TID nowcasting – MSTIDs

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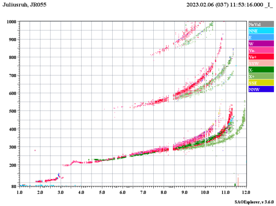
Solar-Terrestrial Centre of Excellence

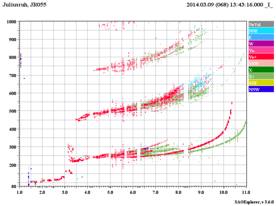
Outline

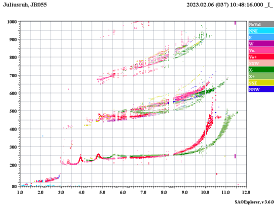
1. Introduction
2. Processing of Doppler sounder data
3. TID detection & characterization
4. Accessing CDSS data in the PITHIA portal

MSTID detection using ionosonde

It is possible to detect MSTIDs in ionograms...





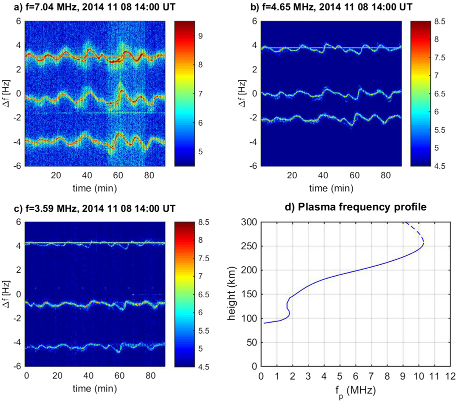


...but:

- on the limit of time resolution,
- no TID characteristics (amplitude, periods,...),
- not automated, not in real time.

Continuous Doppler sounder system (CDSS) observations

Simultaneous Doppler sounding at multiple frequencies (with additional height information from a nearby ionosonde) provide continuous monitoring at high time-resolution.



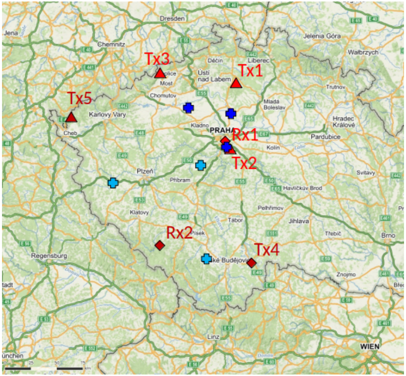
Doppler shift can be affected by many things:

$$\Delta f = -\frac{2f}{c}\int_0^h \frac{\partial \mu}{\partial n_e}\frac{\partial n_e}{\partial t}\,dr$$

Assuming the only relevant process is plasma movement, this is highly simplified:

$$\Delta f = -\frac{2f}{c}v_p$$

CDSS configuration

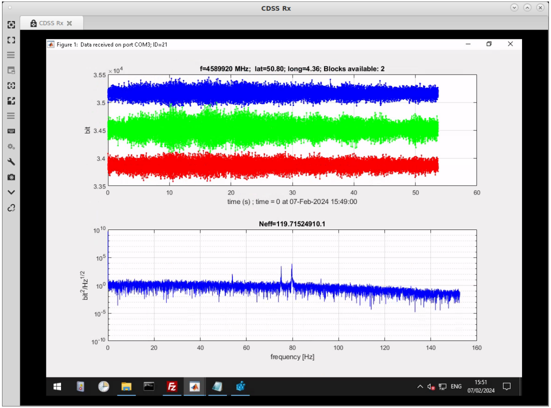


Some important aspects of the CDSS installation:

- Each Tx/Rx combination provides one measurement.
- Multiple Rx's can listen to the same Tx, and multiple Tx's received by the same Rx.
- Measurements are done on oblique paths, from tens to over one hundred km distances.
- Each link uses a slightly different frequency, to allow distinguishing signals.
- Different frequencies can be employed to cover day and night.

CDSS data

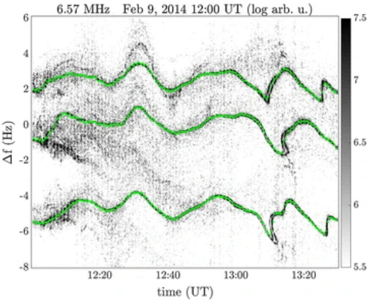
Receiver samples the incoming signal at more than 300 Hz.



The data collected from CDSS instruments are spectrograms.

Maximum spectral density identification

The first step in the analysis is to identify the trace of maximum spectral density for each sounding path.

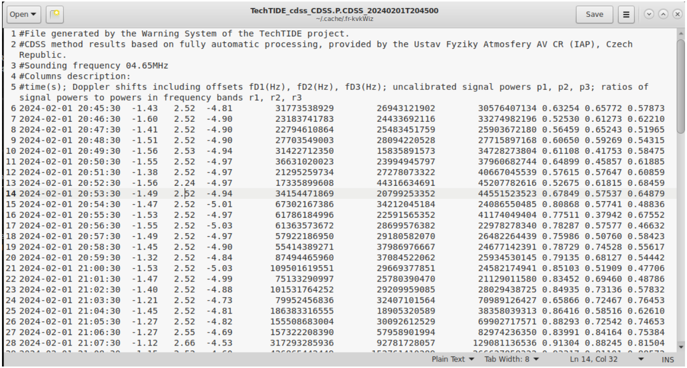


This can be done automatically in real time, although manual correction can occasionally improve results.

See: Fišer *et al.*, 2017, doi:10.1186/s40623-017-0719-y

Time series of Doppler shifts

The result is a time-series of Doppler shifts f_D.

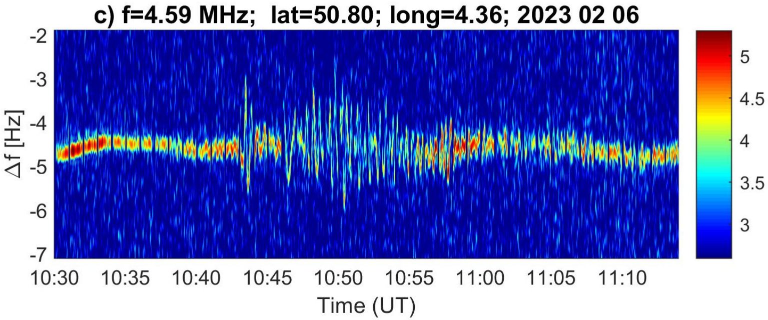



```
#File generated by the Warning System of the TechTIDE project.
#CDSS method results based on fully automatic processing, provided by the Ustav Fyziky Atmosfery AV CR (IAP), Czech
Republic.
#Sounding frequency 04.65MHz
#Columns description:
#time(s); Doppler shifts including offsets fD1(Hz), fD2(Hz), fD3(Hz); uncalibrated signal powers p1, p2, p3; ratios of
signal powers to powers in frequency bands r1, r2, r3
2024-02-01 20:45:30  -1.43    2.52  -4.81        31773538929        26943121902        30576407134 0.63254 0.65772 0.57873
2024-02-01 20:46:30  -1.60    2.52  -4.90        23183741783        24433692116        33274982196 0.52530 0.61273 0.62210
2024-02-01 20:47:30  -1.41    2.52  -4.90        22794610864        25483451759        25903672180 0.56459 0.65243 0.51965
2024-02-01 20:48:30  -1.51    2.52  -4.90        27703549003        28094220528        27715897168 0.60650 0.59269 0.54315
2024-02-01 20:49:30  -1.56    2.53  -4.94        31422712350        15835891573        34728273804 0.61108 0.41753 0.58475
2024-02-01 20:50:30  -1.55    2.52  -4.97        36631020023        23994945797        37960682744 0.64899 0.45857 0.61885
2024-02-01 20:51:30  -1.38    2.52  -4.97        21295259734        27278073322        40667045539 0.57615 0.57647 0.60859
2024-02-01 20:52:30  -1.56    2.24  -4.97        17335899608        44316634691        45207782616 0.52675 0.61815 0.68459
2024-02-01 20:53:30  -1.49    2.52  -4.94        34154471869        20799253352        44551523523 0.67849 0.57537 0.64879
2024-02-01 20:54:30  -1.47    2.52  -5.01        67302167386        34212045184        24086550485 0.80868 0.57741 0.48836
2024-02-01 20:55:30  -1.53    2.52  -4.97        61786184996        22591565352        41174049404 0.77511 0.37942 0.67552
2024-02-01 20:56:30  -1.55    2.52  -5.03        61363573672        28699576382        22978278340 0.78287 0.57577 0.46632
2024-02-01 20:57:30  -1.49    2.52  -4.97        57922186950        29180582070        26482264439 0.75986 0.50760 0.58423
2024-02-01 20:58:30  -1.45    2.52  -4.90        55414389271        37986976667        24677142391 0.78729 0.74528 0.55617
2024-02-01 20:59:30  -1.32    2.52  -4.84        87494465960        37084522062        25934530145 0.79135 0.68127 0.54442
2024-02-01 21:00:30  -1.53    2.52  -5.03       109501619551        29669377851        24582174941 0.85103 0.51909 0.47706
2024-02-01 21:01:30  -1.47    2.52  -4.99        75133290997        25780390470        21129011580 0.83452 0.69460 0.48786
2024-02-01 21:02:30  -1.40    2.52  -4.88       101531764252        29209959085        28029438725 0.84935 0.73136 0.57832
2024-02-01 21:03:30  -1.21    2.52  -4.73        79952456836        32407101564        70989126427 0.65866 0.72467 0.76453
2024-02-01 21:04:30  -1.45    2.52  -4.81       186383316555        18905320589        38358039313 0.86416 0.58516 0.62610
2024-02-01 21:05:30  -1.27    2.52  -4.82       155508683004        30092612529        69902717571 0.88293 0.72542 0.74653
2024-02-01 21:06:30  -1.27    2.55  -4.69       157322208390        57958901994        82974236350 0.83991 0.84164 0.75384
2024-02-01 21:07:30  -1.12    2.66  -4.53       317293285936        92781728057       129081136536 0.91304 0.88245 0.81504
```

(Data is sampled here to one minute resolution.)

What is smaller than a “medium-scale” TID?

CDSS can observe phenomena time-scales much shorter than MSTIDs!



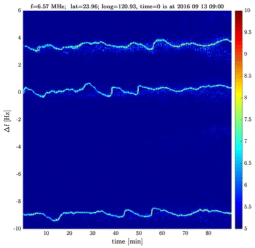
The time series f_D is band-pass filtered to remove variations shorter than 4 or longer than 50 minutes.
The time series is also mean centered.
If data is bad (e.g., low signal to whole-band power), no TID detection is performed.

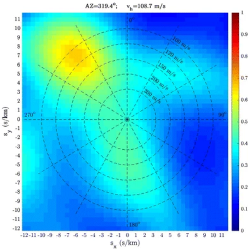
TID detection & characterization

Analysis is done every 15 minutes with a 90 minute sliding window. A TID is considered to be present when the variance $\sigma(f_D)$ is above some empirical threshold.

Propagation velocity and direction (in 2D) are obtained by slowness (reciprocal velocity) search:

$$W(s_x, s_y) = \sum_{t_i} \left(\sum_{Tx} \frac{f_{D,Tx}\left(t_i + s_x \delta x_{Tx} + s_y \delta y_{Tx}\right)}{N} \right)^2$$





Results

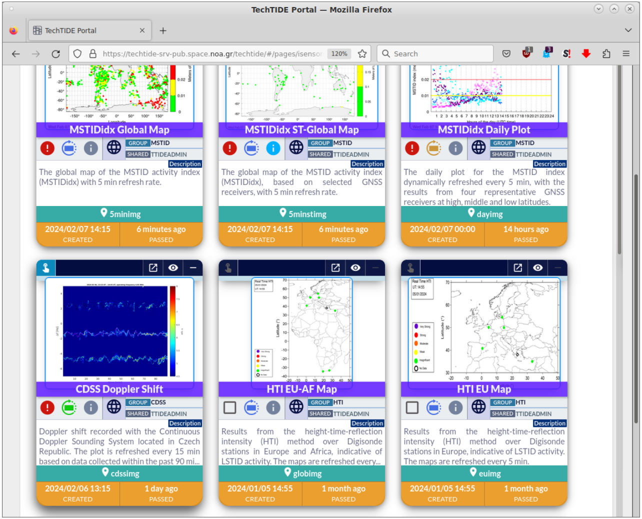
Outputs obtained are horizontal velocity and azimuth of the best fitting TID, the variance of Doppler shifts, and the dominant period of variations (all with estimates of uncertainty).

Remarks:

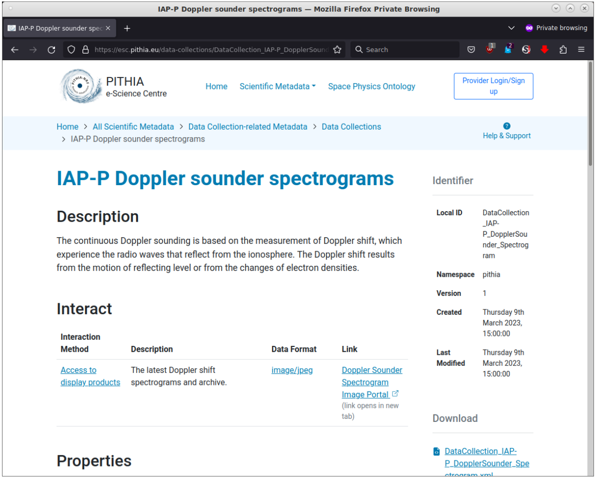
- Some (empirically obtained) minimum for the normalised maximum of $W(s_x, s_y)$ can be used to consider a result reliable.
- There is an assumption that there is only one TID present, constant for the 90 minute analysis window.

Real-time, operation MSTID detection

During the TechTIDE project (2017–2021) MSTID detection from CDSS data was brought into real-time operation, and the relevant code made open source. However: currently only working for the Czech data.

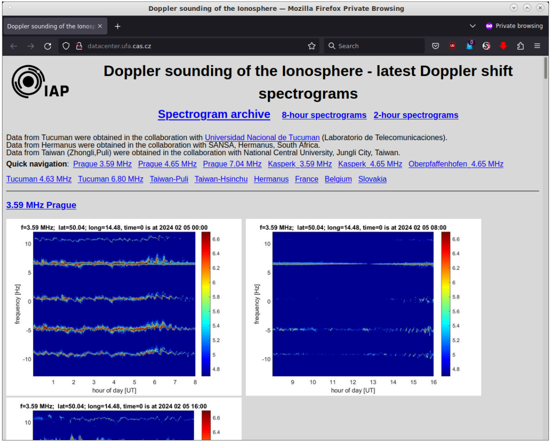


Finding CDSS data in the PITHIA portal



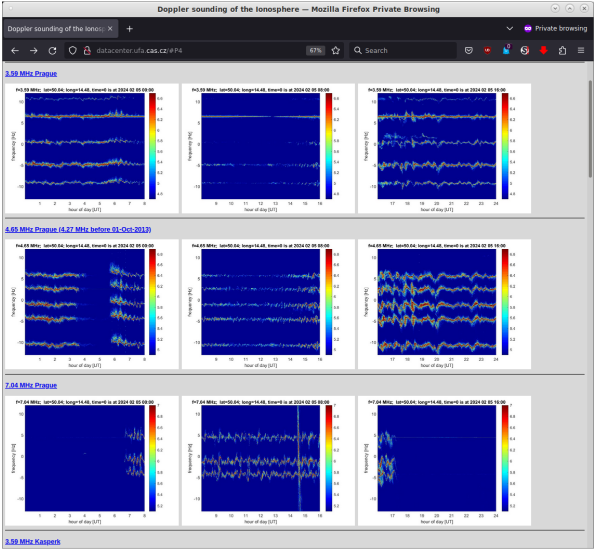
Since we know what we are looking for, we can either browse directly to this data-set or simply search for “Doppler sounder.”

Archive of CDSS spectrograms

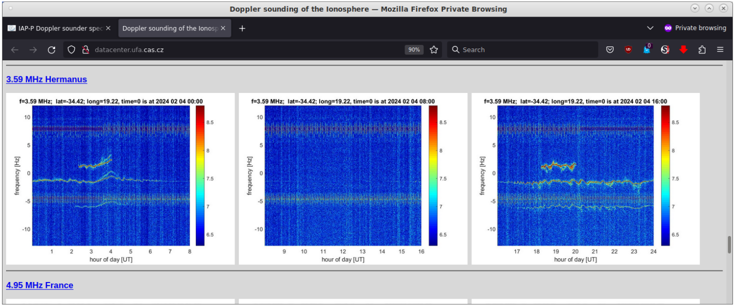


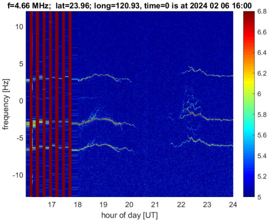
In the archive are all spectrograms from the instruments in Czech Republic, Argentina, Taiwan, South-Africa, France, Belgium, Slovakia, and Germany. The repository contains all spectrograms, but currently only as images.

Example spectrograms



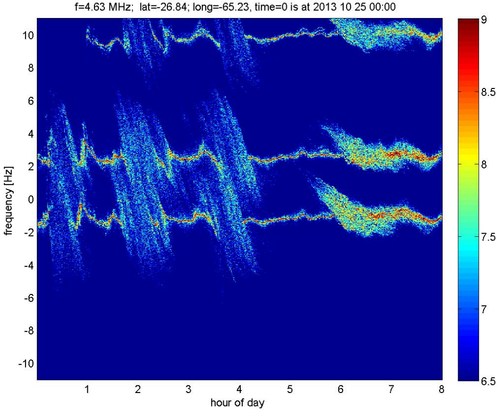
Example spectrograms





Not all data is equally nice...

Example spectrograms



Question

What is going on here? Which country would this be from?

Summary

1. Continuous Doppler sounding systems provide the best data for MSTID detection.
2. Data processing and TID detection can be done in (near) real-time, which good results.
3. Data coverage is very limited, real-time operations currently only for one location.

The end!

Questions?

Starting point for further reading:

J. Chum & K. Podolská (2018): 3D Analysis of GW Propagation in the Ionosphere, *Geophys. Res. Lett.* **45**(21), 11,562–11,571, doi:10.1029/2018GL079695.