Minutes of Meeting - Milestone Meeting #2

21.10.2019 - ESRIN, ESA, Frascati

CCN2 - Swarm4Anom

Attendees:

[AS] - Anja Stromme (ESA)
[RH] - Roger Haagmans (ESA)
[FC] - Filomena Catapano (ESA)
[EQ] - Enkelejda Qamili (ESA)
[LT] - Lorenzo Trenchi (ESA)
[JB] - Jan Błęcki (CBK)
[JM] - Janusz Młynarczyk (AGH)
[ES] - Ewa Słomińska (OBSEE)
[MS] - Marek Strumik (CBK)

Prepared by:	**E. Slominska**
Approved by:	
Jan Błęcki (CBK) **Janusz Młynarczyk (AGH)**	Jan Błęcki Janusz Młynarczyk
Roger Haagmans (ESA)	

Agenda:

Part I - Swarm4Anom - Swarm I_NDD product for Ionospheric Anomalies
Ewa Slominska, OBSEE

Normalized density difference index - from the concept to main findings
- Status of the product,
- main scientific results
- applicability of the index to the equatorial ionosphere
Marek Strumik, CBK

TIEGCM modeling and 3D visualizations as tools for interpretation of Swarm (and other satellite) measurements

Discussion

Part II - Swarm for TLEs (Transient Luminous Events)
11:30- 12:15 (Ewa Slominska, OBSEE)
Capabilities of the Swarm magnetometers to detect events related to lightning activity:
- Approach to the problem, main goals and review of selected results
- Synergies with other satellite mission.
12:15 - 12:50 (Marek Strumik, CBK)
Swarm measurements and lightning activity: minimum variance and inter-satellite cross-correlation analysis

Lunch

14:00 - 14:45 (Janusz Mlynarczyk, AGH)
Searching for correlations between magnetic field variation on Swarm and atmospheric discharges observed by ELF ground stations
14:45 - 15:15 (Jan Blecki, CBK)
Remarks on the "whistler" type waves registered in space.

Report #1: ES reviewed the main concept of the Swarm index product. ES reported that the data product stored on the CBK servers is upgraded on a regular basis, since the beginning of the mission.
The link to the product is:
http://swarm4anom.cbk.waw.pl/s4a/prodcdf/

Report #2: ES reported that results obtained from the modeling studies focused on the impact of the geomagnetic field secular variation and its impact on the spatial pattern of the Weddell Sea Anomaly has been submitted to Journal of Geophysical Research - Space Physics. The manuscript "Analysis of the impact of long-term changes in the geomagnetic field on the spatial pattern of the Weddell Sea Anomaly" has been assigned the manuscript #2019JA027528 and is under revision. Draft of the manuscript is attached as one of MS deliverables.

Report #3: ES reported that detailed analysis of Swarm response to the decreasing phase of the solar cycle is still under preparation. RH pointed out, that analysis should also include the seasonal dependence of the index.

Report #4: MS presented vast range of results from numerical simulations based on the NCAR TIEGCM model. Presentations included discussion of key mechanisms responsible for the formation of the WSA. MS reported that in order to give a more accurate representation of physical conditions, in future simulations, TIEGCM should be fed with real data reflecting solar and magnetic conditions, instead of stand-alone runs based on fixed parameters.

Report #5: AS suggested to start closer cooperation with the TIEGCM NCAR team, for potential further improvements of physical description of the WSA anomaly, and other linked phenomena.

Report #6: AS, RH, LT agreed that simulation presented by MS, should be used presentations promoting the Swarm mission and its capabilities.

Report #7: ES presented improved approach to analysis of fluctuations in Swarm MAG VFM 50 Hz data possibly triggered by strong lightning discharges. Several examples of cross-analysis with GLM data from the GEOS-R satellite were presented. Selected cases provide a critical set of examples showing the response of Swarm`s magnetometers to strong discharges.

Action #1: RH stated that, for publication purposes, synchronization between Swarm and GLM time-series has to be improved in order to assess more convincing representation of results.

Report #8: LT pointed that VFM data is very noisy, thus it is recommended to expand analysis with ASM burst data, when available. ES showed that such attempt has been made and obtained results suggest that despite lower resolution 50 Hz MAG VFM data show very good agreement with 250 Hz ASM readings.

Report #9: EQ reported that full set of the 250 Hz ASM data should be available in two weeks time.

Report #10: MS presented detailed analysis of wave properties for selected cases in the American sector using minimum variance approach. Applied method suggests that due to emissions triggered by TLEs, two main classes of effects can be observed by Swarm - waves propagating directly from the ground to the satellite, and those which were reflected and amplified in the IAR.

Report #11: LT suggested that maybe it is worth to supplement analysis with the 16 Hz TII ion outflows gathered by the TII instrument, and see if additional information can be derived from other data provided by Swarm.

Action #2: Based on informal communication with the ASIM team, AS informed that data from ASIM should be available by November. AS and RH pointed out that additional work on cross-correlation between ASIM and Swarm is of interest for the project and both missions.

Report #12: JM provided confirmation with ground-based data from the WERA system, showing that for a series of selected cases there is agreement between Swarm and ULF data proving that Swarm is able to detect signatures of TLEs.

Report #13: JB gave the review of types of plasma waves and stated that observed on Swarm whistler-type emissions, should be properly called ion cyclotron waves.

Deliverables scheduled for the MS2:

1. Draft of publication submitted to JGR:

"Analysis of the impact of long-term changes in the geomagnetic field on the spatial pattern of the Weddell Sea Anomaly" - manuscript #2019JA027528

2. *Database of Swarm and TLEs used for verification with ground-based observations*

http://swarm4anom.cbk.waw.pl/gauss/**YYYYMM/**

Selection of cases is stored in a QuickLook form of images showing following types:

- Synthetic gauss function, fit to data samples: "*_f.png"- file ending: extended name of the file (after the Mod- prefix) denotes time and location of detected spikes, and amplitudes: T0 = 153416, lon0 = 74.6, lat0 = 34.1

SW_OPER_MAGA_HR_1B_????????T000000_????????T235959_0505_20181101_000000_20181101_235959_Mod6.012_153416_74.6_34.1_-0.16_0.21_f.png

- Gobal distribution of detected spikes: in "ascending" and "descending" passes. Files with ending **"_a.png"** denote all detected spikes, while with **"_g.png"** limit cases to those meeting criteria of lightning occurrence.

  Selected piece of data with detected event, with time-series representing magnetic field spectrum and plasma properties in the time frame around observed peak.

  SpectrumPlasma-SwA-????-F-????????T??????_????????T??????_011636w.png

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Presentations and materials from the MS meeting are stored in the directory:

http://swarm4anom.cbk.waw.pl/CCN2/**MS2/**

Conclusions: All deliverables which were due to MS2 were provided. They are acceptable in the current state. Study team accepts that revision to the document may be done at the request by ESA at a later stage. MS2 review was successfully completed and the corresponding invoices can be submitted

Normalized density difference index - from the concept to main findings

OBSEE & CBK

MS2
ESRIN

October 21, 2019

Agenda

Swarm4Anom

I - dedicated to macro-scale features (Cont. of the previous studies) in the Earth's ionosphere and long-term analysis (CBK/ OBSEE)

II - dedicated to small scale perturbations originating from thunderstorm activity (AGH/ CBK/ OBSEE)

PART I - Swarm4Anom - Swarm I_{NDD} product for Ionospheric Anomalies

1. (Ewa Slominska, OBSEE) **Normalized density difference index - from the concept to main findings**
   - Status of the product,
   - main scientific results
   - applicability of the index to the equatorial ionosphere
2. (Marek Strumik, CBK) **TIEGCM modeling and 3D visualizations as tools for interpretation of Swarm (and other satellite) measurements**

Agenda - Part II

Part II - Swarm for TLEs (Transient Luminous Events)

1. **Capabilities of the Swarm magnetometers to detect events related to lightning activity**
   - Approach to the problem, main goals and review of selected results
   - Synergies with other satellite mission.
2. Swarm measurements and lightning activity: minimum variance and inter-satellite cross-correlation analysis (Marek Strumik, CBK)
3. Searching for correlations between magnetic field variation on Swarm and atmospheric discharges observed by ELF ground stations (Janusz Mlynarczyk, AGH)
4. Remarks on the "whistler" type waves registered in space (Jan Blecki, CBK)

I_{NDD} - Normalized density difference index - the idea behind and purpose of the study

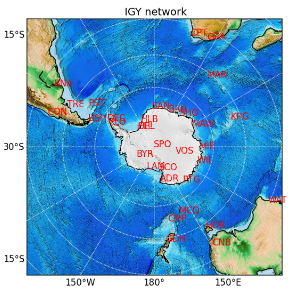
Swarm+Innovations: **Swarm4Anom**alies with main goals:

- to provide better representation of the Weddell Sea Anomaly (WSA) (multi-point observations, multi-instrumental observations, different altitudes),
- to expand analysis to more general phenomenon of a mid-latitude nighttime summer anomaly and nighttime density enhancements,
- to gain better understanding of the phenomena.
- to provide long-term representation of changes in the spatial morphology of the reversed ionospheric diurnal cycle

http://swarm4anom.cbk.waw.pl/s4a/prodcdf/

The Weddell Sea Anomaly (WSA) in brief

- The peculiar feature of the ionosphere in the vicinity of the Antarctic Peninsula, the Weddell Sea and the Bellingshausen Sea, was discovered in the late the 50's during the International Geophysical Polar Year (1957).
- Analysis from data of the $F2$ layer over Antarctica showed that, the regions of the Antarctic Peninsula and the Weddell Sea have an anomalous pattern in f_0F2.
- During the summer, the f_0F2 varies in such a way that the daily peak occurs at a local night and the daily minimum at local daytime. During the winter the f_0F2 shows a typical mid-latitude diurnal behaviour, when the maximum occurs at local noon and the minimum at a local night.



Identification of the WSA and NPDEs

Normalized density difference index - I_{NDD}

$$I_{NDD}(\lambda,\theta) = \frac{N_e^{night}(\lambda,\theta,@LT) - N_e^{day}(\lambda,\theta,@LT+12h)}{N_e^{night}(\lambda,\theta,@LT) + N_e^{day}(\lambda,\theta,@LT+12h)}.$$

- I_{NDD} index which estimates the values of normalized electron density difference
- relies on separation between measurements taken on ascending and descending passes (12-hour difference needed to capture diurnal variations)
- I_{NDD} varies in the range [-1:1];
- LT-frame representation, for WSA LT: (22:00-02:00)
- in the first approach $I_{NDD} > 0$ indicates regions with anomalous characteristics.

TIEGCM modeling and 3D visualizations as tools for interpretation of Swarm (and other satellite) measurements

CBK & OBSEE

TIEGCM MODEL

Physics-based global model of the ionosphere: 100-700 km (boundaries depend on atmosphere dynamics and solar-wind state or solar-cycle phase)

Inner boundary: atmospheric tides, GSWM model

Sun/solar-wind influence: solar irradiance and magnetosphere state as dependent on solar-cycle phase
- F107 (radio emissions correlated with ionizing UV emissions)
- CTPOTEN (cross-tail potential)
- POWER (hemispheric power, auroral precipitation)

TIEGCM AUTHORS SUGGEST:

	F107	CTPOTEN	POWER
SMIN	70	30	18
SMAX	200	60	40

BENCHMARK CASES

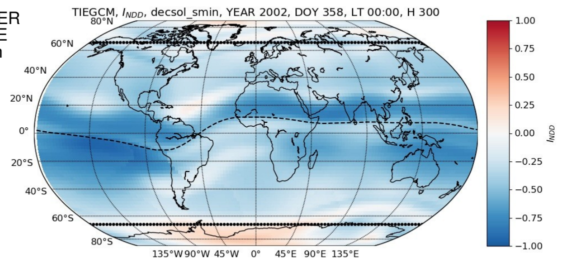
TIEGCM simulations
Study focused on $I_{NDD}=(NE_t-NE_{t-12h})/(NE_t+NE_{t-12h})$

Four seasons: March equinox, June solstice, September equinox, December solstice
Two sets of solar conditions: solar min and max

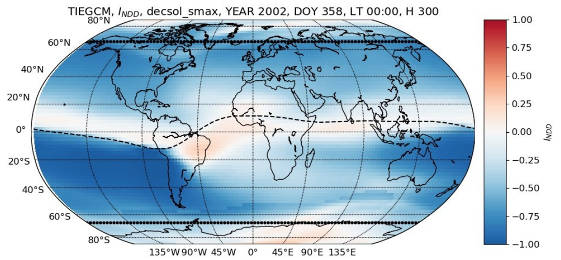
TIEGCM-benchmark cases are treated as sanctity: no change of parameters with respect to values recommended by code authors for simulated cases

DECEMBER SOLSTICE
H=300 km

SMIN

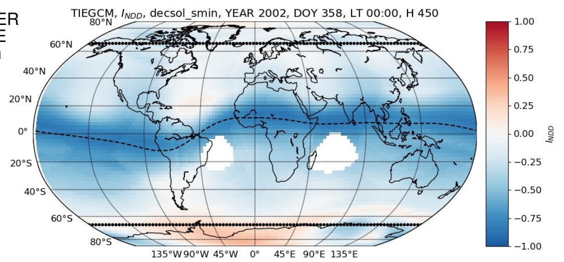


SMAX

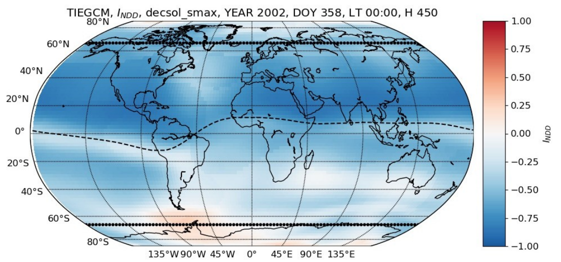


DECEMBER SOLSTICE
H=450 km

SMIN

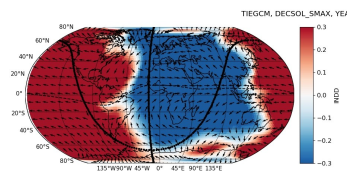


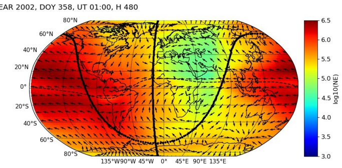
SMAX



In solar max, nicely-formed Weddell Sea anomaly for H>420 km

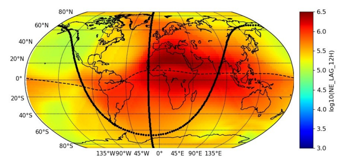
Constant-UT maps





$I_{NDD}=(NE_t-NE_{t-12h})/(NE_t+NE_{t-12h})$

General pattern:
dayside $I_{NDD}>0$
nightside $I_{NDD}<0$
with some lag effects in post-dawn and post-dusk regions



Capabilities of the Swarm magnetometers to detect events related to lightning activity

AGH & CBK & OBSEE

MS2
ESRIN

October 21, 2019

Agenda

Swarm for TLEs (Transient Luminous Events)

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- Swarm measurements and lightning activity: minimum variance and inter-satellite cross-correlation analysis (Marek Strumik, CBK)
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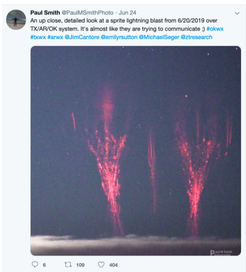
- Remarks on the "whistler" type waves registered in space (Jan Blecki, CBK)

Scope of the study

- Registrations from Swarm ASM Burst mode data (250 Hz) proved to be effective in detection signatures of lightning
- **Is is possible to detect with Swarm magnetometers, signals related to such lightning discharges that are accompanied by strong luminous events (Transient Luminous Events - TLEs)?**
- Believed to be rather rare - High-speed cameras many evidences provided on regular basis

Plenty of daily updates with Jets:



https://twitter.com/paulmsmithphoto

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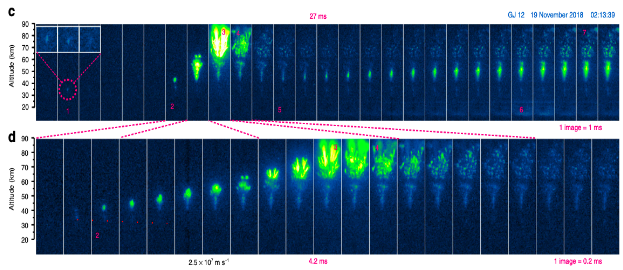
Problem of interest

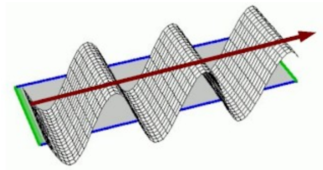


Gigantic jet discharges evolve stepwise through the middle atmosphere -`https://doi.org/10.1038/s41467-019-12261-y`

Swarm measurements and lightning activity: minimum variance and inter-satellite cross-correlation analysis

CBK, OBSEE & AGH

Minimum variance analysis



Plane wave in the magnetic field

$$\mathbf{k} = (k_x, 0, 0) \quad \frac{\partial}{\partial y} = \frac{\partial}{\partial z} = 0$$

$$\nabla \cdot \mathbf{B} = 0 \quad \Rightarrow \quad \frac{\partial B_x}{\partial x} = 0$$

$$-\nabla \times \mathbf{E} = \frac{\partial \mathbf{B}}{\partial t} \quad \Rightarrow \quad \frac{\partial B_x}{\partial t} = 0$$

These idealized conditions can be translated to

$$\sigma^2_{B_x} \ll \max(\sigma^2_{B_y}, \sigma^2_{B_z})$$

for time series obtained from satellite measurements

Minimum variance analysis

The problem is that the frame for our dataset is usually not co-aligned with the wave frame i.e.

$$\mathbf{k} = (k_x, k_y, k_z)$$

But for a time series of measurements of the magnetic field components we can construct the covariance matrix

$$\mathrm{M}_{i,j} = \langle B_i B_j \rangle - \langle B_i \rangle \langle B_j \rangle$$

which is symmetric.

Thus solving eigenproblem for the covariance matrix

$$\mathrm{M}_{i,j} v_j = \lambda v_i$$

we get real eigenvalues and othogonal eigenvectors.

Minimum, intermediate and maximum variance directions can be identified.

Eigenvalues correspond to variances along those directions, i.e.

$$\lambda = \sigma^2$$

What do we get from minimum variance analysis?

The smallest-eigenvalue eigenvector can be interpreted as minimum variance direction. **It gives an estimation of propagation direction for plane waves** (although not the vector direction), which may give us information about wave origin. It is however problematic to interpret if we deal with propagation in nonhomogeneous medium.

Indication whether the plane wave model applies to our dataset

$$\lambda_1 \ll \max(\lambda_2, \lambda_3)$$

From minimum variance vectors we can construct a new orthonormal vector base. If we rotate our time series to the minimum variance frame (i.e. wave frame), we can plot a hodograph from B_2,B_3 components and study wave polarization.

This analysis method is universal, it can be applied to both harmonic waves and isolated structures, although we need to be careful with choosing properly time span for the analysis.

Interpretation of results

By solving the eigenproblem for the covariance matrix

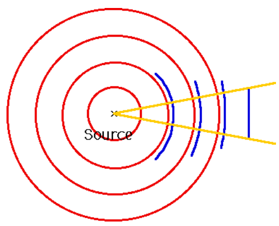
$$\mathrm{M}_{i,j} v_j = \lambda v_i \qquad \lambda = \sigma^2$$

We can get the following generic cases:

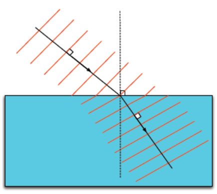
$\lambda_1 \ll \lambda_2 \ll \lambda_3$	Well separated eigenvalues, e.g. elliptically polarized wave
$\lambda_1 \ll \lambda_2 \approx \lambda_3$	Well separated smallest eigenvalue, e.g. circularly polarized wave
$\lambda_1 \approx \lambda_2 \ll \lambda_3$	Well separated largest eigenvalue, linearly polarized wave
$\lambda_1 \approx \lambda_2 \approx \lambda_3$	No minimum variance direction, plane-wave model does not apply

Comments on the wave-propagation direction

Spherical wave front can be locally approximated as plane wave



Non-homogeneous background for wave propagation (e.g. density or magnetic field gradients) can change the normal direction of a wave front



Searching for correlations between magnetic field variation on Swarm and atmospheric discharges observed by ELF ground stations

Janusz Mlynarczyk[1], Andrzej Kulak[1], Karol Martynski[1], Martin Popek[4], Ewa Slominska[2], Jan Blecki[3], Jan Slominski[3], Roman Wronowski[3], Marek Strumik[3]

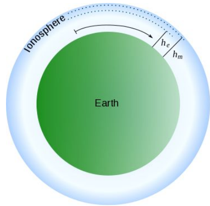
[1]Department of Electronics, AGH University of Science and Technology, Krakow
[2]OBSEE, Warszawa
[3]Space Research Centre PAS, Warszawa
[4]Institute of Atmospheric Physics CAS, Prague, Czechia

Source of ground-based ELF data

The data is provided by our system called World ELF Radiolocation Array (WERA), which consists of three ELF stations:

1. The Hylaty station in Poland (installed in 2005, upgraded in 2013)
2. The Hugo station in Colorado, USA (installed in 2015)
3. The Patagonia station in southern Patagonia, Argentina (installed on March 26, 2016)

-> Use of three stations on different continents allows us to measure strong atmospheric discharges occurring anywhere on Earth.



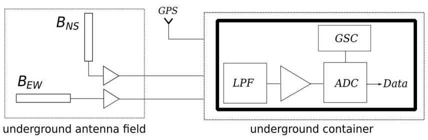
unimodal up to ~1.5kHz
very small attenuation rate

- Each station is equipped with a broadband magnetometer, composed of a receiver and two magnetic antennas
- The stations are fully automated and perform continuous recording

Ground-based measurements in the ELF range

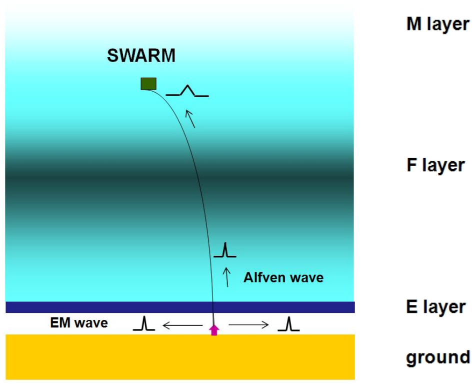
- Two magnetic antennas, NS and EW, and an ELF receiver,
- A remote area with low power line noise, and low noise in the lowest part of the spectrum (f<1 Hz)

Parameters of the WERA system
- frequency range 0.03 - 300 Hz
- sampling frequency 887 Hz
- sensitivity 0.04 pT/sqrt(Hz) at 10 Hz
- battery powered



Installaton of the Hugo ELF station in Colorado, USA, in May 2015

Wave phenomena associated with an atmospheric discharge



Model of Alfven wave generation by an atmospheric discharge

The waves are generated due to discontinuity of the parameters at the border of the atmosphere and the ionospheric E layer

The efficiency of the atmosphere-ionosphere wave coupling is determined by Hall and Pedersen conductivities at the altitude of E layer.

The existing models are based on full-wave solution of a set of equations describing the electromagnetic fields in the atmosphere and the field of magnetosonic and Alfven waves in the ionosphere $B_{\phi}(z,\rho,t)$

The model predicts the impulse amplitude of Alfven wave based on the charge moment of the discharge *p* [C m]

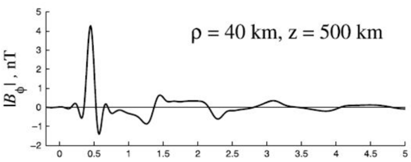
Due to non-uniformity of F layer (steep gradient of electron concentration at the altitudes of the order of 500 km), some portion of energy reflects back. The mechanism of penetration of the ionosphere-magnetosphere boundary strongly depends on frequency (the wave-reflection ratio reaches 0.9). Waves that return to E layer are reflected almost completely. Multiple reflections between the boundary regions lead to ionospheric Alfvena wave resonance (IAR). It can be observed at the frequencies up to a few Hz.

References

Surkov et al., 2005 – model based on a simplified layered ionosphere
Plyasov et al., 2012 – analytical model – layered ionosphere
Mazur et al., 2018 – generalization – full numerical model that uses IRI

Predictions of the model for mid lattitudes based on Mazur et al. 2018

1 – an atmospheric discharge generates the first impulse of Alfven wave



2 – the delay of the impulse is about 0.45 s

3 – the following waveform results from the waves reflected in the Ionospheric Alfven Resonator

4 – field distribution inside the magnetic tube is proportional to the $exp(r/r_c)$ where r_c is the radius of the tube

5 – the radius of the tube depends on the wavelength of Alfven wave.

6 – during the night the radius of the tube it is about 3 times longer than during the day (at 10 Hz ~100 km and ~30 km, respectively)

Remarks on the whistler type waves registered in space

Jan Błęcki,
Space Research Centre PAS Warsaw

Atmospheric whistlers

„The whistler mode is a cold plasma wave mode with an upper cutoff frequency at the plasma frequency (f_{pe}) or cyclotron frequency (f_{ce}), whichever is lower.
Waves propagating in whistler mode (W-mode) are found in all regions of the Earth's magnetosphere. They are also found in the magnetospheres of other planets. These waves may originate in sources residing outside the magnetosphere, such as lighting or VLF transmitters, or they may originate within the magnetosphere as a result of resonant wave-particle interactions.
W-mode waves have been detected on every spacecraft carrying a plasma wave receiver and at numerous ground stations."

V.S. Sonwalkar

Atmospheric whistlers

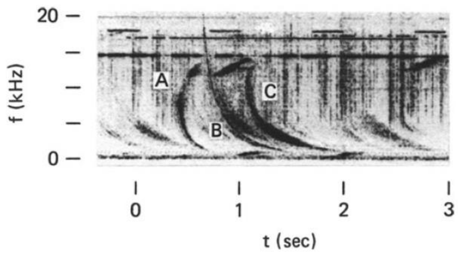
Ionospheric whistlers were discovered during World War I while German radio monitors were trying to intercept Allied radio transmissions [Barkhausen 1919]. Without narrow band tuners, the whistlers occurred as declining tones in the audio band. They were later traced to lightning and propagation in the ionosphere and the magnetosphere [Barkhause 1930].

It occurs in frequency range:

$$\omega_{ci} \ll \omega \ll \omega_{ce} \sim \omega_{pe},$$

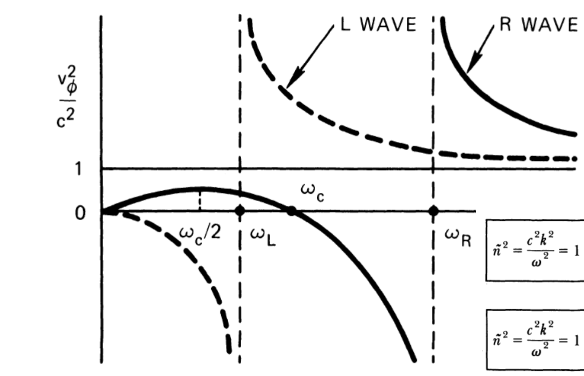
so we are above the lower hybrid resonance but well below the electron cyclotron resonance.

Atmospheric whistlers



Actual spectrograms of whistler signals, showing the curvature caused by the low-frequency branch of the *R*-wave dispersion relation (Fig. 4-39). At each time *t*, the receiver rapidly scans the frequency range between 0 and 20 kHz, tracing a vertical line. The recorder makes a spot whose darkness is proportional to the intensity of the signal at each frequency. The downward motion of the dark spot with time then indicates a descending glide tone. [Courtesy of D. L. Carpenter, *J. Geophys. Res.* **71**, 693 (1966).]

Atmospheric whistlers



$$\tilde{n}^2 = \frac{c^2k^2}{\omega^2} = 1 - \frac{\omega_p^2/\omega^2}{1-(\omega_c/\omega)} \quad \text{(R wave}$$

$$\tilde{n}^2 = \frac{c^2k^2}{\omega^2} = 1 - \frac{\omega_p^2/\omega^2}{1+(\omega_c/\omega)} \quad \text{(L wave}$$

The v_ϕ^2/c^2 vs. ω diagrams for the *L* and *R* waves. The regions of nonpropagation ($v_\phi^2/c^2 < 0$) have not been shaded, since they are different for the two waves.

Francis F. Chen

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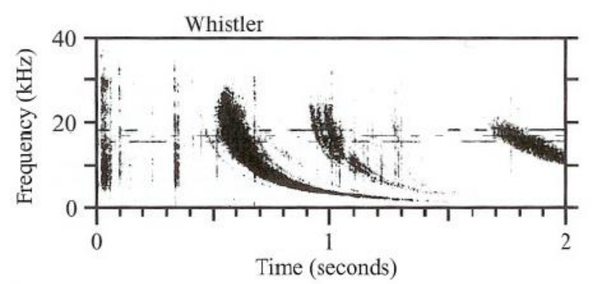

$$n^2 = \frac{\omega_p^2}{\omega(\omega_c - \omega)}$$