# Estimation of spectral parameters from oblique Equatorial Electrojet echoes using a double skewed Gaussian model at JRO

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## Abstract

Coherent echoes from the equatorial electrojet (EEJ) region are detected at the Jicamarca Radio Observatory (JRO) by using an array of 16 Yagi antennas with a main beam pointed obliquely to the west with an elevation of about 35 deg. The spectrum of these observations are composed of two types of EEJ echoes (Type I and Type II)[1] from which we can estimate their main spectral parameters such as Doppler shift and spectral width independently for each type. Previously, the method applied to obtain these parameters was a standard fitting approach based on a double Gaussian model. However, in some cases, the shape of the spectral measurements are not symmetric (resembling the shape of a skewed distribution). Based on simulations, we determined that the skewed shape of the oblique EEJ spectrum comes from the fact that the measured spectrum is the result of the sum of spectral contributions coming from different heights, with different Doppler shifts and spectral widths weighted by the antenna beam shape. The overall result is an asymmetric spectrum with a peak that does not coincide with the average Doppler shift. Thus in order to account for this effect, we have implemented a double skewed Gaussian distribution model to fit the oblique EEJ measurements and estimate their spectral parameters. In this work, we present the results obtained in the simulation showing the skewed shape of the spectrum. Based on our simulations, we have also proved that the shift of the skewed Gaussian model can be interpreted as the Doppler shift of the echoes. In addition, some examples of the new fitting procedure are shown in comparison with the classical Gaussian fitting where it can be seen the better agreement between the data and the double skewed Gaussian model.

## 1. Data

EEJ echoes are usually detected using the JULIA (Jicamarca Unattended Long-term Investigations of the Ionosphere and Atmosphere) mode at JRO. From these data, spectra are calculated (Figure 1) every minute, where the returned signal from the main beam is the one located at a range between 160 km and 200 km. A cut in range is shown in Figure 2, where it can be seen that the spectrum cannot be modeled by two Gaussians which was unexpected.

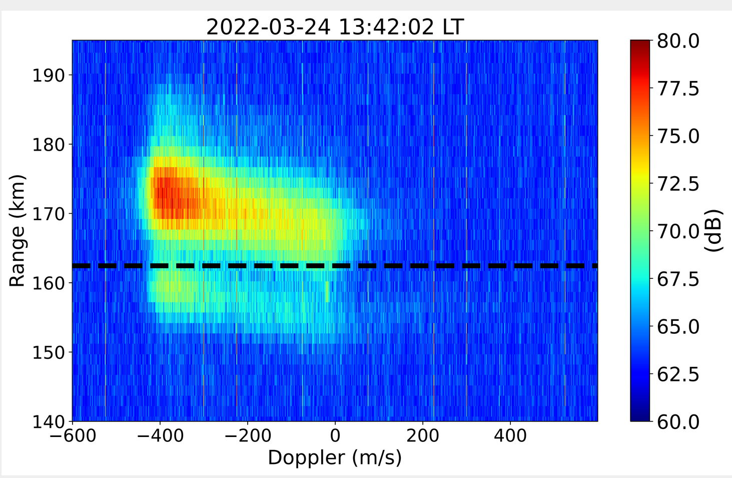


**Figure 1.** EEJ spectrum seen with the oblique beam.

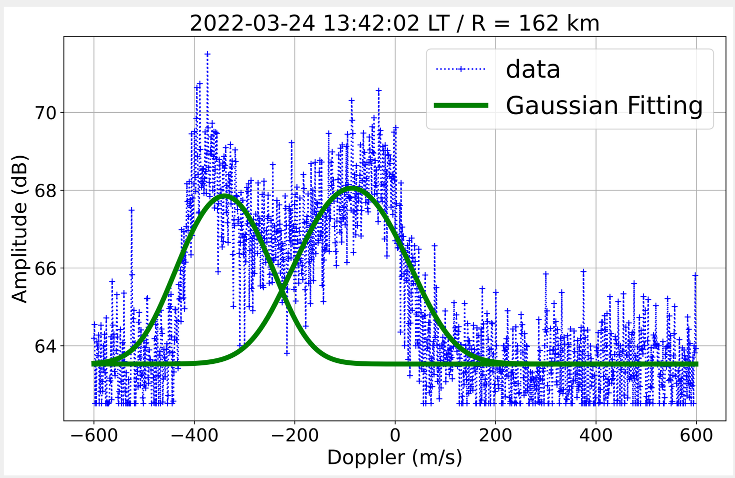


**Figure 2.** EEJ spectrum at R = 162 km.

## 2. Simulation

Due to the radar beamwidth of 3° (Figure 3), data acquired at a specific range comes from a contribution of data from different heights as shown in Figure 4.

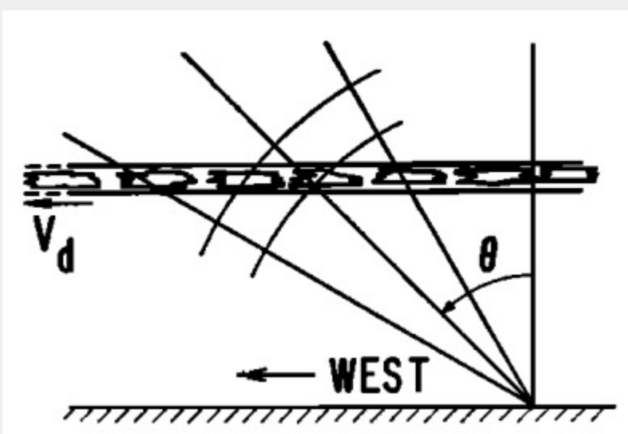


**Figure 3.** Radar beam and EEJ region. Balsley, 1969.

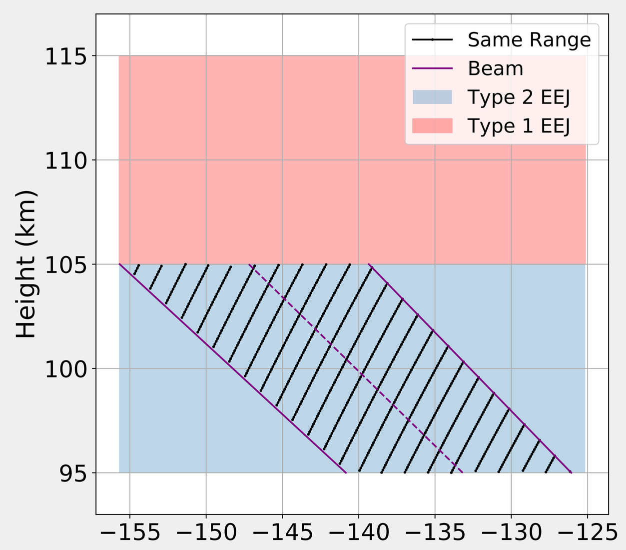


**Figure 4.** Contribution of different heights to the same range.

This means that the final spectrum is the sum of spectra with different Doppler shifts and spectral widths, i.e., the equations used to model the measurements are:

$$G(R) = \sum_{\theta} \frac{A(h,\theta)}{\sqrt{2\pi \times c(h)^2}} \times exp\left(-\frac{\left[dop - \hat{k} \cdot \vec{u}(h)\right]^2}{2 \times c(h)^2}\right), \qquad h = R \times cos(\theta) \qquad (1)$$

$$A(h,\theta) = \frac{A(h)}{\sqrt{2\pi \times bw^2}} \times exp\left(-\frac{\theta^2}{2 \times bw^2}\right), \qquad \theta \in \left[-\frac{bw}{2}, \frac{bw}{2}\right] \qquad (2)$$

$$A(h) = \frac{A_0}{\sqrt{2\pi \times 3^2}} \times exp\left(-\frac{(h-100)^2}{2 \times 3^2}\right), \qquad h \in [95, 105] \qquad (3)$$

$$c(h) = 3.95h - 14.75, \qquad h \in [95, 105] \quad \Rightarrow \quad c(h) \in [5, 400] \qquad (4)$$

$$\vec{u}(h) = -\sqrt{12247.5h - 1163487.5}\hat{i}, \qquad h \in [95, 105] \quad \Rightarrow \quad |\vec{u}(h)| \in [5, 350] \qquad (5)$$

Where *R* is the range, $\theta$ is the angle between the vertical and the beam direction, *bw* is the radar beamwidth, $A(h,\theta)$ is the power contribution due to the beamshape, *A(h)* is the power contribution in height due to the EEJ echoes, *c(h)* and $\vec{u}(h)$ are the spectral width and Doppler shift of a Gaussian at a certain height, respectively.

## 3. Results

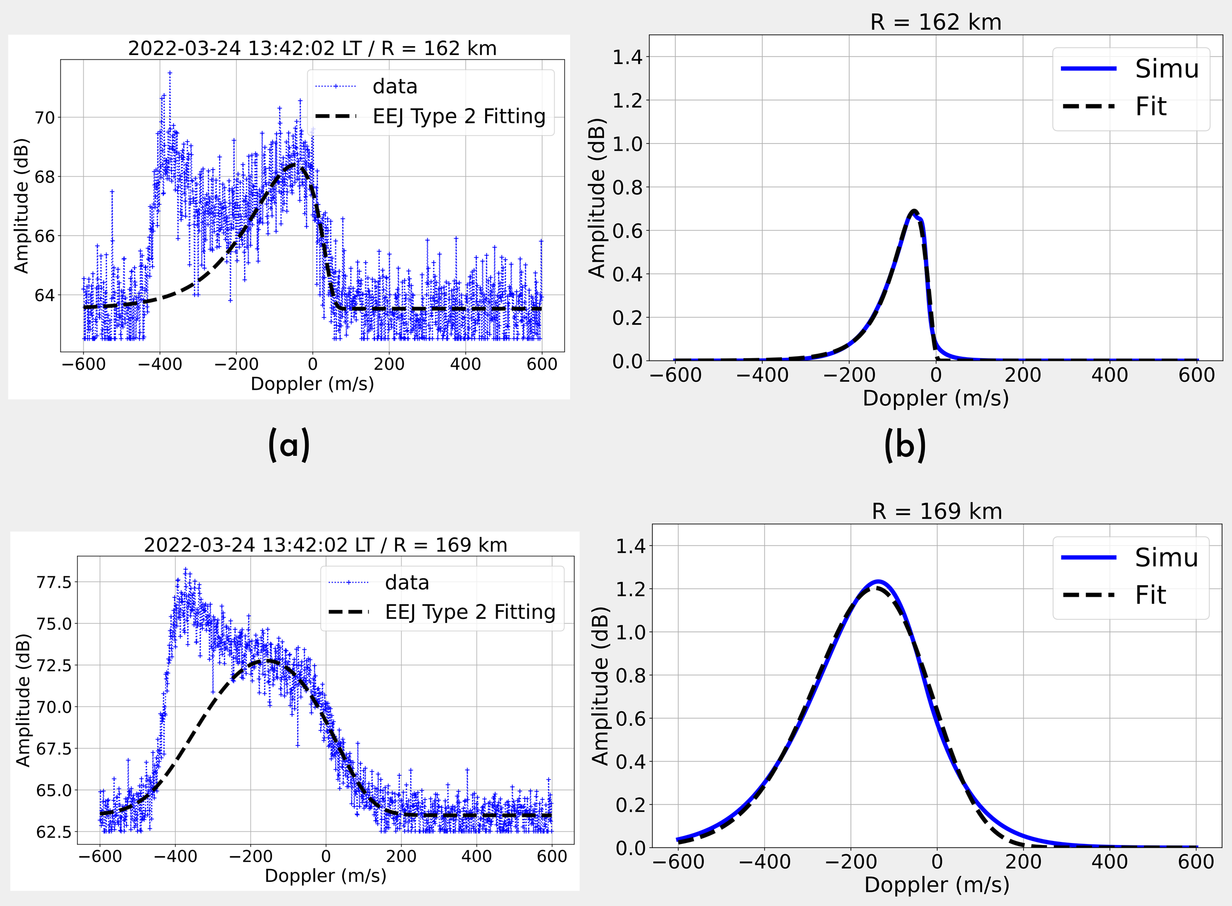


**Figure 5.** Comparison between data and simulation. (a) y (c) data and fitting. (b) y (d) simulation and fitting curve.

For skewed Gaussian models, the peak and the shift do not coincide. This fact can be appreciated in Figure 6, where the red stars represent the velocity where is located the peak, while the yellow ones represent the shift of the skewed Gaussian.

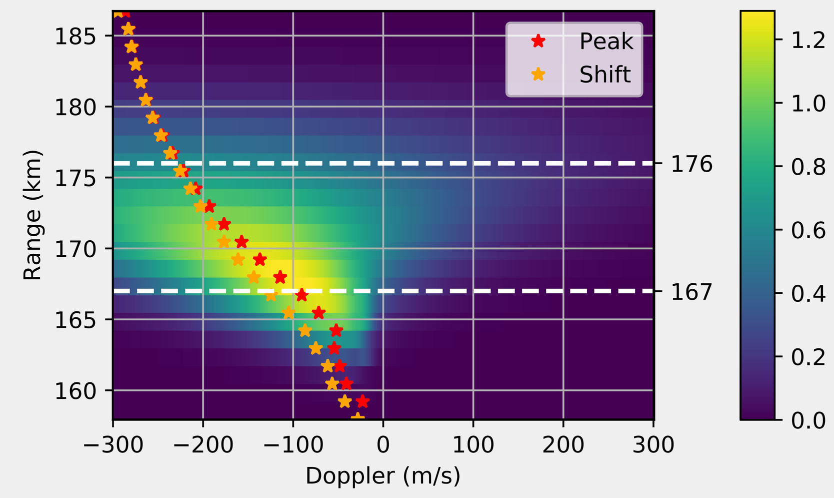


**Figure 6.** Simulation of EEJ Type 2 spectrum.

Initial Doppler shifts considered in our simulation are shown as a green curve in Figure 7. In fact, it can be seen that the shift parameter of the skewed Gaussian model is a better estimator than the peak.

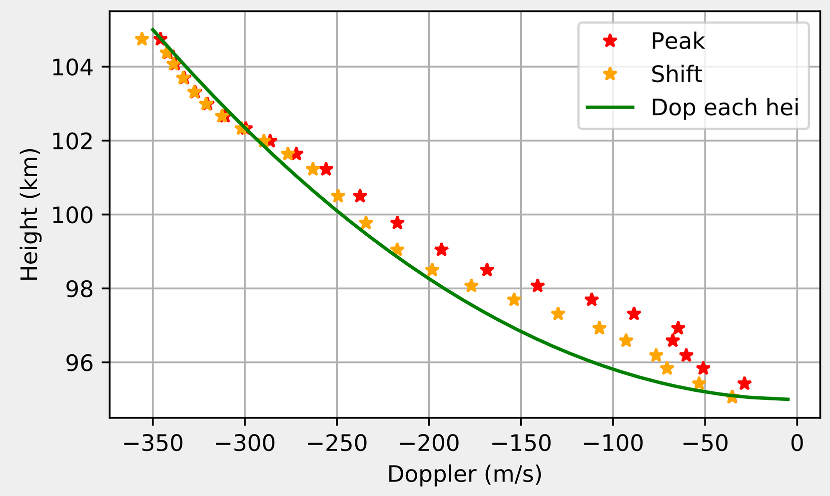


**Figure 7.** Final EEJ Doppler shift (yellow stars), final EEJ peak position (red stars) and Doppler shift of a EEJ at a certain height.

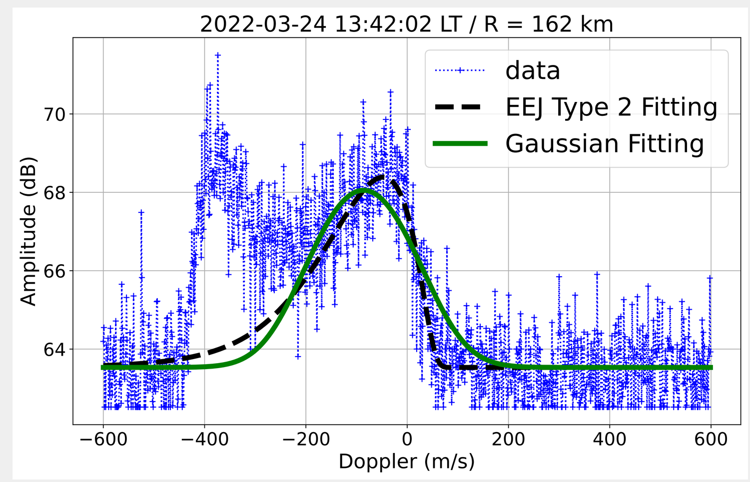


**Figure 8.** Standard Gaussian Fitting vs Skewed Gaussian Fitting.

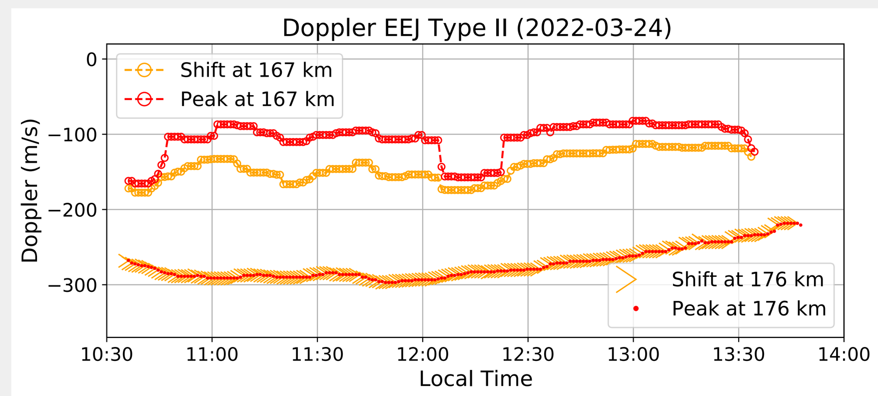


**Figure 9.** Doppler shifts and peaks for two different ranges on March 24, 2022.

## 4. Conclusions

- EEJ skewness is a combined effect of the radar beamwidth with the Doppler gradient.
- The shift of the skewed Gaussian model is a better interpretation of the EEJ Doppler shift.
- The skewed Gaussian model fits better to data than a standard Gaussian model.

## 5. Acknowledgments

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## 6. References

[1] Farley, D. T. "Theory of equatorial electrojet plasma waves-new developments and current status." Journal of Atmospheric and Terrestrial Physics 47 (1985): 729-744.

[2] Hysell, D. L., et al. "Combined radar observations of equatorial electrojet irregularities at Jicamarca." Annales Geophysicae. Vol. 25. No. 2. Copernicus GmbH, 2007.

[3] Shume, Esayas. "The equatorial electrojet: Radar observations and modeling." Cornell University, PhD dissertation, hdl.handle.net/1813/3234 (2006).



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