Science and engineering of sensing TIDs with Digisondes

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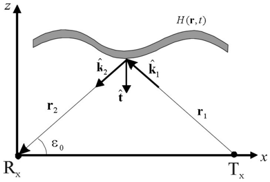
Outline

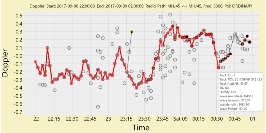
The Tech-TIDE project

- Tech-TIDE is a project funded by the European Commission within the Horizon 2020 framework. Its goal is to develop warning and mitigation techniques for travelling ionospheric disturbances.
- The detection of TIDs is done using eight different methodologies. These are based on observations from either GNSS networks, CDW soundings, or Digisonde soundings.
- In this presentation we focus on one of the Digisonde-based TID detection techniques: the FAS-based HF-TID method. For validation, we will also look at vertical ionograms.

HF-TID method

1. Single frequency digisonde-to-digisonde soundings are performed at fixed intervals.
2. Doppler-shift, angle-of-arrival and range are measured.
3. Clustering and tracking algorithm distinguishes between various propagation modes and interpolates missing data.
4. FAS technique gives the variations in the isodensity contour at the reflection point.
5. Fourier analysis is used to detect TIDs.

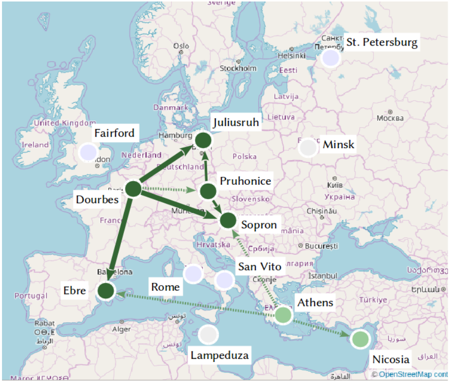




For further details, see: B. Reinisch, I. Galkin, A. Belehaki, *et al.*, *Pilot ionosonde network for identification of travelling ionospheric disturbances*, Radio Science (2018).

The Tech-TIDE Digisonde network

- The Tech-TIDE consortium members operate 6 DPS4Ds in European
- Collaboration with the newly installed DPS4D in Sopron
- Some other ionosondes in Europe from which data could be used
- Additionally, 4 DPS4Ds operate in South-Africa



Main operational challenge:

Scheduling the synchronised soundings at all contributing Digisondes at the same time (timing, frequency selection, etc.).

High temporal cadence operations

Question: how often should ionograms be produced?

- The FAS-based TID detection does not directly use traditional ionograms, but other TID detection methods do. For these methods, a higher temporal resolution is always better.
- The current standard is to have ionograms at five minute intervals. This requires some careful programming of the Digisonde to make the ionogram program short enough.
- For the FAS-based technique it is required to have at least some of the ionograms on each operating link synchronised in order to obtain oblique traces.
- Possibly sounding at 2.5 minute intervals in the future?

D2D single frequency soundings

The operations for the single frequency, Digisonde-to-Digisonde soundings—needed for the FAS-based TID detection—are much more complicated.

The big questions:

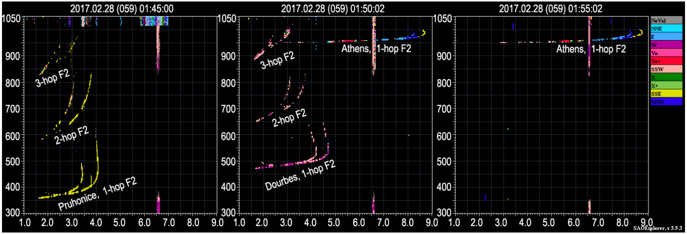
What frequency to use for each D2D link?
How to schedule D2D soundings?

This depends on several parameters:

1. Network geometry: length (and direction) of the links
2. Network topology: which stations are listening to which transmissions?
3. Time of day and season
4. Possibly also geomagnetic conditions

Frequency selection

It is clear that the same frequency can not be used on links with different lengths, so multiple receivers at widely different distances can not listen to the same transmitter simultaneously.

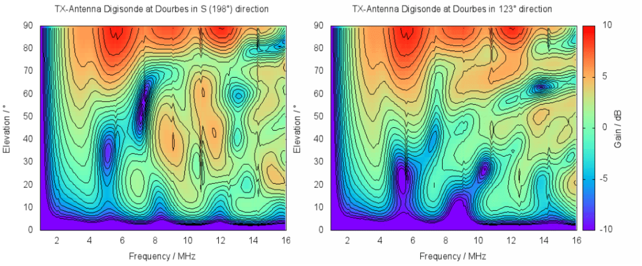


Conclusion

A fixed sounding frequency can be chosen based on oblique ionogram traces

Frequency selection

Additionally, Tx gain at low elevation angles is dependent on the azimuth (because the Tx antennas are optimised for vertical transmission).

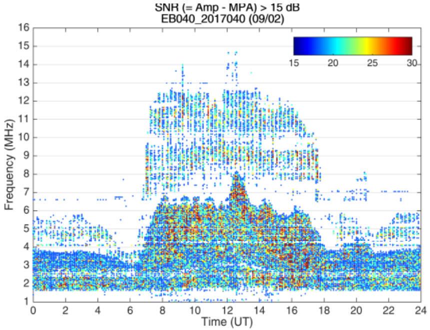


Conclusion

Selection of frequencies has to be done on each individual link, even if the length is the same

This becomes more complicated when multiple receivers have to listen to the same transmitter.

Diurnal variation in sounding frequencies



For any D2D link, a frequency can be chosen by inspecting the SNR plot of oblique ionogram traces.

Problem: no single frequency is usable throughout the day.

The FAS technique requires as few frequency changes as possible. Currently we operate with two frequencies on each link: one for day-time and one for night-time.

Conclusion

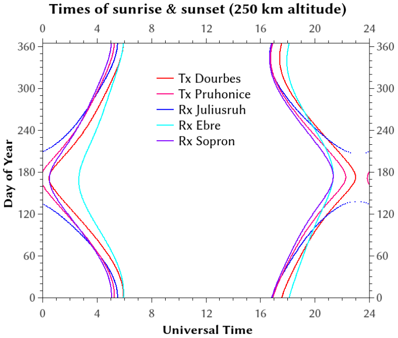
Day and night frequencies selected based on oblique ionogram SNR

Seasonal variations in scheduling

Different day- and night-time frequencies implies seasonal changes to the day/night switch times.

Problem: sunrise and sunset can vary significantly over a single link

It is the condition of the ionosphere at the reflection point that is important. When multiple links are operating together, a compromise must be found.



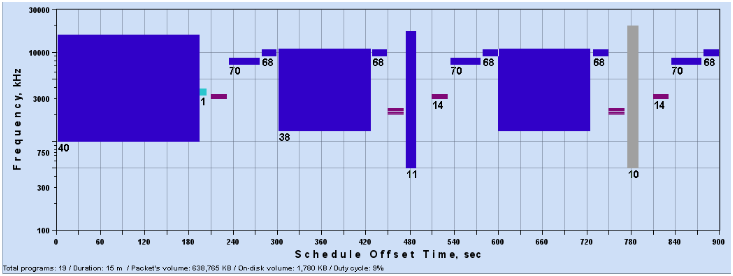
Conclusion

Seasonal changes in day-night times have to be adapted manually

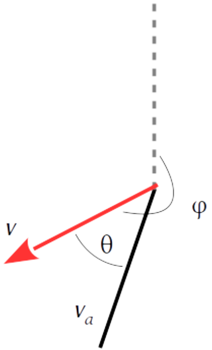
Possibly also adapt frequencies to disturbed ionospheric conditions.

Cadence of D2D soundings

- Due to the way the FAS technique is currently implemented, only soundings at fixed intervals are useful.
- These should be done with a cadence of at most five minutes; this cadence determines the Nyquist frequency of the FAS Fourier transforms.
- Thanks to recent hardware upgrades, we could shorten the D2D sounding duration to 20 seconds, allowing to decrease the sounding interval to 2.5 minutes.



Sanity checking the FAS result



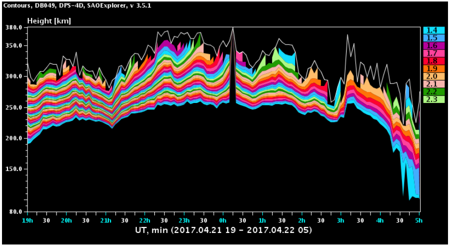
FAS has been in operation detecting TIDs in real time for a few years now. By looking at the vertical ionograms at the end-points of a D2D link, we can verify the results.

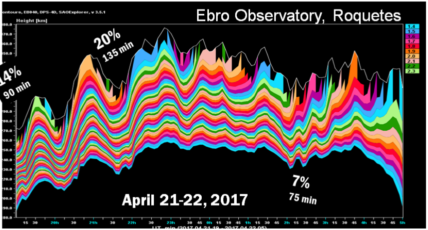
1. Determine the delay ΔT between the TID signature in the VI at both stations.
2. From this, calculate the apparent velocity v_a (link length is fixed and known).
3. Assuming the FAS azimuth φ is correct, calculate the true velocity $v = v_a \cos\theta$.
4. Assuming the FAS velocity v is correct, calculate $\theta = \arccos \frac{v}{v_a}$ and from that calculate the azimuth φ.

The so calculated v and φ can then be compared to the values given by FAS.

21–22 April 2017 TID event

At 19:48 UT on the Dourbes–Roquetes link, a strong TID (15.45% amplitude) was detected with $\lambda = 2465$km, $P = 100$min., $\varphi = 246.9°$.





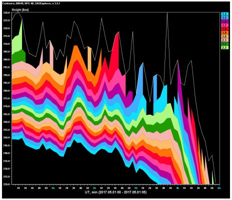
From the true height contour plots, the minima of the waves can de determined at 21:10 UT in Dourbes and 21:35 UT in Roquetes. The link length is 1082 km, so the velocity would be $v_a = 721$ m/s if the TID travelled along the link.

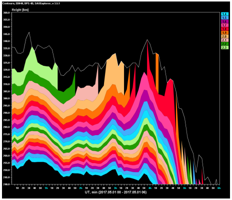
1. Assuming $v = 410$ m/s is correct, then $\theta = 55.34°$ and $\varphi = 254.02°$
2. Assuming $\varphi = 246.9°$ is correct, then $\theta = 48.22°$, and $v = 480$ m/s.

This is a rather good agreement, keeping in mind that the time resolution for determining the minimum at each station is five minutes.

2017-05-01 TID event

FAS detected a moderate TID (11.4% amplitude) around 02:00 UT in the data from the DB049–EB040 link. This was a slow TID, with $\lambda = 780$km, $P = 75$min, and $\varphi = 327.4^\circ$, and thus $v = 173$m/s.





Minimum in Dourbes at 02:00 UT, in Roquetes at 03:15 UT. So, $\Delta T = 75$min, $v_a = 240$m/s.

1. Assuming $\varphi = 327.4^\circ$ is correct, $\theta = 128.7^\circ$ and $v = v_a \cos\theta = 150$ m/s.
2. Assuming $v = 173$m/s is correct, $\theta = \arccos \frac{v}{v_a} = 44^\circ$ and $\varphi = 335^\circ$

Again, the results are consistent.

Conclusions

1. Configuring synchronised soundings between multiple Digisondes is possible, but requires some careful attention at each observatory.
2. D2D soundings at 2.5 minute intervals are possible (with some hardware upgrades), but the scheduling on a complex network of stations is not trivial.
3. Once all these operational problems are solved, the FAS technique does indeed work! The main limitation is the sounding cadence.

References:

- T. Verhulst, D. Altadill *et al.* (2017) *Vertical and oblique HF sounding with a network of synchronized ionosondes*, Adv. Space Res. **60**(8), 1644–1656.
- B. Reinisch, I. Galkin *et al.* (2019) *Pilot ionosonde network for identification of travelling ionospheric disturbances*, Radio Sci. **53**, RS006263.

Details about Tech-TIDE at www.tech-tide.eu

The end, thank you!