly turbulence in the air, the full-width at half maximum of an object's point spread function, or its astronomical seeing, can increase depending on the intensity of atmospheric turbulence. Turbulence can cause variations in the index of refraction of air causing plane wavefronts from distant light sources to become distorted. These distortions produce amplitude variations and positional shifts causing image degradation [1].

Aside from deducing astronomical seeing optically, it can also be calculated using meteorological parameters, particularly temperature, wind and atmospheric pressure vertical profiles. These variables can be forecasted, hence astronomical seeing can also be predicted [2].

In this study, the astronomical seeing is simulated over the Thai National Observatory (TNO) in Chiang Mai, Thailand using the Weather Research and Forecasting (WRF) model version 3.8.1 from February 10 – April 25, 2021 based on [3]. The model outputs are then compared to observations using the Polaris seeing monitor and the Differential Image Motion Monitor (DIMM) installed at TNO.

2. Methodology

According to [3], there are four variables that need to be determined prior to calculating the astronomical seeing from weather models. These are: (1) the mean potential temperature gradient; (2) the wind shear vertical profile; (3) the temperature structure vertical profile; and (4) the refractive index vertical profile.

2.1. Mean potential temperature gradient

The potential temperature, θ, is a theoretical temperature used in weather forecasting for comparing different air masses at different altitudes and different locations in the atmosphere without having the height dependence of air temperature. It is used for determining if there are warm or cold air masses being transported or advected over an observation site. The potential temperature is determined by bringing down an air mass to a standard pressure (1000 hPa) without losing energy to its surroundings. It generally has a value of around 300 K near the surface and increases with altitude to around 500 K at 20 km above the ground. The mean potential temperature gradient is then calculated by determining the change of the mean potential temperature with respect to height, z.

2.2. Wind shear vertical profile

Using the east-west and north-south horizontal wind components, $u(z)$ and $v(z)$, respectively, the square of wind shear vertical profile is calculated as the sum of squares of the change of $u(z)$ and $v(z)$ with respect to z. Physically, the wind shear vertical profile depicts changes in both the wind speed and wind direction from the ground to higher altitude levels.

2.3. Temperature structure vertical profile

Multiplying the mean potential temperature gradient with the square-root of the wind shear vertical profile and a parameter deduced from weather balloons, the temperature structure vertical profile can be calculated. In this study, we don't have the parameter deduced from weather balloons, therefore, a bias correction is necessary in the end.

2.4. Refractive index vertical profile

Using the temperature structure vertical profile, the atmospheric temperature vertical profile and the pressure profile, the refractive index vertical profile can be determined. The refractive index vertical profile shows how much the refractive index of air is perturbed by turbulence. It is usually high near the surface, at around 10 km altitude and at around 18 km from the ground [4]. High altitude turbulence is important since the astronomical seeing is an integrated profile from the ground to the top of the atmosphere.

2.5. Astronomical seeing

The astronomical seeing is calculated by integrating the refractive index vertical profile ideally from the ground to the top of the atmosphere divided by the fifth root of the wavelength (the visible wavelength of 532 nm was used in this study) [4].

3. Discussion

The results of the simulations are shown in figure 1. It can be seen that the astronomical seeing derived from the Polaris seeing monitor is generally higher than both the DIMM and the model simulations. The reason is that the Polaris seeing monitor points near the horizon (around 19 degrees from the horizon) all night where most of the turbulence occurs. In this case, the mean value of the DIMM observations are used for correcting the bias (11.72 arc seconds) in the model since DIMM tracks stars near the zenith and the model calculates the seeing along the zenith. The reason for the large bias of 11.72 arc seconds needs to be investigated further.

4. Conclusion

The astronomical seeing for TNO has been simulated for forecasting purposes. An offset of 11.72 arc seconds has been subtracted from the model output to match the DIMM observations. The reason for this bias will be investigated in future studies.

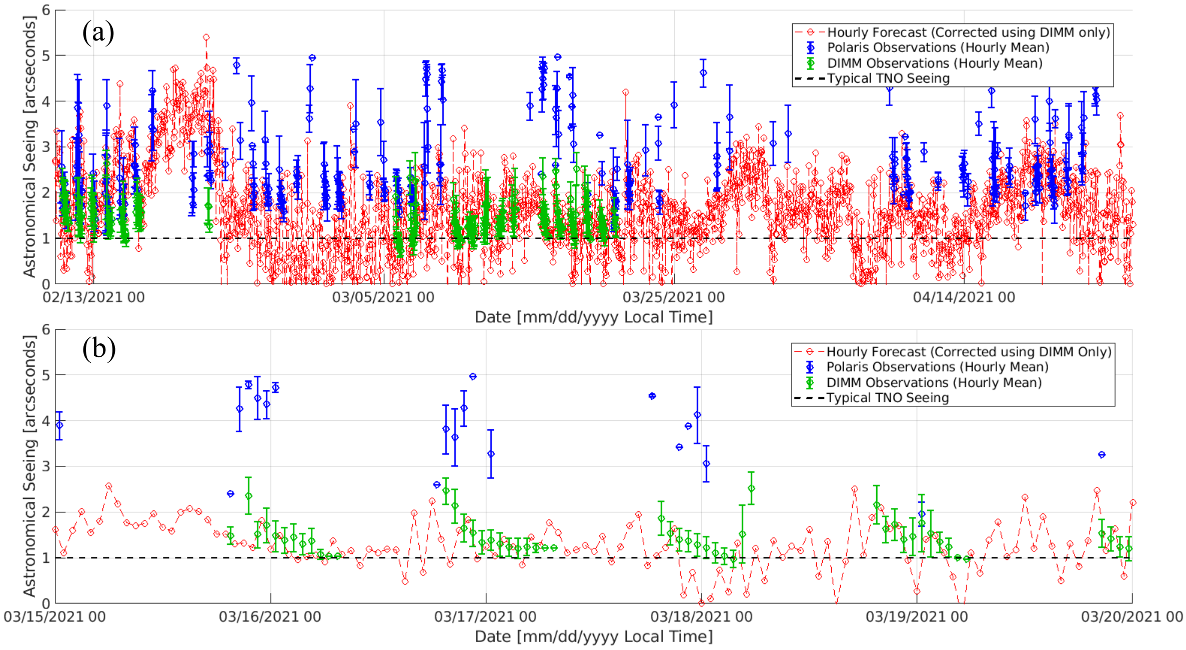

Figure 1. Astronomical seeing forecasts (red) as compared to the Polaris (blue) and DIMM (green) seeing observations for (a) the entire study period and (b) from March 15 – 20, 2021. Also shown is the typical TNO seeing of 1 arc second [5].

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