Long-term trends at the geomagnetic equator: Trend analysis

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Introduction

According to the literature, it has been established the importance of greenhouse gas concentrations in trends in the ionosphere. However, recent works suggest the role of the Earth's magnetic field (Qian, 2021; Elias, 2022). In this work, experimental results on ionospheric parameters trends linked to the geomagnetic field secular variation and solar influence are analyzed..

The ionosonde used in Jicamarca Radio Observatory (JRO) is the "Digisonde Portable Sounder" (DPS) from Lowell Digisonde International. The DPS acquisition system comes with a data processing software called ARTIST (Automatic Real-Time Ionogram Scaler with True heights), which is responsible for the automatic scaling of the echoes, and the inversion of parameters.

The SAO format was initially developed to store the ionograms processed by ARTIST. However, it was the creation of the SAO 4.1 format (currently used in JRO) that has allowed it to become the standard format for the exchange of ionograms produced by different acquisition systems. In this sense, an application was written in Python that processes the SAO files to generate files that shows the date and time in UT (the correction with the local time is -5:00 h) and also different values of F2 parameters.

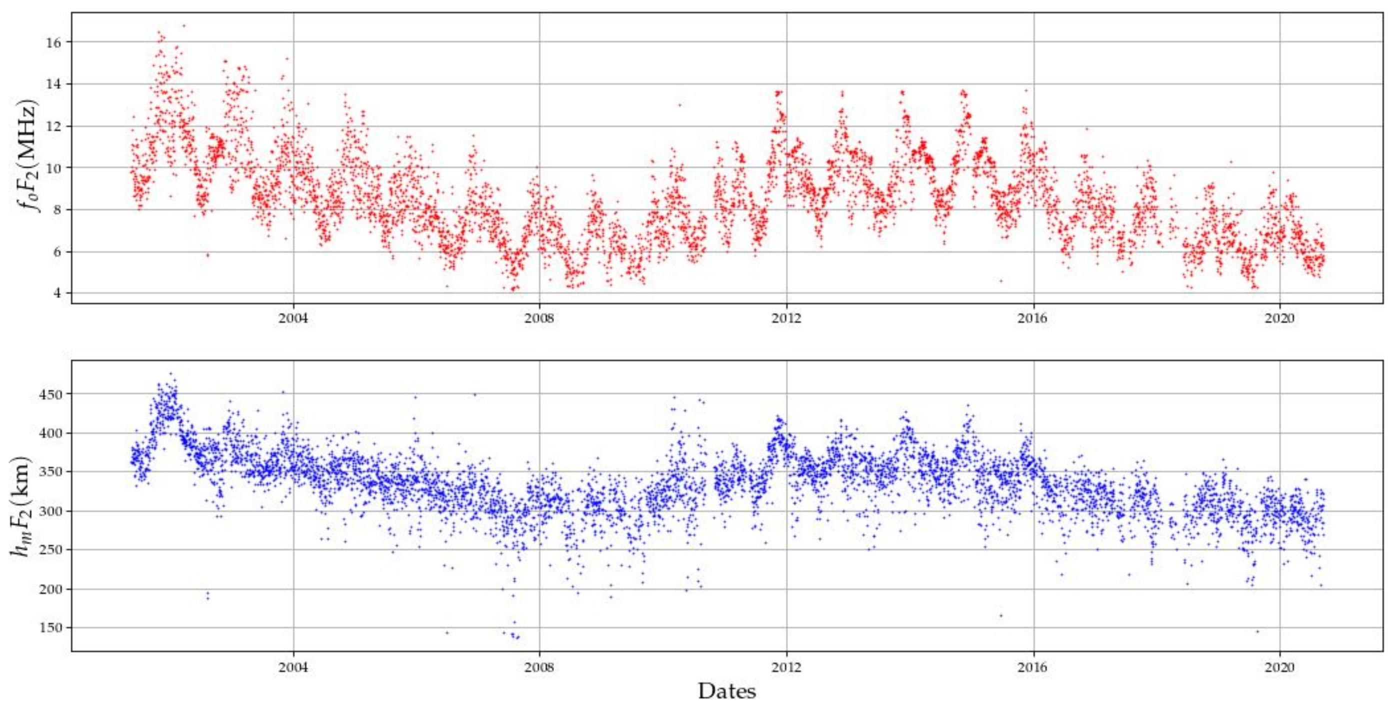

Figure 1. Time series of foF2 and hmF2 at 12 h LT between 2001 and 2020..

Figure 1 shows high resolution time series (TS) of foF2 and hmF2 at 12 h LT between 2001 and 2020 from Jicamarca's Digisonde, which measures each 15 minutes on average). Also, it is important to mention that some data preprocessing was done such as outlier removal and calculations of hourly medians. Besides, In addition, TS for all the other hours of the day were constructed..

Comparing ionosonde and ISR data

We made comparisons between ionosonde and ISR data for foF2 and hmF2 for some days (campaigns) between 2001 and 2020 (see Fig. 2). The points of the ionosonde data, as well as those of the ISR data, represent median values of different measurements of a same hour.

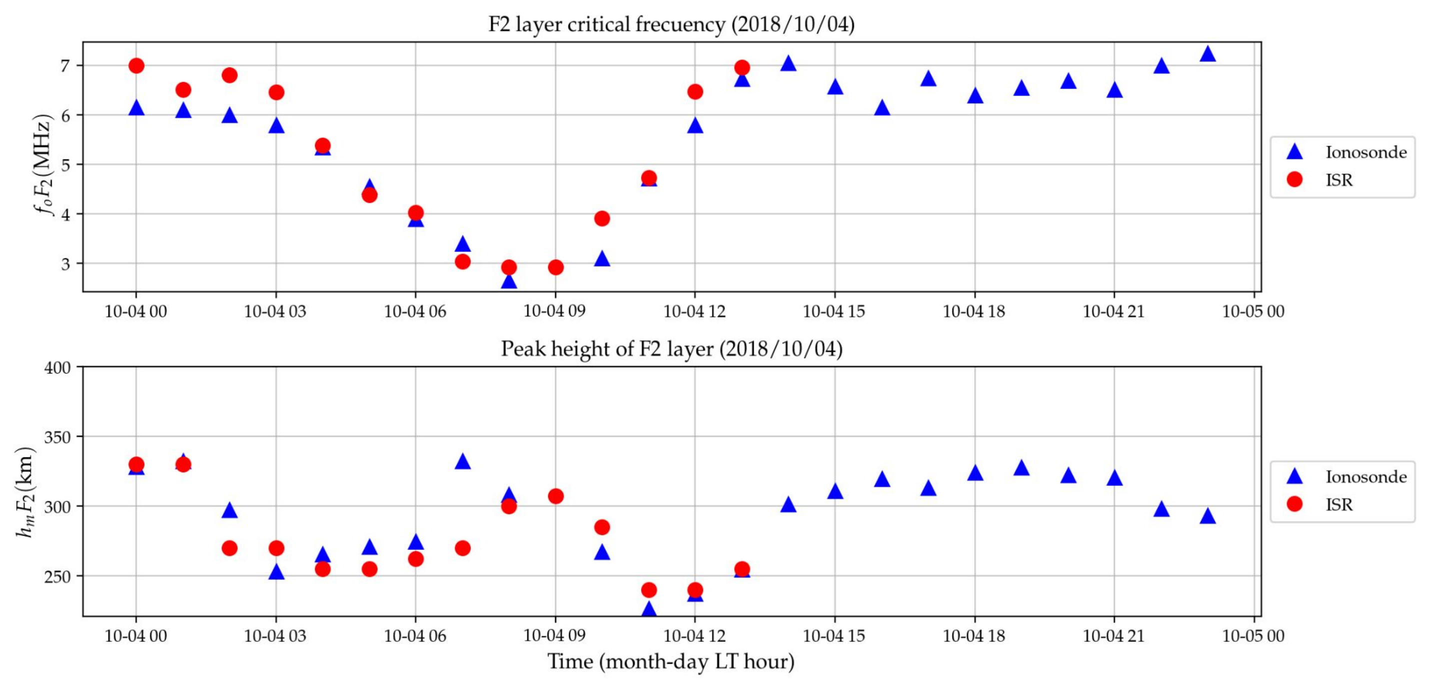

Figure 2. Comparison between ionosonde and ISR data of parameters foF2 and hmF2 (2018 Oct 04th)

Statistics of the discrepancies of F2 parameters

In Figures 4 and 5 we can see discrepancies between digisonde and ISR data for foF2 and hmF2, versus day of the year (DOY), hour of the day, and F10.7. In the case of the plot versus DOY, it can be seen an apparent systematic error throughout the time, that is, focused negative values of ΔfoF2 and ΔhmF2 along different parts of the year.

Respect to F10.7, it can be seen more negative values of ΔfoF2. This means that ISR data overestimates foF2 values. Besides, respect to the hour of the day, it seems that discrepancies increase in the first and last hours of the day.
In summary, ISR estimates tend to be larger than sounder's.. Discrepancies seem to correlate with solar activity and hour.

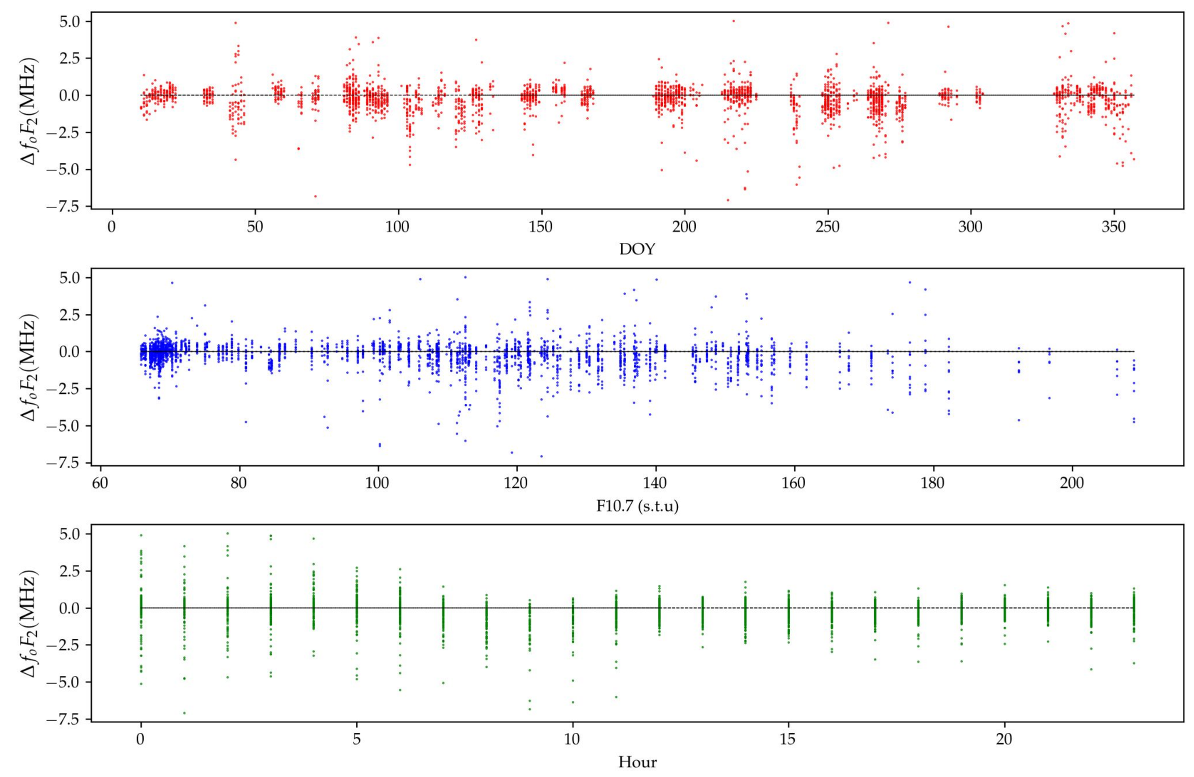

Figure 4. Discrepancies (Δ = ionosonde - ISR) between digisonse and ISR foF2 data between 2001 and 2020.

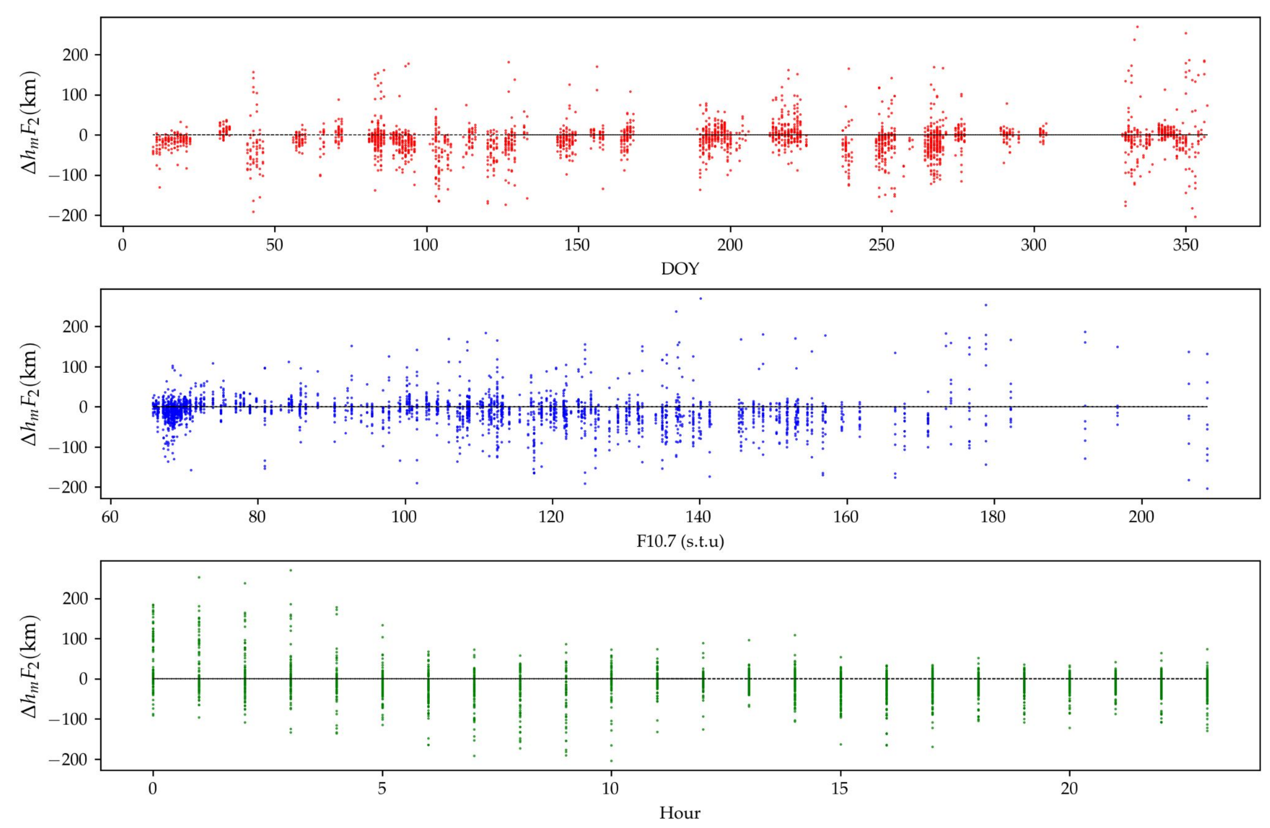

Figure 5. Discrepancies (Δ = ionosonde - ISR) between digisonse and ISR hmF2 data between 2001 and 2020.

Using Seasonal-Trend-LOESS Decomposition for trend analysis

Seasonal-Trend-LOESS (STL) is a filtering procedure for decomposing a time series into trend, seasonal, and remainder components.

STL consists of a sequence of smoothing operations of which, with one exception, employs the same smoother: locally weighted regression, or LOESS. In principle, it can work with missing values and does not assume specific functional forms.(Cleveland, 1990).

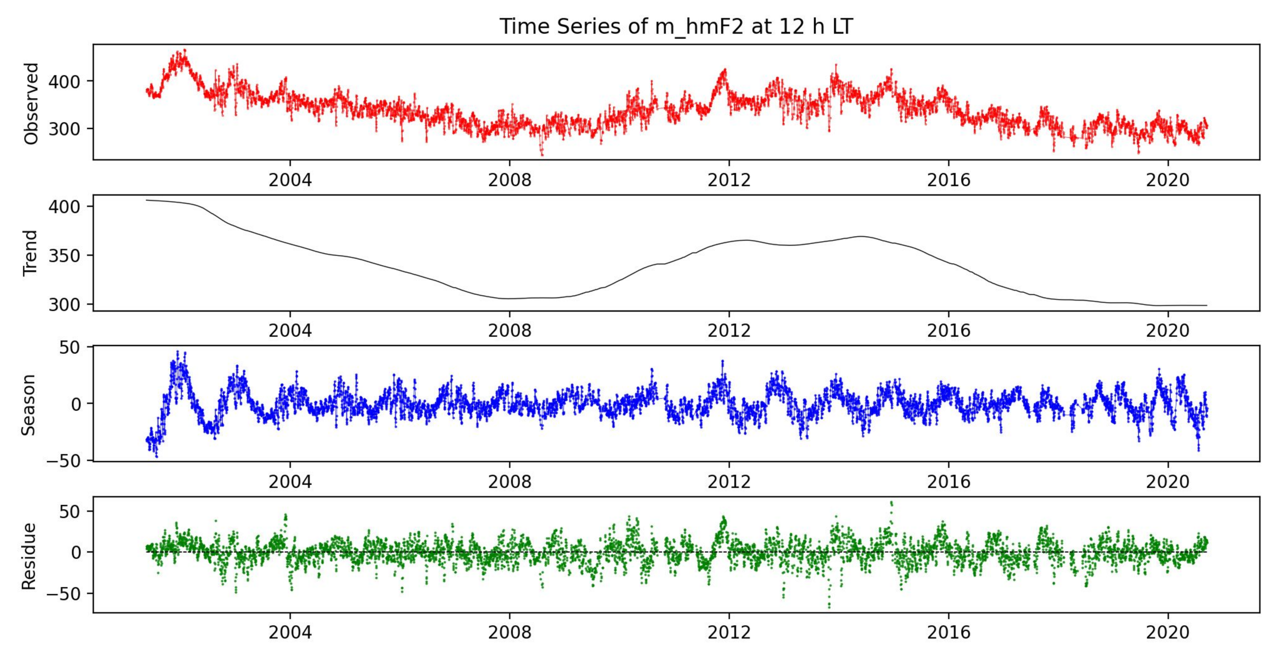

Figure 6. STL descomposition of TS of hmF2 at 12 h LT.

Limitations of STL in this TS and similars is the fact that ionosphere parameters have more than 1 seasonality. In that sense, it is better to implement a multiple STL whose algorithm requires for each period or stationality a several number of iterations to refine the descomposition. Finally, with the last iteration, it is calculated the trend and the residue.

Figures 8 and 9 show periodicities less than or equal to 30 days, less than or equal to 0.5 year (semi-annual), less than or equal to 1 year (annual), and less than or equal to 11 years (solar cycle).

Building `MSTL`

Here I will follow the algorithm proposed by Bandara(2011):

1. Define `PeriodsArray` (periods for decomposition).
2. Sort `PeriodsArray` in ascending order.
3. Define `TimeSerie = SAO_m[IonoParam]` and chosen hour.
4. Define `Seasons = Zeros((NumSeasons, TimeSeries.shape[0]))`
5. Define `DeSeasonal = TimeSerie`
6. Main iteration:

```
for IterRefine in NumIterRefine:

    for i in range(PeriodsArray.shape[0]):

        DeSeasonal = DeSeasonal + Seasons[i]
        stlfit = STL(DeSeasonal, period=PeriodsArray[i])
        Seasons[i] = stlfit.seasonal
        DeSeasonal = DeSeasonal - stlfit.seasonal
```

7. Calculate `Trends = stlfit.trend`
8. Calculate `Residue = stlfit.resid`

Figure 7. MSTL algorithm (Bandara, 2011).

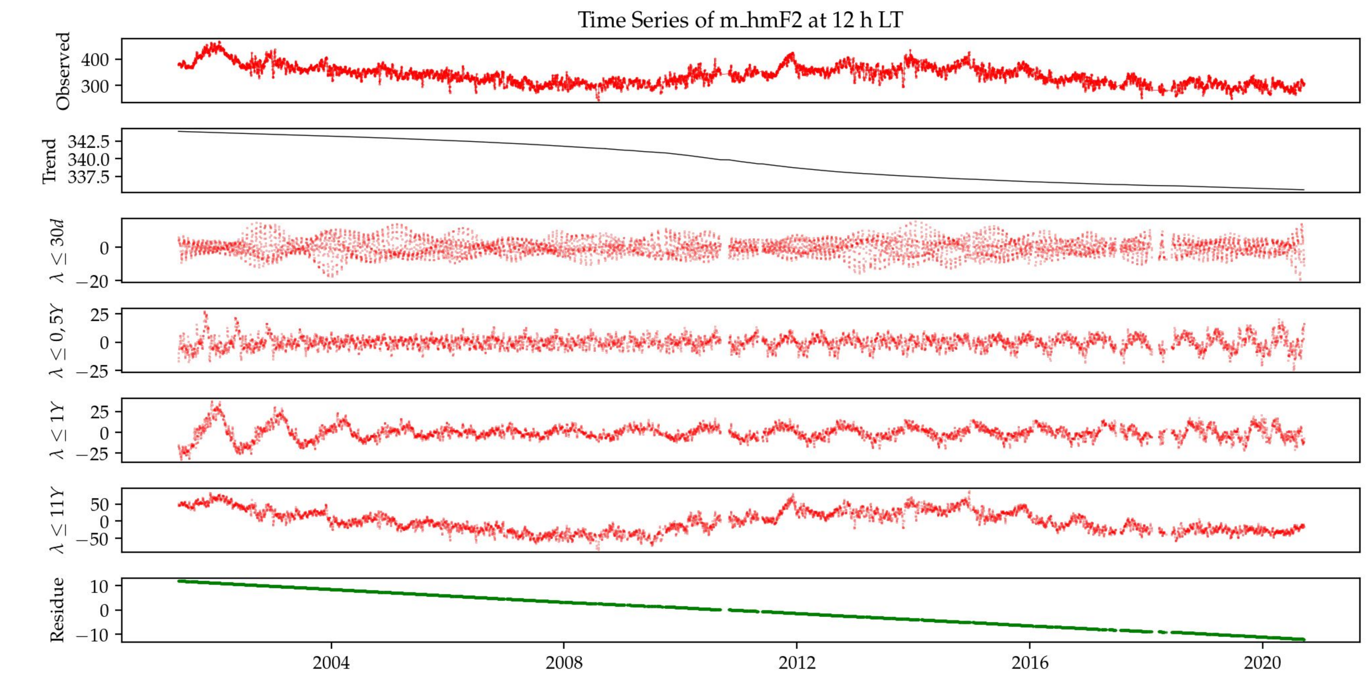

Figure 8. MSTL descomposition of TS of hmF2 at 12 h LT.

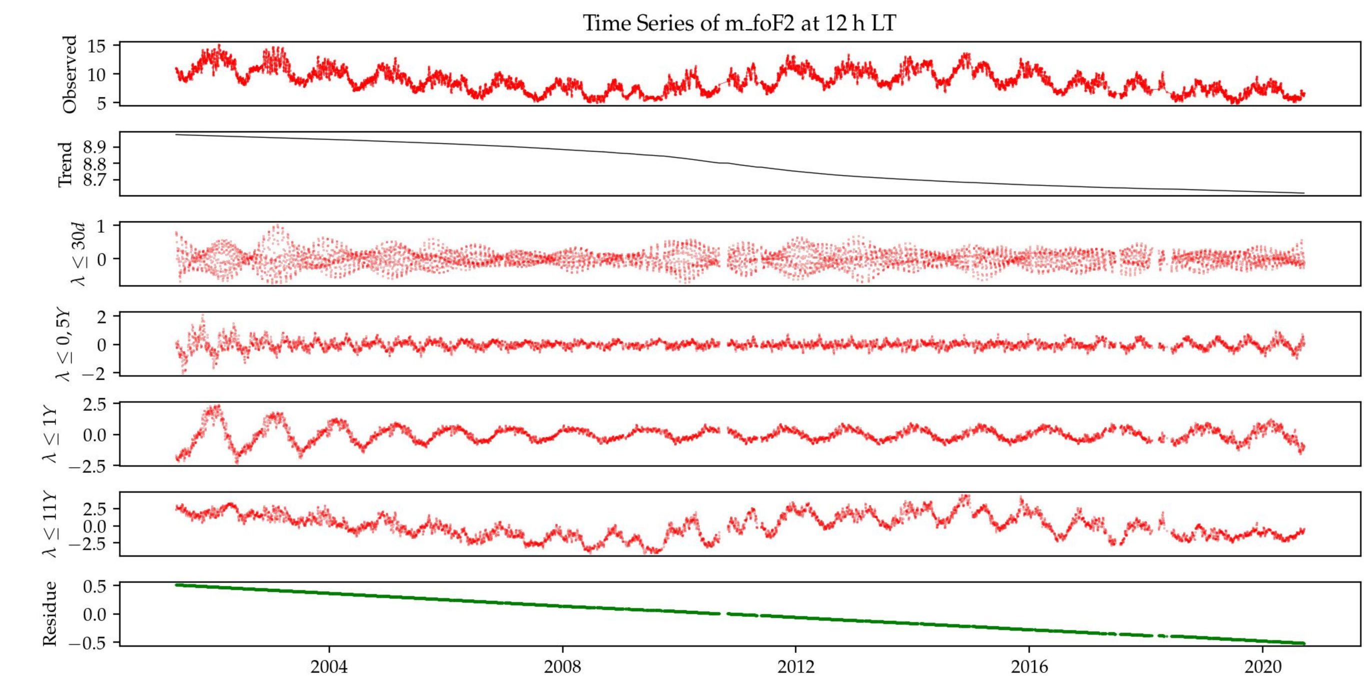

Figure 9. MSTL descomposition of TS of foF2 at 12 h LT.

According to MSTL, at 12 h LT Trend value for hmF2 is -1.23 km/year and for foF2 is -0.05 Mhz/year. Trend seem to be overestimated, and this is probably due to the large amplitude of the solar activity cycle. Additionally, trend calculations can be seen for each month between 2001 and 2020 using the monthly medians.

Conclusions and Future work

There seem to be systematic discrepancies between ISR and ionosonde that could affect long term trends analysis.. The multiple STL model may be useful to analyze trends with missing data and without assuming a specific model.
Future work focuses on 2 aspects:

- Extend the analysis for other ionosphere parameters as hmE, foE, h'F and vertical plasma drifts..
- Use MgII as different solar proxie (Lastovicka, 2019) to calculate trend estimates, also using MSTL and assuming a linear model.

Acknowledgements

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