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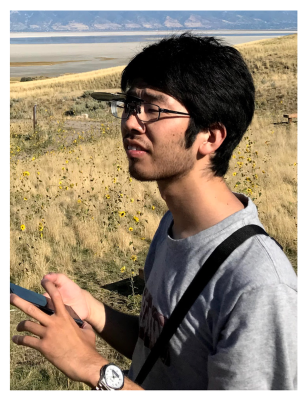

TELESCOPE ARRAY PROJECT

# The atmospheric transparency of Telescope Array observation site by the CLF


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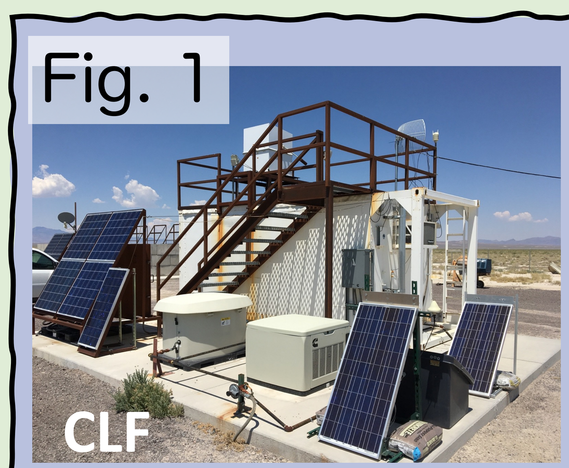
ABSTRACT: The Telescope Array (TA) experiment continues to observe Ultra High Energy Cosmic Rays (UHECRs) both with its original TA detectors as well as with the new TAx4 expansion detectors. These observations employ Fluorescence Detectors (FDs) to capture the air shower induced by the primary UHECRs. The FD observes fluorescence light emitted from atmospheric nitrogen molecules excited by air shower particles. The observation of the FD extends over tens of kilometers, and the fluorescence light is attenuated by scattering from atmospheric molecules and aerosols during the propagation process. Seasonal dependence was found when assessing the attenuation of fluorescence by aerosols. We also captured the weather characteristics. We report on the effect of aerosols on the atmospheric transparency of the TA sites.


## CLF : Central Laser Facility

Fig. 1




**Laser condition**
- Vertical
- 355nm
- 10Hz
- 300 shots
- every 30min

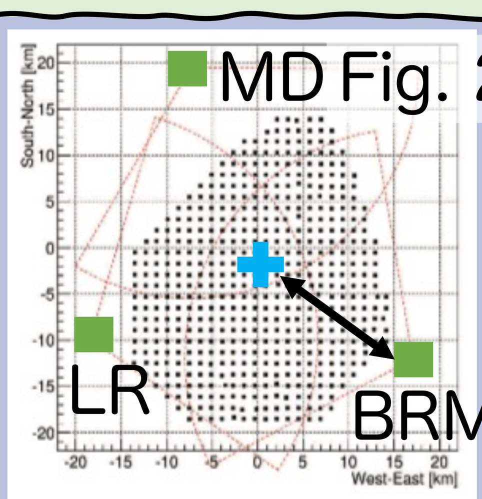



Fig. 2

FD received signal by CLF

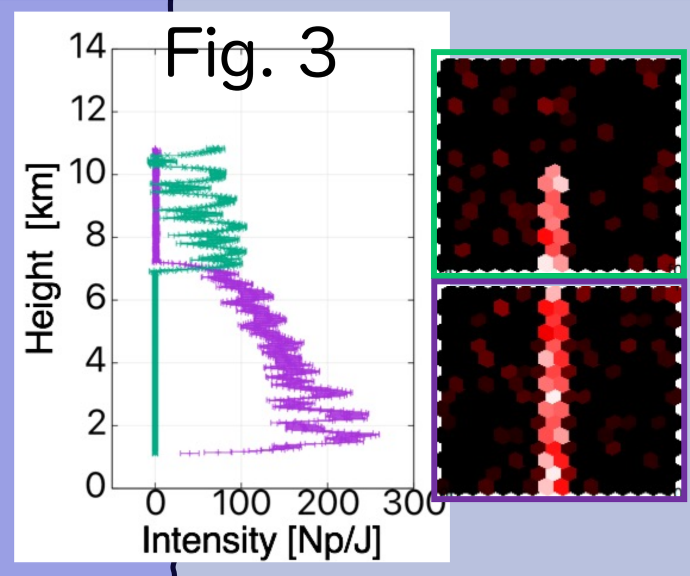



Fig. 3

Waveform Image

CLF is located at same distance (20.8 km) from 3 FD stations. CLF fires a series of vertical laser shots every 30 minutes during FD observations. Atmospheric transparency as Vertical Aerosol Optical Depth(VAOD) obtained by comparing each observation data with the clear night. Figure 3 shows the received photon's intensity by FD at each scattering height.

Fig. 4

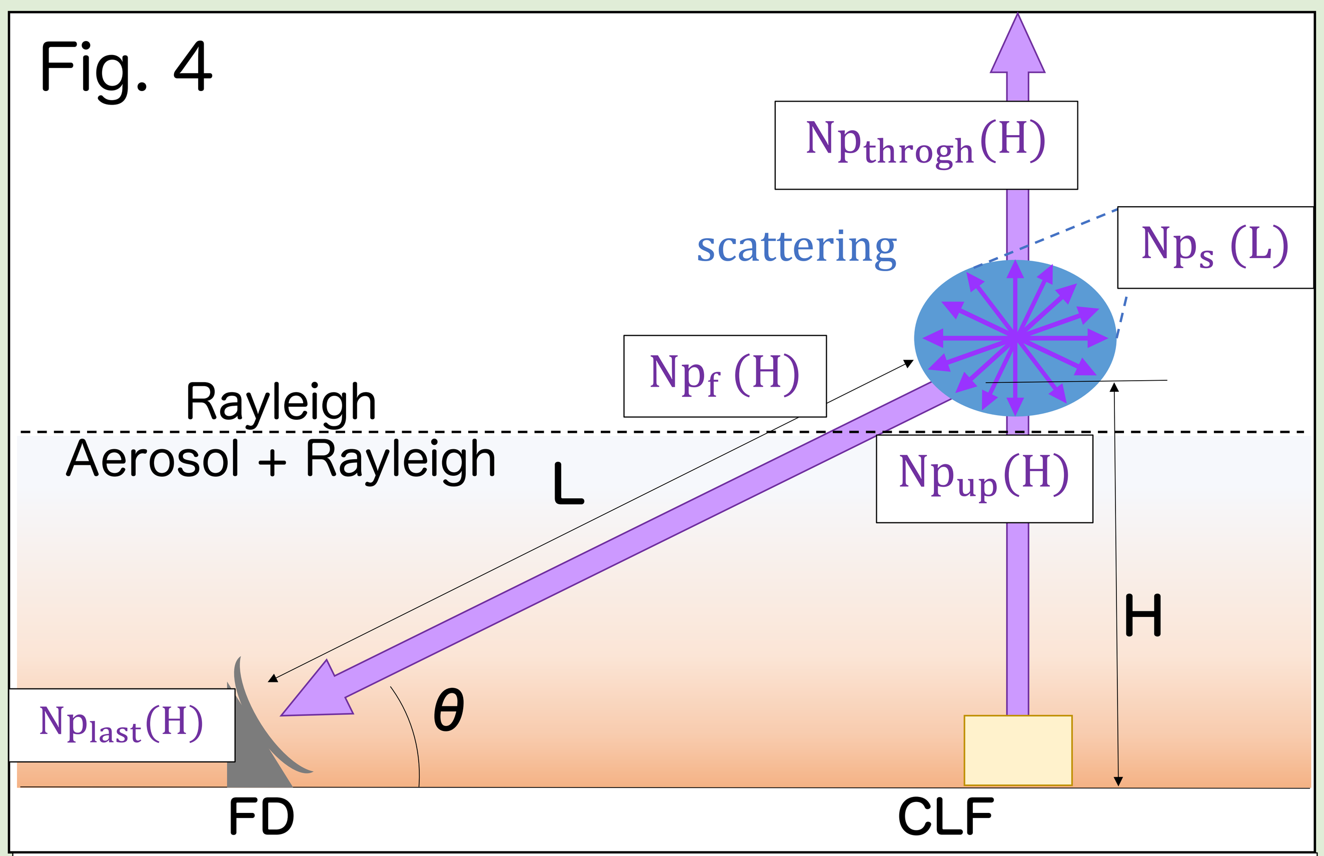



Image of Atmospheric observation

$$Np(H) = Np_0 T_{AS}(H) T_{Ray}(H) (S_{AS} + S_{Ray}) T_{AS}(L) T_{Ray}(L) \quad :(1)$$

$$Np_{ideal}(H) = Np'_0 T_{Ray-i}(H) S_{Ray-i} T_{Ray-i}(L) \quad :(2)$$

The figure 4 is a conceptual diagram of observation by CLF. The process until the laser emitted from the CLF reaches the FD is expressed by Eq.1. Equation 2 represents the ideal observation conditions in the absence of aerosols. The solution is obtained by adding the following conditions to the ratio of the two equations.

① The atmospheric state is constant in the horizontal direction.
② The aerosol suspend only up to altitude of 5 km.

**Observation's Parameters**
- Np: Number of Photon
- S : Scattering cross-section
- T : Atmospheric Transparency
- H : Height of Scattering point
- L : Distance H – FD
- $\tau$ : VAOD

**Elements**

$\tau = \int_0^h \sigma \, dh$

$T = \exp[-\tau(h)]$

$S = \exp[-\alpha \, \Delta h]\sigma$

$L = \frac{H}{\sin\theta}$

We obtained the solution shown in Eq.3. This is different from the method used in the conventional TA-CLF, and the influence of the seasonal dependence of Rayleigh scattering by atmospheric molecules is also taken into consideration, and more only the scattering by aerosol is expressed.

$$\tau_{AS}(h) = -\frac{\sin\theta}{\sin\theta+1} \log\left[\frac{Np(H)\, Np'_0}{Np_i(H)\, Np_0}\right] + \left(\left(\tau_{R-i}(h) - \tau_R(h)\right) + \frac{\sin\theta}{\sin\theta+1}(\alpha_{R-i} - \alpha_R)\Delta h\right) \quad :(3)$$

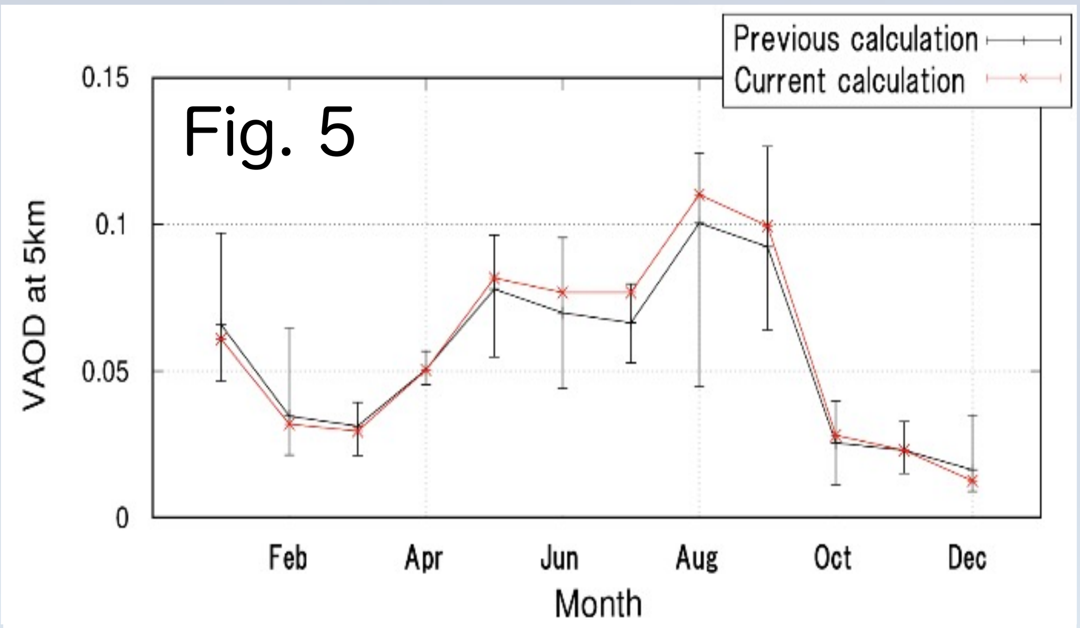



Fig. 5

Annual transition of VAOD

VAODs were calculated for each observation every 30 minutes for 3 years (2012, 2015, 2016) where stable operation of the equipment can be confirmed, and the monthly average was obtained. Figure 5 shows the annual fluctuation of the monthly average VAOD obtained by the conventional calculation method and the solution method in this work. The error bars at each point show a 1σ distribution, which is within the range of the VAOD distribution, but changes from the conventional VAOD can be confirmed. In addition, the transparency of the atmosphere is low in the summer and high in the winter. This seasonal dependence is consistent with the results previously reported in TA. However, the atmospheric transparency in January and February is lower than in other winter months.

We found that the observed waveforms in January and February contained many Unique ones. The upper right of Fig. 6 shows the normal CLF waveform (black) and the Unique waveform (purple). The waveform shows the presence of scatterers staying near the ground (at an altitude of 2 km or less). Figure 6 shows the frequency of occurrence of this Unique waveform. We suspect that fog is frequent in winter. In the future, we will investigate the relationship with humidity.

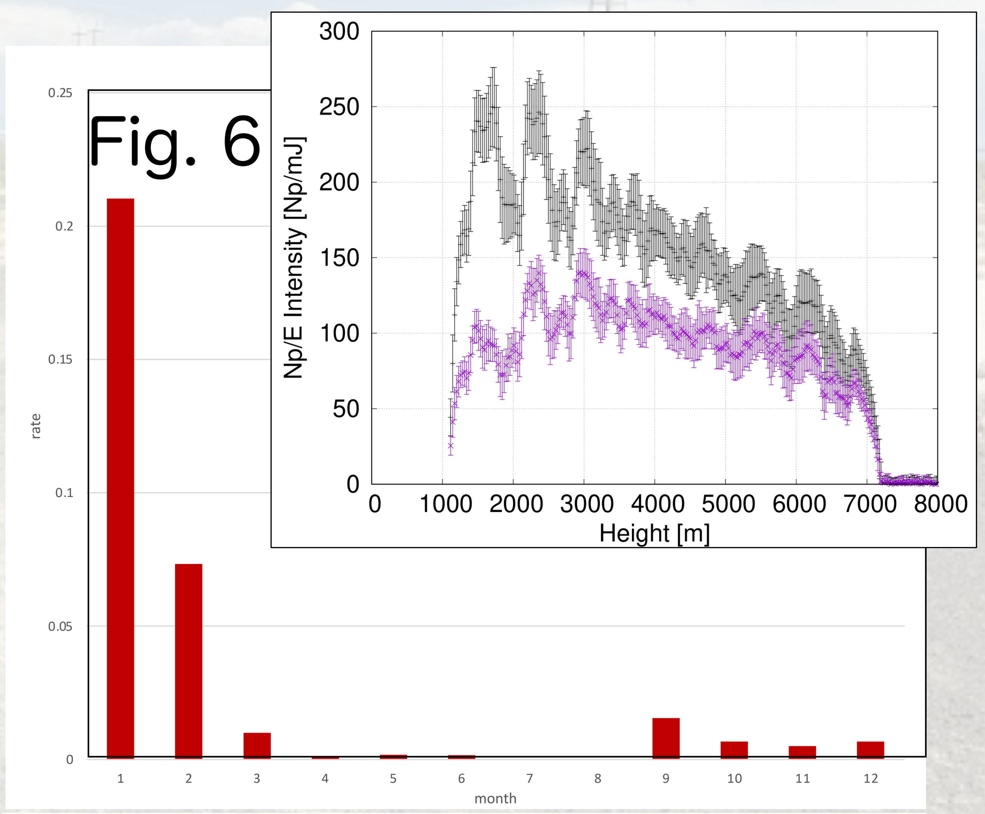



Fig. 6

Unique CLF waveform and frequency of occurrence

## Summary

Equation 3 was obtained as a new solution for CLF. This equation removes Rayleigh scattering due to atmospheric molecules and is suitable for evaluating aerosol scattering. Annual fluctuations in the Atmospheric Transparency Index (VAOD) were obtained by this work. And, we confirmed hints of peculiar weather in winter.