The Time-Frequency Analysis (TFA) Toolbox: a Versatile Processing Tool for the Recognition of Magnetospheric and Ionospheric Signals in Swarm Time Series

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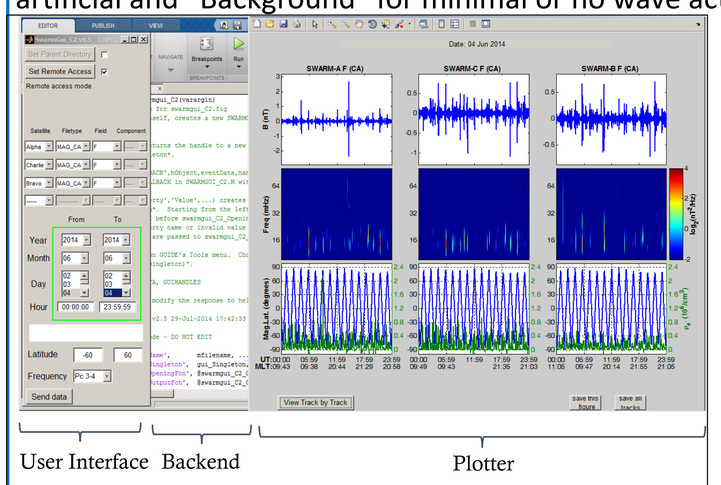
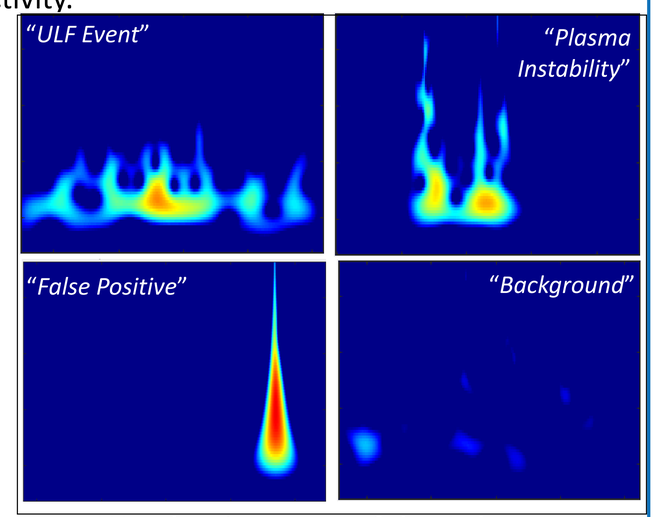
THE TIME – FREQUENCY ANALYSIS TOOL (ORIGINAL VERSION)

The original Time Frequency Analysis (TFA) tool was a MATLAB application that was used to perform wavelet analysis on time series of magnetic and electric field data from the Swarm mission (Balasis et al., *EPS* 2013). Parts of the series that exhibited significant wave power were then classified into four categories of either actual "Wave Events" for true ULF waves, "Plasma Instabilities" for pulsations that were attributed to the satellite passing through turbulent plasma flux tubes, "False Positives" for wavelet signatures that were caused by spikes or data gaps in the data and were thus completely artificial and "Background" for minimal or no wave activity.



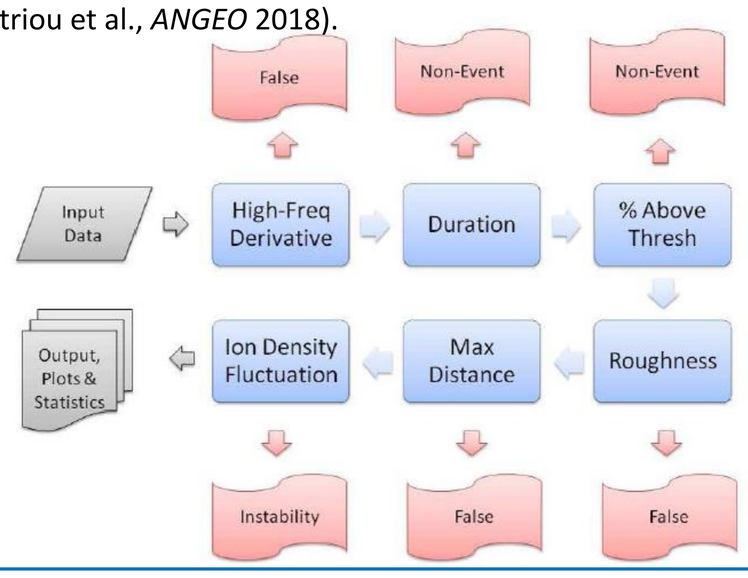
The Graphical Interface of the TFA Tool



Wavelet signatures of the 4 classes

WAVE DETECTION AND INDEX

The tool not only performs the wavelet analysis, but also checks the parts of the signal that exhibit significant wave power against a series of criteria, in order to remove wave signatures that are caused by plasma instabilities and artificial spikes or other outliers. If the signal passes all tests, it is considered a true wave signal and by summing its power in all frequencies of the particular frequency range in which it belongs, the tool produces a Wave Index (Papadimitriou et al., *ANGEO* 2018).



DEMO AND EXAMPLES

```
import datetime as dt
from swarmpal.io import create_paldata, PalDataItem
from swarmpal.toolboxes import tfa

dataset = "SW_OPER_MAGA_LR_1B"
variables = ['B_NEC', 'Flags_B']
time_start = dt.datetime(2015, 3, 14)
time_end = dt.datetime(2015, 3, 14, 23, 59, 59)

data = create_paldata(
    PalDataItem.from_vires(
        collection = dataset,
        measurements = variables,
        models = ["Model='CHAOS-Core'+'CHAOS-Static'"],
        auxiliaries = ["QDLat", "MLT"],
        start_time = time_start,
        end_time = time_end,
        server_url = "https://vires.services/ows",
        options = dict(asynchronous=False,
                       show_progress=True)))

preproc = tfa.processes.Preprocess()
preproc.set_config(
    dataset = dataset,
    active_variable = variables[0],
    active_component = None,
    convert_to_mfa = False,
    use_magnitude = True,
    sampling_rate = 1,
    remove_model = True,
    clean_by_flags = True)
preproc(data)

filt = tfa.processes.Filter()
filt.set_config(cutoff_frequency = 20 / 1000)
filt(data)
wave = tfa.processes.Wavelet()
wave.set_config(min_frequency = 20 / 1000,
    max_frequency = 100 / 1000, dj=0.1)
wave(data)
```

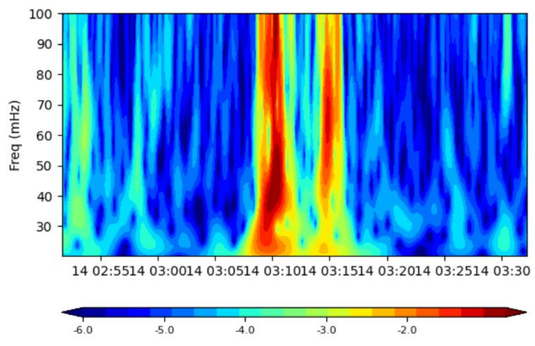
imports

dataset, model and date-range selection

initialization & data retrieval

pre-processing (convert vector to magnitude, remove CHAOS, cleaning by flags, etc)

filtering and wavelet analysis

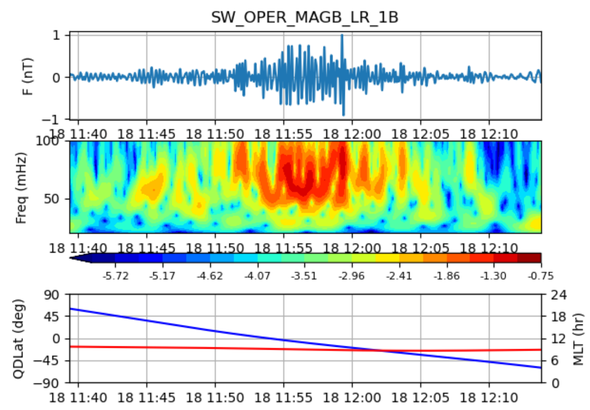


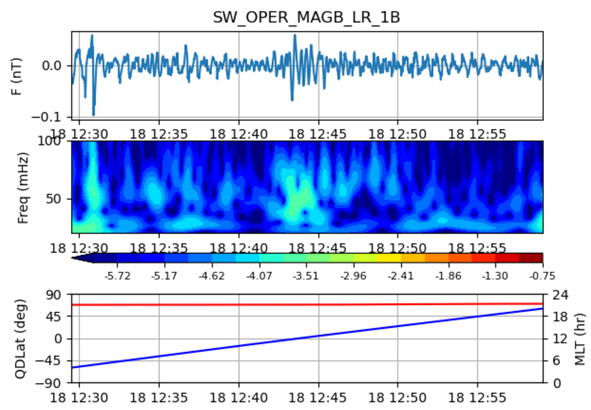
Visualization of the Wavelet Power Spectrum of the 1Hz Magnetic Field data from Swarm-A for the 4th track (half-orbit) of the satellite at the 14th of March, 2015.

Get the TFA tool and all the other SwarmPAL products from

https://github.com/Swarm-DISC/SwarmPAL

Merging the various plots of the TFA tool in one figure can produce outputs such as these, with the filtered magnetic field time series (top), the wavelet power spectrum (middle) and the Magnetic Latitude and MLT series (bottom).

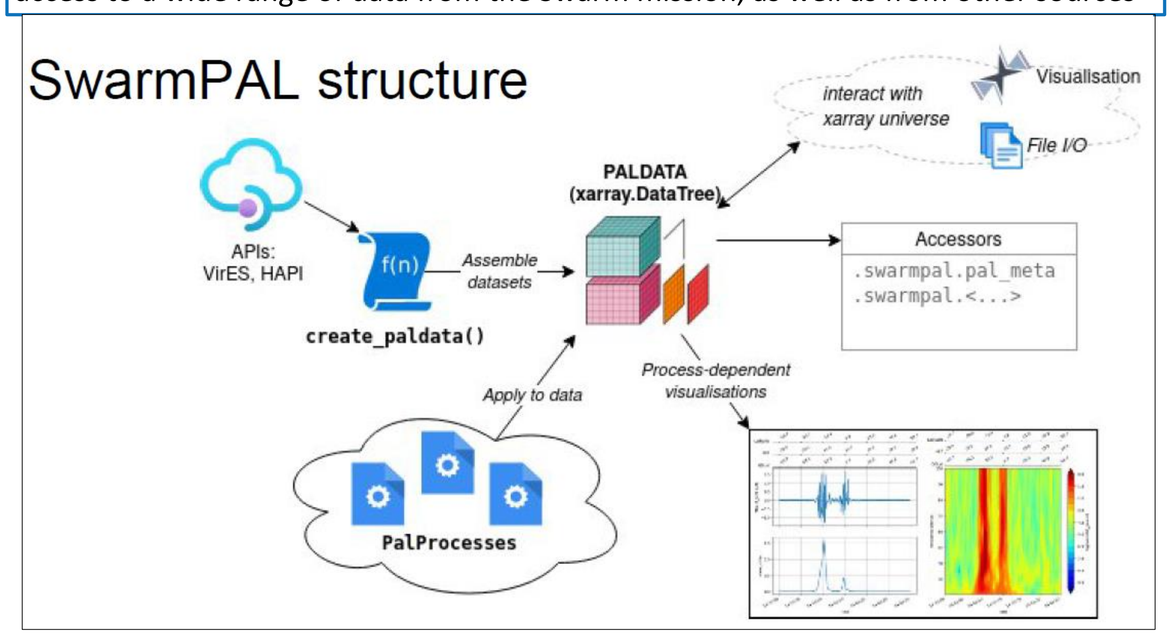




https://swarmpal.readthedocs.io/en/latest/
https://swarmpal.readthedocs.io/en/latest/guides/tfa/intro_tfa.html

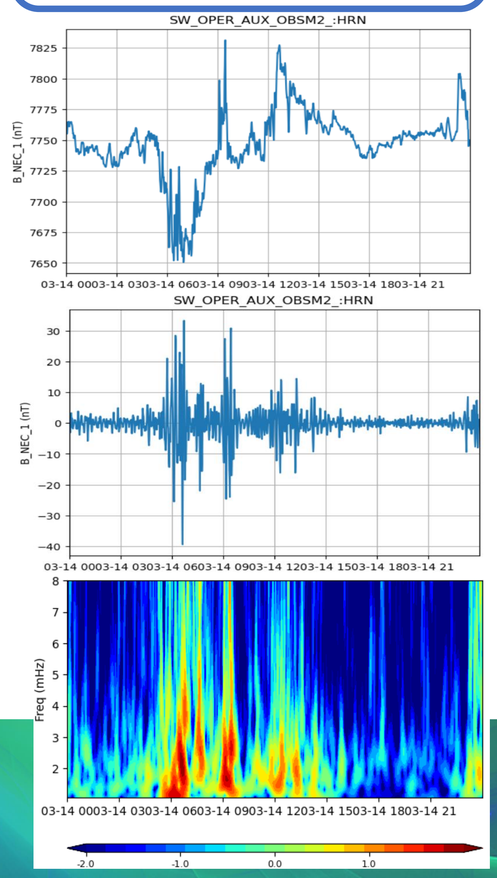
THE NEW TFA TOOLBOX

The new TFA toolbox is a part of the SwarmPAL family of products. As such it has access to a wide range of data from the Swarm mission, as well as from other sources



Ground-based Data Analysis

Using data from the Hornsund station in Svalbard



ESA Cluster Mission Data Analysis

Using data from the Cluster satellite constellation

Even though the TFA tool does not offer direct access to data from the Cluster mission, if the data are locally saved and have been read in Python, a user can load these into the TFA tool and proceed with the analysis as usual.