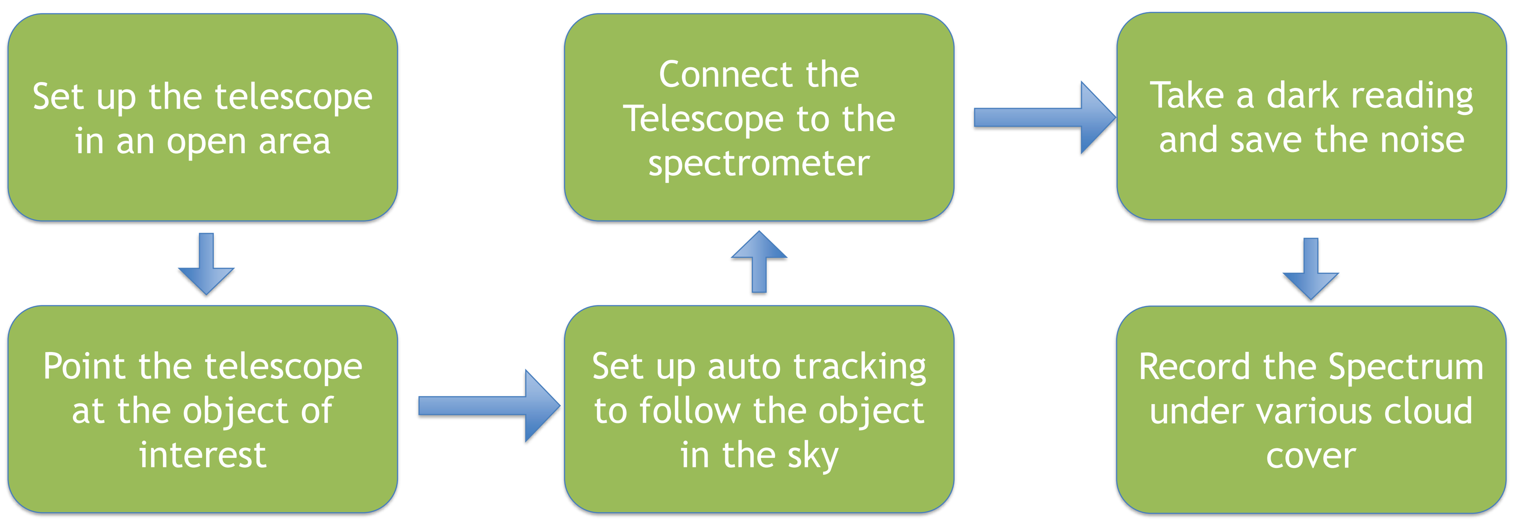
INVESTIGATING THE FEASIBILITY OF SPACE-TO-GROUND LASER COMMUNICATIONS IN SINGAPORE'S WEATHER

Introduction

- Space to ground communications are extremely important today
  - Enables information transfer across the globe
  - Enables services such as long-distance phone calls and GPS systems to function
- Radio waves have long been used for these communications with remarkable success
  - Drawback: Low frequency (GHz range) → Low bandwidth → Low data transfer rate
- To make data transfer faster, lasers can be used
  - Much higher frequencies (THz range)
  - Much more secure than radio waves (the indirect signal reaching an outside observer has a high signal-to-noise ratio, rendering it undecodable)
- However, lasers, with shorter wavelengths, are more prone to Rayleigh scattering ($\propto \frac{1}{\lambda^4}$)
- **Our aim: investigate this attenuation in the context of Singapore's weather**
  - **Find out how characteristics of Singapore's weather (e.g. cloud density) affect the attenuation of the laser**

Methodology



Different Cloud Cover Classifications

(a) Minimal-to-no clouds: The object is clearly visible in the sky, and the surrounding area is clear.
(b) Light clouds: The object is shrouded my mostly transparent clouds
(c) Medium clouds: The object appears fuzzy, and the surrounding area is cloudy.
(d) Heavy/dense clouds: The object is mostly/fully shrouded in clouds and is hardly visible.

Characterization

Detector

Our spectrometer uses Silicon detectors
- Varying sensitivities at different wavelengths of light
- Characterization needed

We shone a standard white light source with a known spectrum into the telescope

$$\frac{\textit{Observed spectrum}}{\textit{Known white light spectrum}} = \textit{Calibration curve of silicon}$$

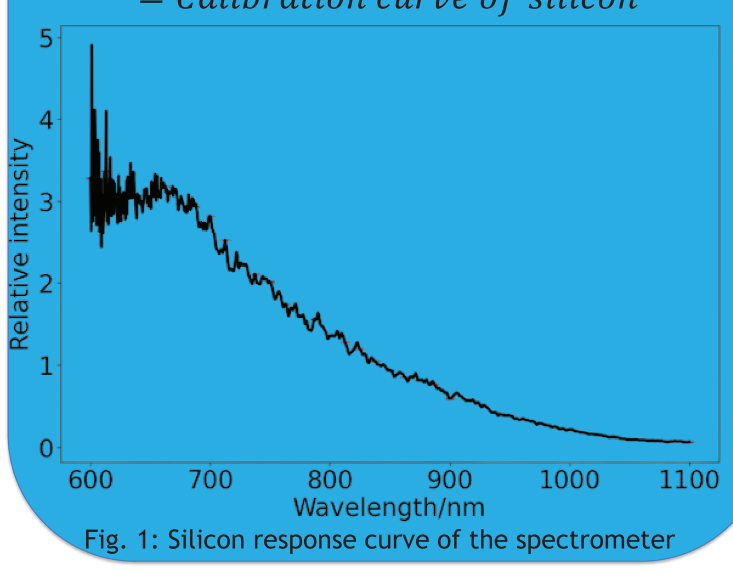


Fig. 1: Silicon response curve of the spectrometer

Atmosphere

Beer- Lambert Law:

$$I = I_0 * e^{-\mu x}$$

μ: attenuation coefficient
x: distance travelled by light ray

μ obtained from Elterman, L. (1963)
Regression function: $y = \frac{1}{ax} + b$
$a = 1.6187 * 10^{-10}$, $b = 0.112267$

x obtained from Airmass: numerical quantity such that
$\text{Airmass} * \text{Atmospheric height} = x$
The effective atmospheric height we used was 18km
Airmass was obtained from Stellarium

After obtaining μ and x, substitute into the Beer-Lambert Law

Satellite Observations

- We obtained data from the geostationary meteorology satellite Himawari-9 to determine the level of cloud cover during the period of observation
- Satellite observations complement qualitative cloud cover observations from the ground
- Himawari-9 detects radiation from earth in different wavelengths known as Brightness Temperatures (BT), the required temperature of a blackbody (i.e. obeying Planck's Law) that produces the observed intensity
- B. Purbantoro et al. (2018) reported that the temperature difference between BT15 and BT16 is strongly correlated with cloud cover (higher difference = clearer sky)
- We used the temperature difference in the patch of sky (2km×2km pixel size) of each observation to determine the cloud cover as seen by from space

Results

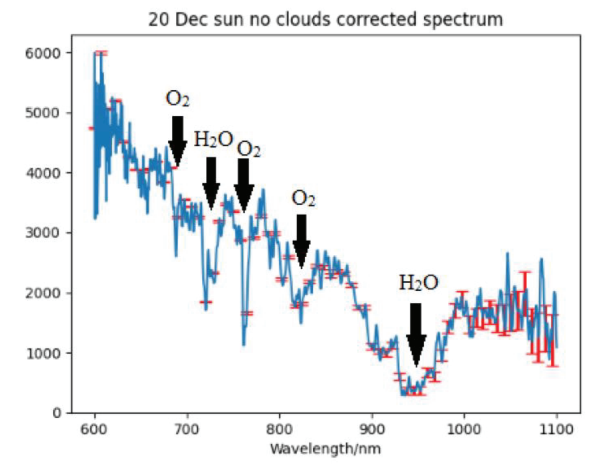
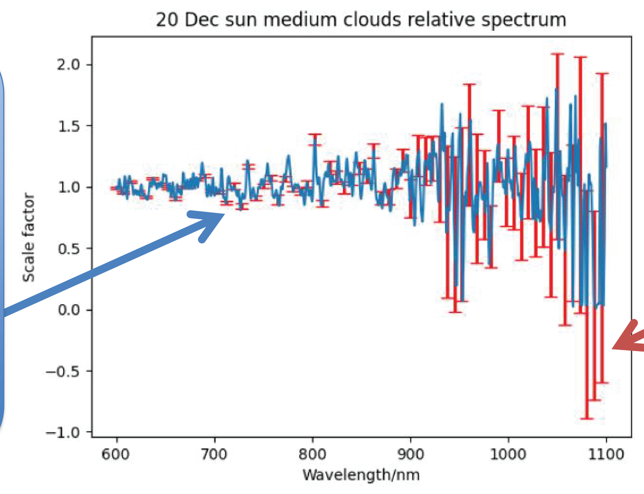


Fig 2: the spectrum of the sun with no clouds present after the Silicon curve and atmospheric attenuation correction

- Multiple noticeable dips in the readings → correspond to the absorption lines of various compounds

The ratio of cloudy readings/clear readings does not differ from unity significantly i.e. **no additional dips in spectrum reading during cloudy condition**



Large errors bars from 900-1100nm → caused by high signal-to-noise ratio + low sensitivity of silicon above 1000nm

Inference: Clouds don't appear to have additional absorption lines in the 600nm to 1000nm range

- Anomaly: Mie scattering cannot be observed from our data →likely due to our equipment not being sensitive enough and the high signal-to-noise ratio
- We also overlaid the "normal" graph with the normalized cloudy graph
- Again, **no visible deviations between cloudy sky and clear sky readings that cannot be explained by noise → clouds do not appear to have additional absorption lines in the 600nm to 1000nm range.**

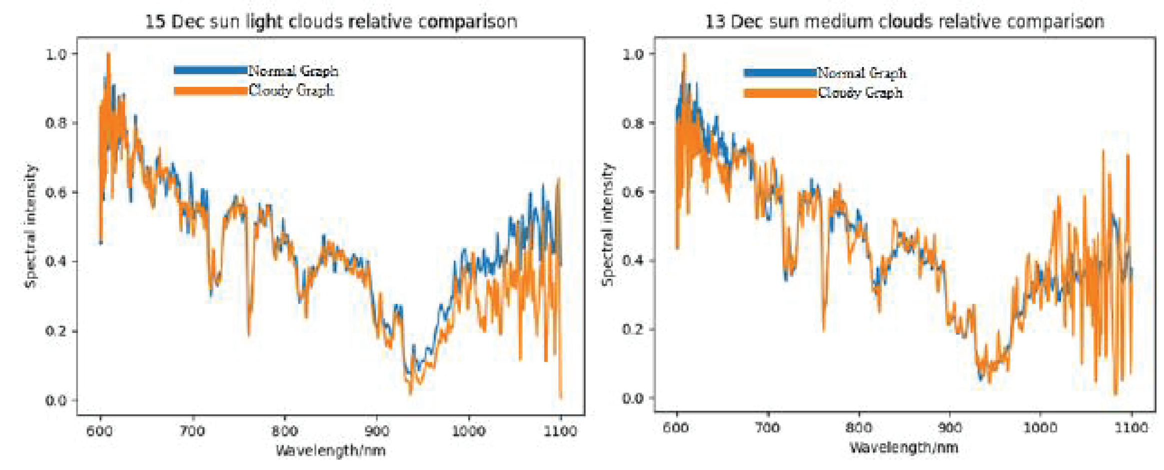


Fig 3: Relative comparison between cloudy sky and clear sky readings. the orange graph is the data under cloud conditions and the blue graph is the clear sky reading with the highest count number for that day.

- We also plotted a graph of the reciprocal of the scale factor (a measure of attenuation), against the temperature difference in the observed patch of sky → Very little, if any, correlation

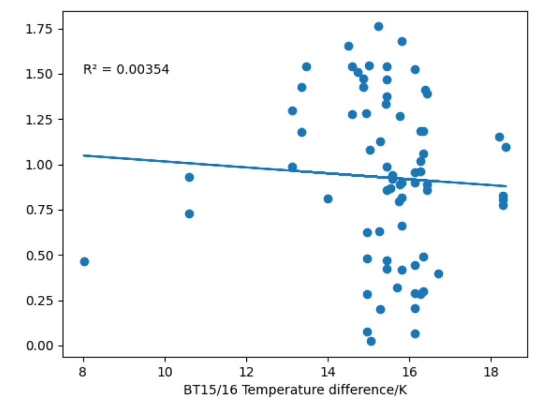


Fig 4: Graph of reciprocal of scale factor against temperature difference for each spectrum reading.

Conclusion

- Solar and Lunar spectra were observed through various cloud covers
- No clear absorption lines observed despite anomalies present
- No clear connection between satellite data and attenuation observed

- We have shown that clouds do not impose wavelength restriction for wavelengths between 600nm and 1000nm
- Wavelengths already absorbed by the atmosphere should still be avoided
- However, a correlation between attenuation and cloud cover was unable to be made
- More advanced technologies or spectrometers with a different material would be necessary to further investigate the feasibility of space-to-ground laser communications

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YDSP Young Defence Scientists Programme
DSTA Defence Science & Technology Agency
DSO National Laboratories