Comparison of zenith opacity between 18-50 GHz and 70-90 GHz as a function of IWV obtained from different data sources

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1 Introduction

Atmospheric opacity is a measure of how much electromagnetic radiation is attenuated as it passes vertically through the Earth's atmosphere. This opacity is caused by the absorption and scattering of energy, primarily by water vapor, molecular oxygen, and other atmospheric gases. Opacity significantly impacts radio astronomical observations, especially at frequencies above 18 GHz. The intense absorption of molecular oxygen around 60 GHz is particularly noteworthy. This effect greatly impacts measurements, limiting the quality and accuracy of observations in these frequency bands.

Integrated water vapor (IWV) is the total amount of water vapor in a vertical column above a given area. It is usually expressed in millimeters. IWV is a critical variable for assessing atmospheric transparency because an increase in IWV implies a significant increase in zenith opacity. This direct relationship makes IWV essential for predicting and correcting atmospheric attenuation in radio astronomical observations, particularly at high frequencies.

This report aims to compare the variability in zenith atmospheric opacity estimation using two different IWV data sources. This comparison will allow a better calibration of the radio telescope at the Yebes Observatory.

2 Data sources

2.1 IWV based on GNSS measurements

The National Geographic Institute (IGN) provides IWV values derived from GNSS (Global Navigation Satellite System) data for two stations installed at the Yebes Observatory.

This data is available in two HTTPS files, updated hourly with data from the previous hour at a 15-minute sampling interval. Due to this delay, the data is not suitable for calibrating the radio telescope; however, it will be useful for comparing zenith opacity.

2.2 Approximation of the IWV using a formula

As the second data source, the IWV is calculated using a specific formula [de Vicente and Pulido, 2012] that uses local atmospheric pressure and surface temperature measurements obtained directly from sensors installed at the observatory, as well as a scale factor:

$$\mathrm{IWV} = 1.3227 \times 10^{-2} \cdot \frac{e^{(17.27 \cdot T_s)/(T_s + 237.7)}}{T_s + 273} \cdot H \cdot h_r \tag{2.1}$$

where T_s is the surface temperature (ºC), h_r is the relative humidity, and H is the scale factor, which is currently set to 1340.

3 Calculation of opacity using ATM model

Subsequent to the calculation of the IWV, the zenith opacity is determined employing the ATM model. This model enables the estimation of atmospheric opacity based on the IWV and the observation frequency.

This report examines atmospheric opacity during the year 2025 at frequencies of 18, 30, 50, 75, and 85 GHz.

4 Results

The following figure illustrates the integrated water vapor (IWV) values recorded by one of the IGN stations at the Yebes Observatory. To smooth out the short-term fluctuations and highlight the underlying pattern in the data, we have applied a moving average—a statistical technique that computes the average of the IWV over a fixed-length window (for example, several hours or days) and then "slides" that window across the time series.

This method has been employed to mitigate the irregularities inherent in the time series, thereby facilitating the visualization of trends over time.

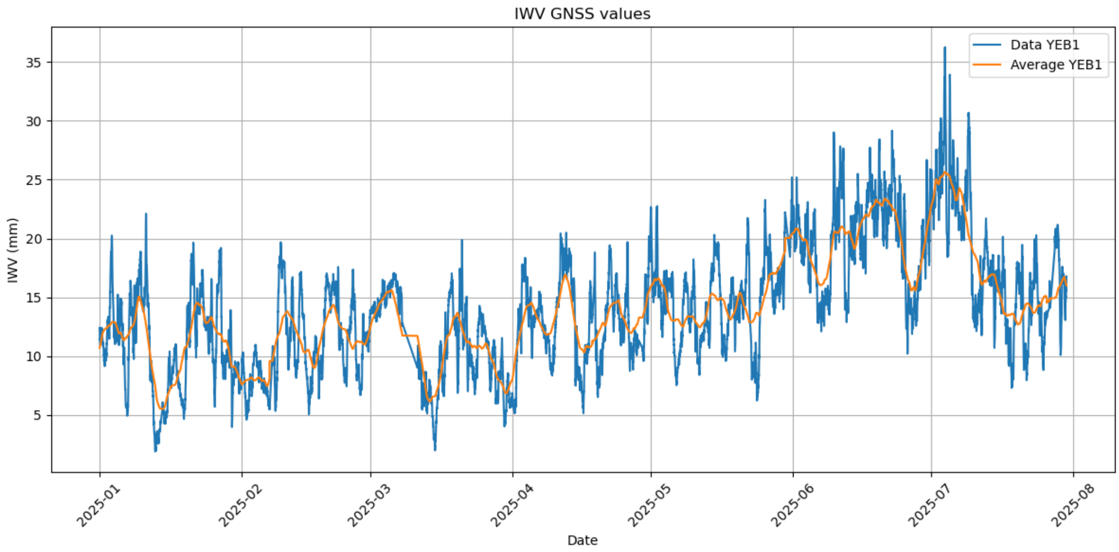


Figure 4.1: IWV provided by IGN GNSS stations.

The next comparison is presented between the IWV obtained from GNSS value and the value calculated using the formula based on temperature and relative humidity data from the observatory.

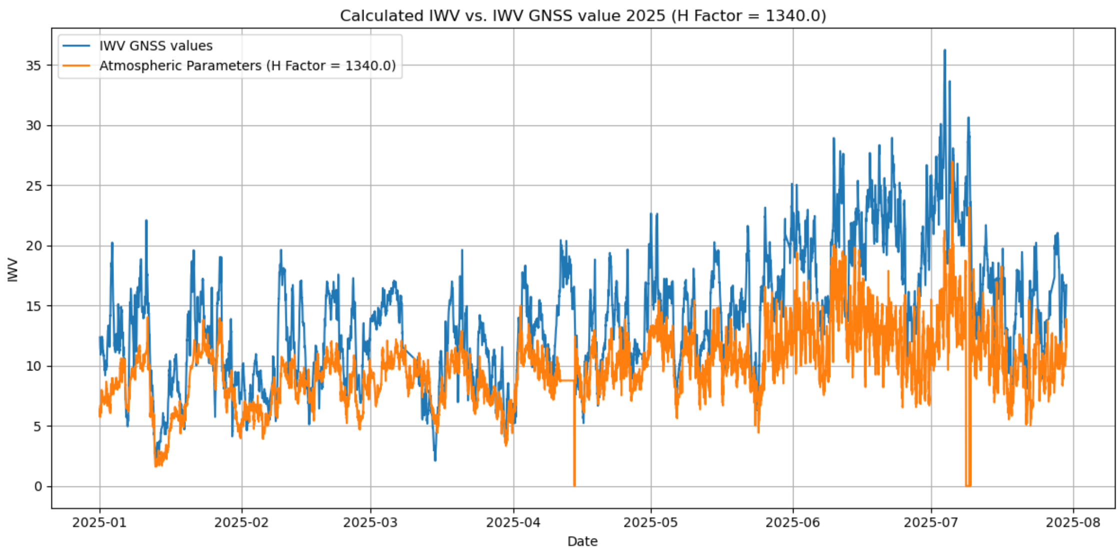


Figure 4.2: Comparison of the IWV calculated using the formula and that provided by the IGN.

The following graphs illustrate the zenith opacity, calculated from the IWV provided by the IGN and the one calculated from the formula with a scale factor of 1340 for frequencies of 18, 30, 50, 75, and 85 GHz, respectively. Each graph is accompanied by a secondary graph that illustrates the opacity ratio between the two data sets.

- **Opacity at 18 GHz:**

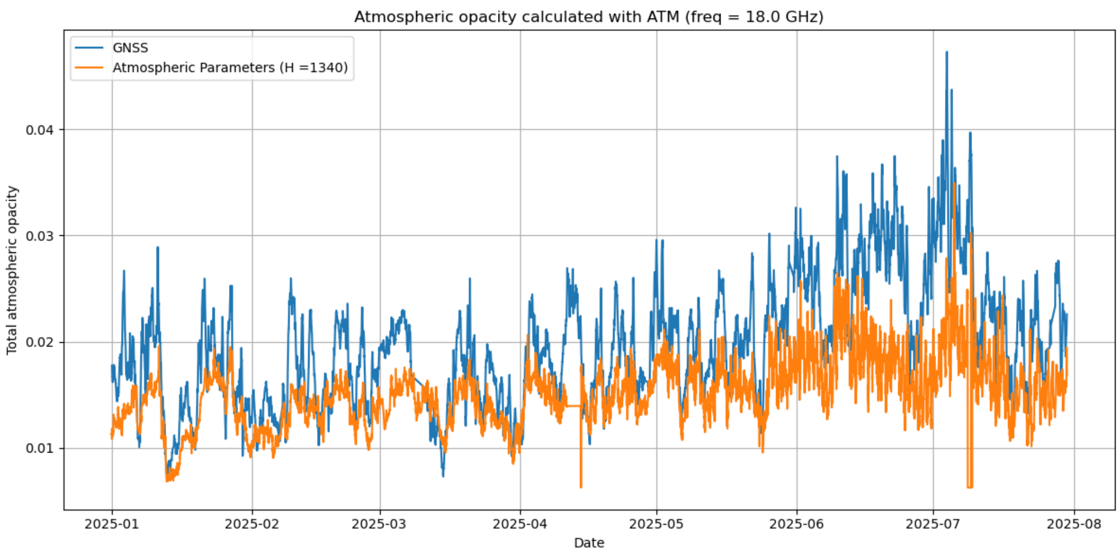


Figure 4.3: Zenith opacity at 18 GHz

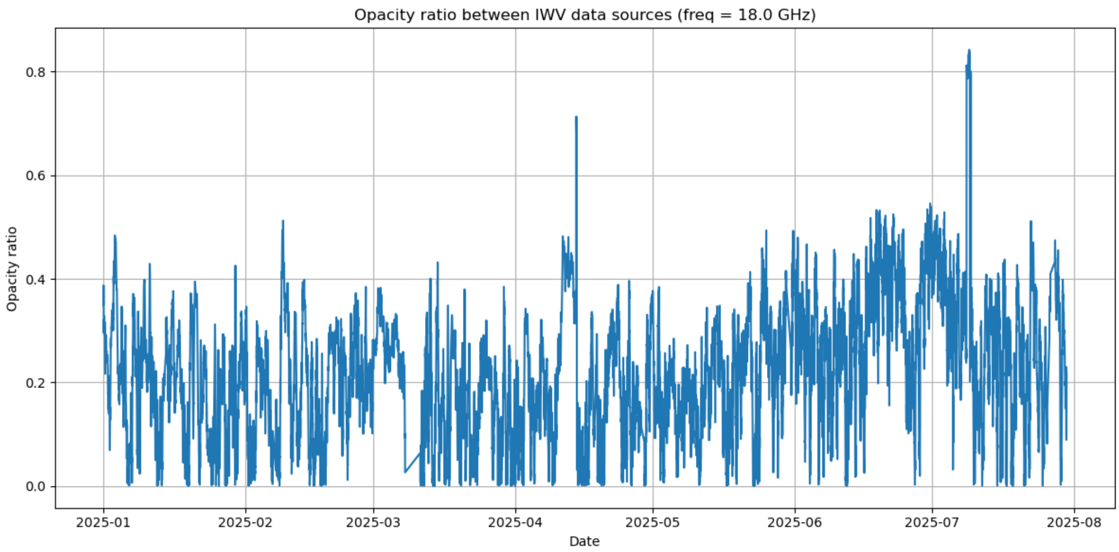


Figure 4.4: Ratio (GNSS/Weather params) between zenith opacities with two different methods at 18 GHz

- **Opacity at 30 GHz:**

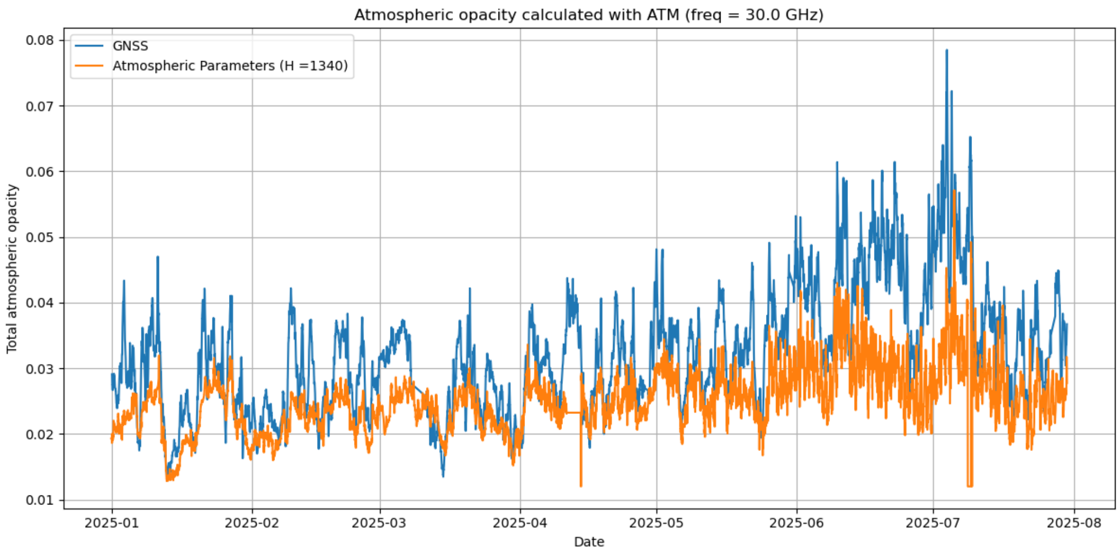


Figure 4.5: Zenith opacity at 30 GHz

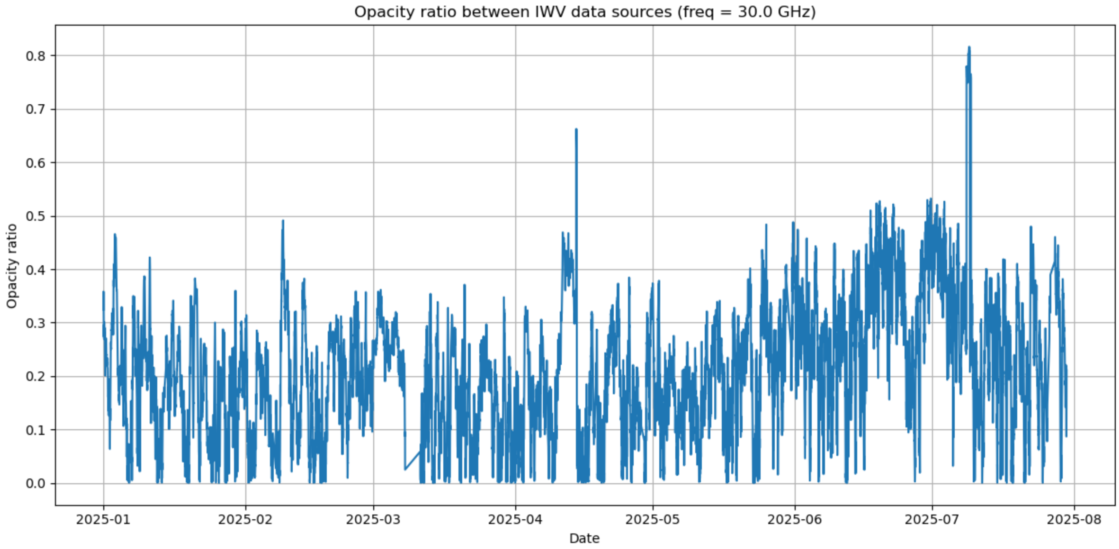


Figure 4.6: Ratio (GNSS/Weather params) between zenith opacities with two different methods at 30 GHz

- **Opacity at 50 GHz:**

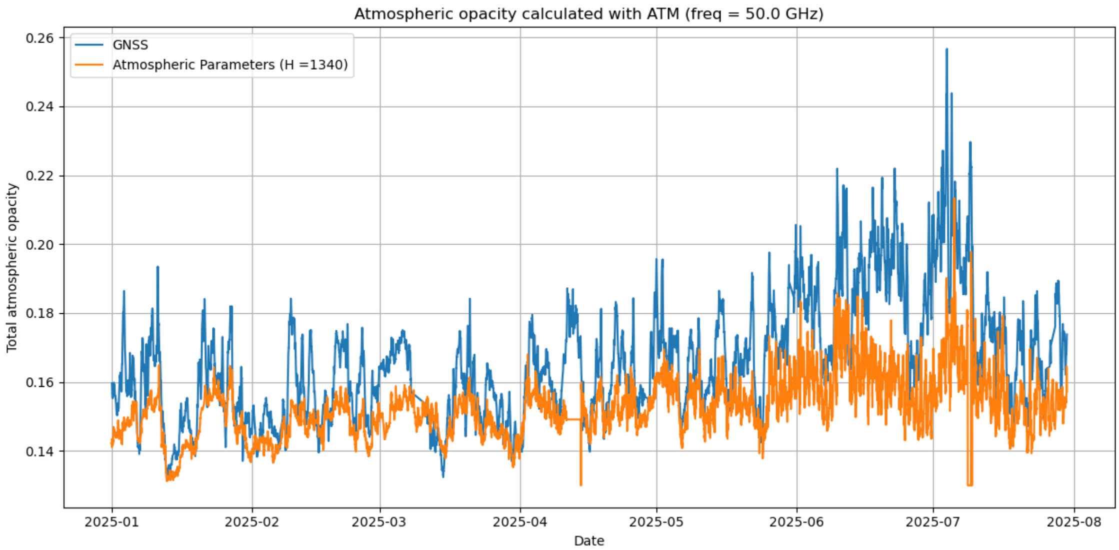


Figure 4.7: Zenith opacity at 50 GHz

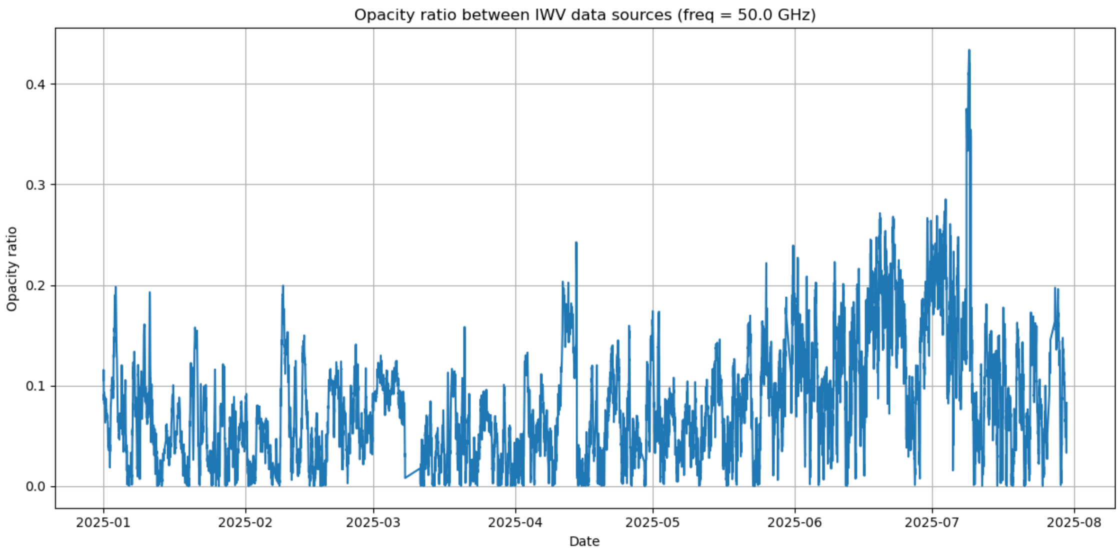


Figure 4.8: Ratio (GNSS/Weather params) between zenith opacities with two different methods at 50 GHz

- **Opacity at 75 GHz:**

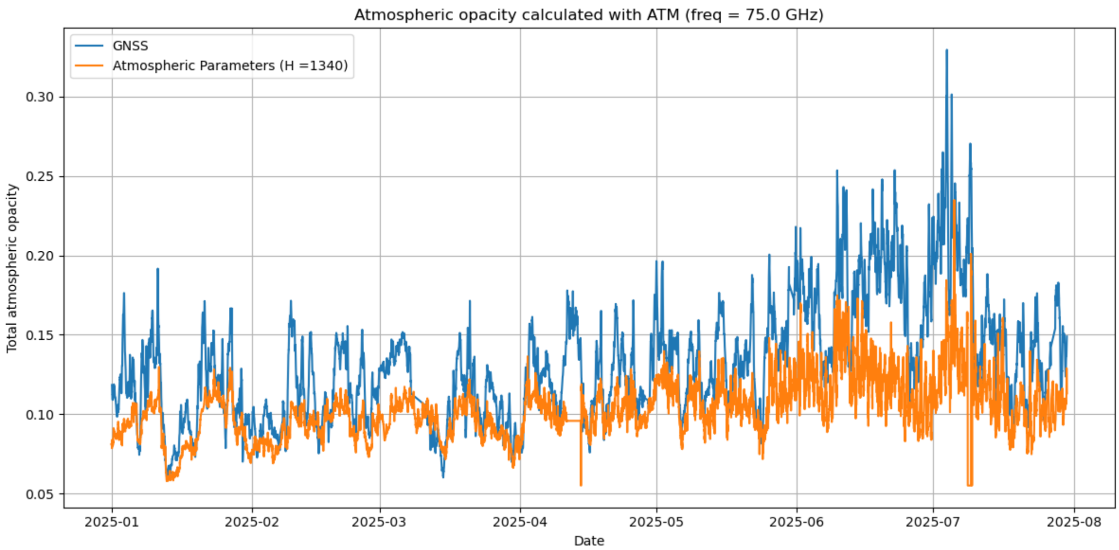


Figure 4.9: Zenith opacity at 75 GHz

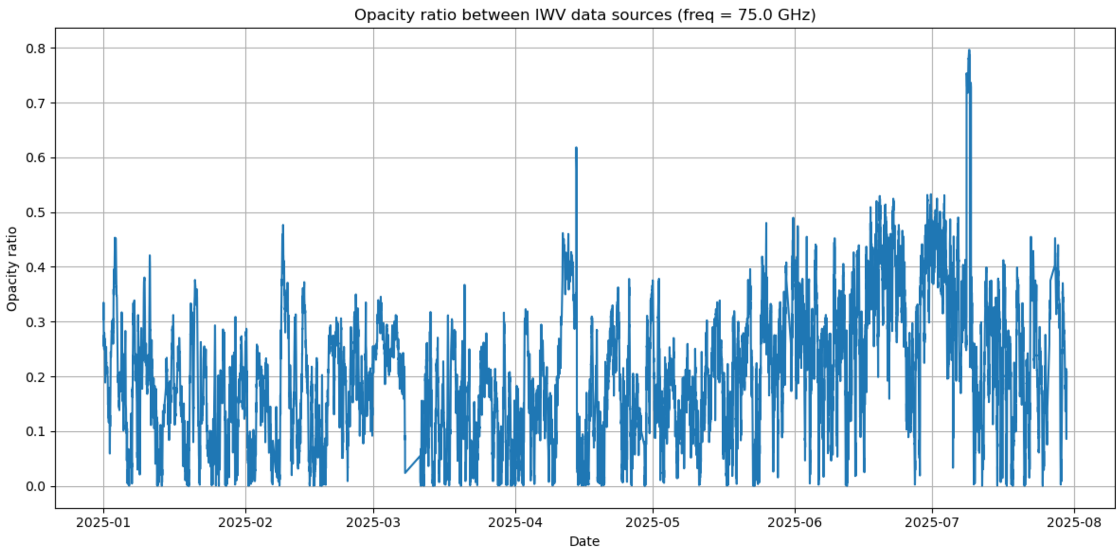


Figure 4.10: Ratio (GNSS/Weather params) between zenith opacities with two different methods at 75 GHz

- **Opacity at 85 GHz:**

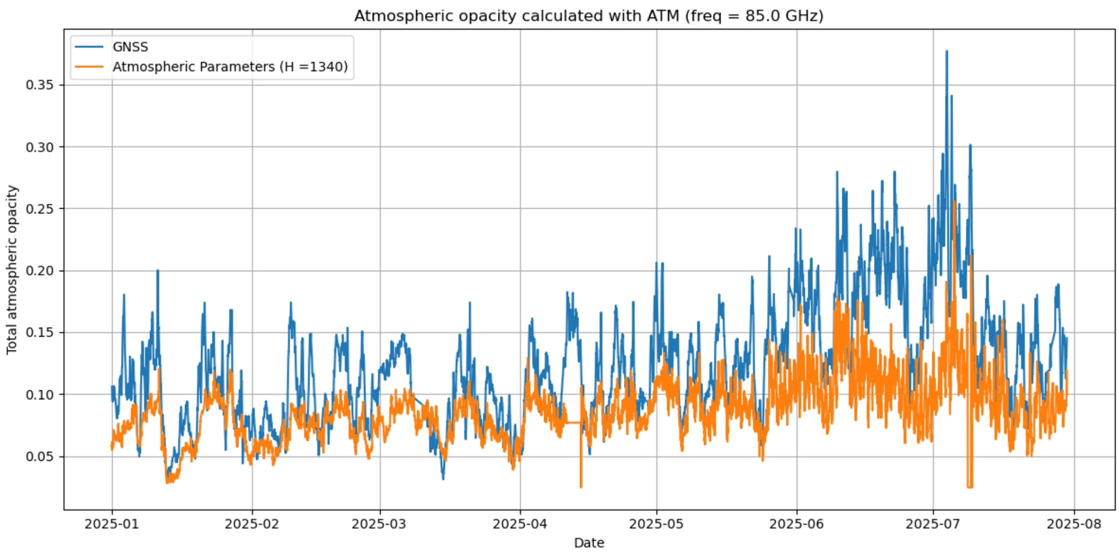


Figure 4.11: Zenith opacity at 85 GHz

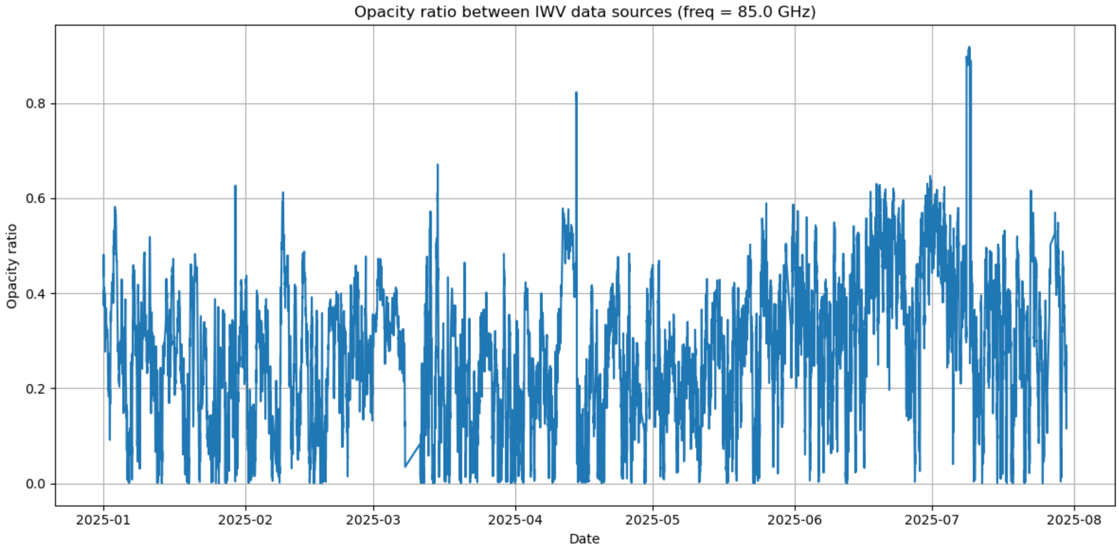


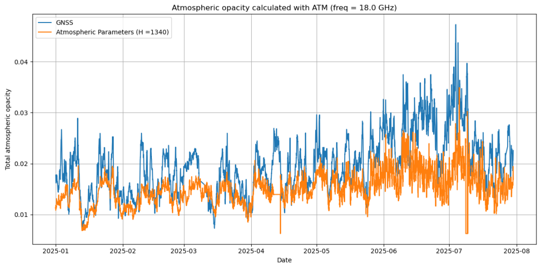
Figure 4.12: Ratio (GNSS/Weather params) between zenith opacities with two different methods at 85 GHz

5 Conclusion

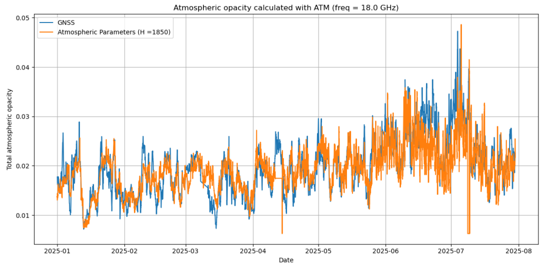
A comparison of the opacity calculations, derived from the formula based on the observatory's temperature and relative humidity data and the values provided by the IGN, reveals a disparity. The opacity calculated using the former formula does not fully align with the opacity calculated using the latter, exhibiting a slight decrease. Consequently, it would be necessary to modify the formula or the scale factor used to improve the accuracy of the calculation.

If we decide to adjust the scale factor, we would see how the opacity ratio is reduced and how the calculated zenith opacity value aligns more closely with the values calculated from the IWV value provided by the IGN. However, it is important to note that this adjustment may not be applicable universally and may require specific calibration for each observation frequency.

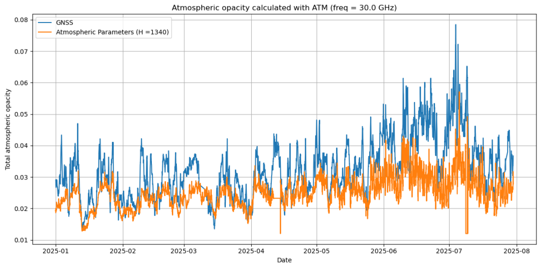
The following images present a comparison between the zenith opacity calculated from the IWV provided by the IGN and that calculated using the formula with a scale factor of 1340. The same graphs are shown, but with a scale factor of 1850, in order to observe the difference.



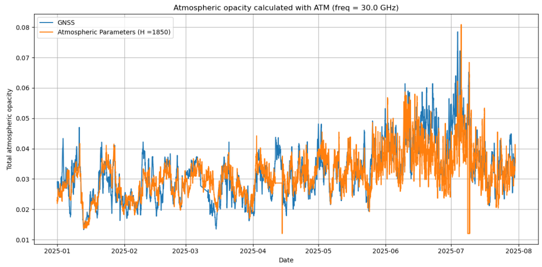
(a) 18 GHz - Factor 1340



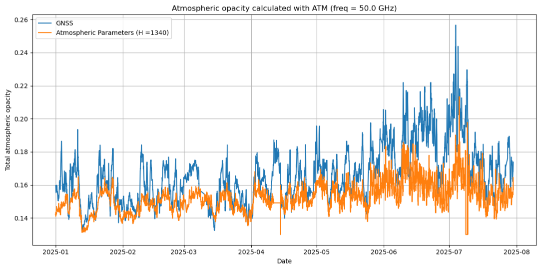
(b) 18 GHz - Factor 1850



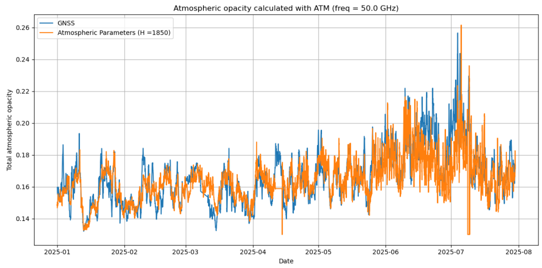
(c) 30 GHz - Factor 1340



(d) 30 GHz - Factor 1850

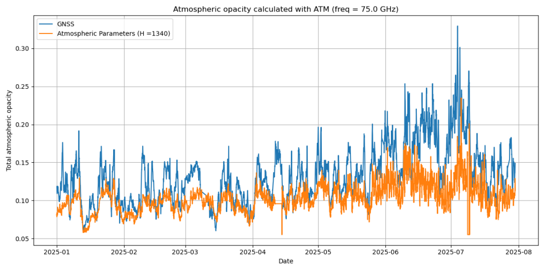


(e) 50 GHz - Factor 1340

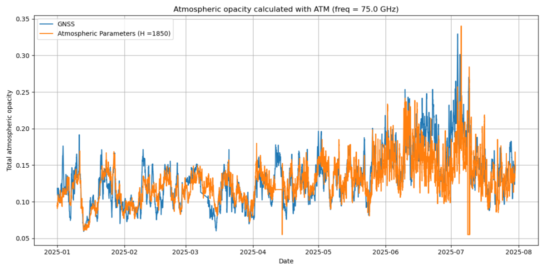


(f) 50 GHz - Factor 1850

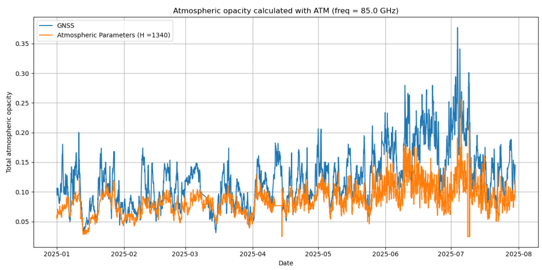
Figure 5.1: Comparison of zenith opacity for different scale factors (18-50 GHz)



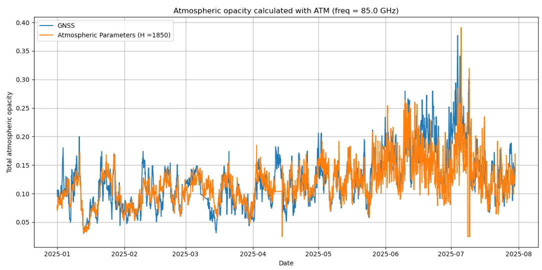
(a) 75 GHz - Factor 1340



(b) 75 GHz - Factor 1850



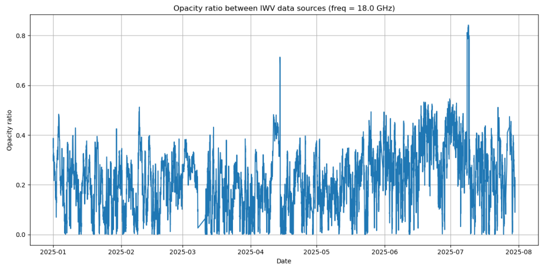
(c) 85 GHz - Factor 1340



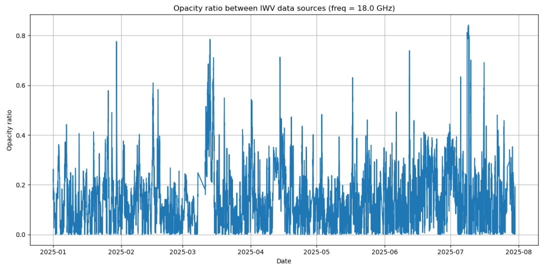
(d) 85 GHz - Factor 1850

Figure 5.2: Comparison of zenith opacity for different scale factors (75–85 GHz)

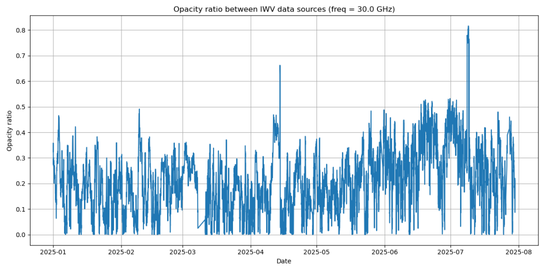
We can also compare the changes of the opacity ratio.



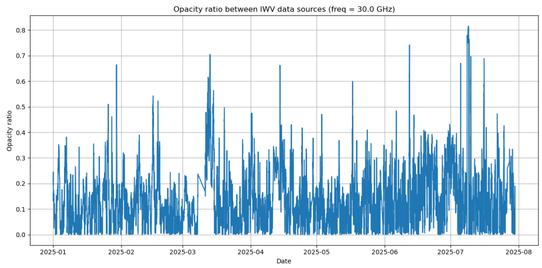
(a) 18 GHz - Factor 1340



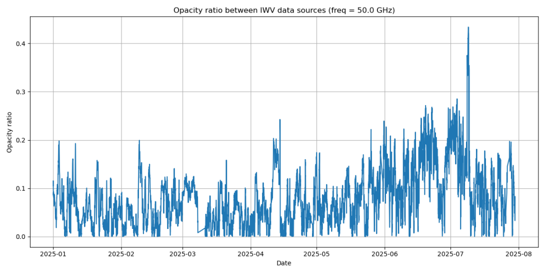
(b) 18 GHz - Factor 1850



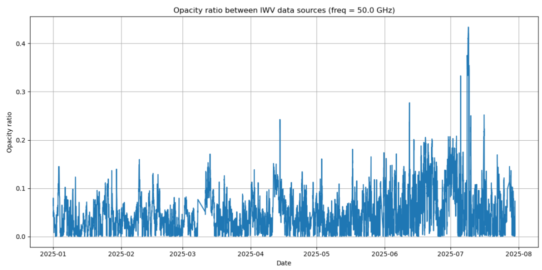
(c) 30 GHz - Factor 1340



(d) 30 GHz - Factor 1850

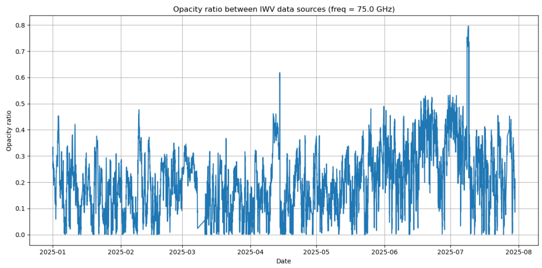


(e) 50 GHz - Factor 1340

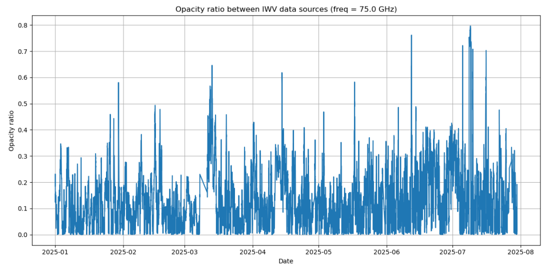


(f) 50 GHz - Factor 1850

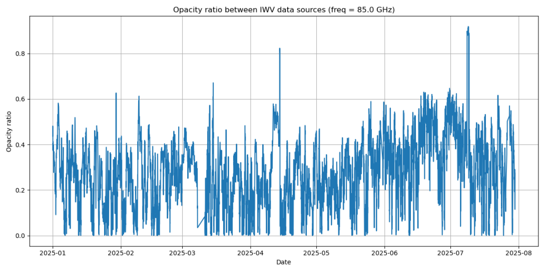
Figure 5.3: Comparison of opacity ratio for different scale factors (18-50 GHz)



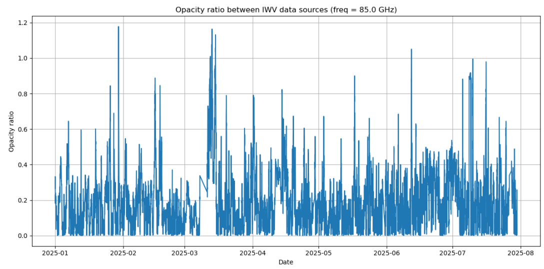
(a) 75 GHz - Factor 1340



(b) 75 GHz - Factor 1850



(c) 85 GHz - Factor 1340



(d) 85 GHz - Factor 1850

Figure 5.4: Comparison of opacity ratio for different scale factors (75–85 GHz)

References

P de Vicente and A Diaz Pulido. The atmosphere in the 40m rt environment. water vapour and opacity. Technical report, Observatorio de Yebes, 2012.