Lightning on different spatial scales from extremely low frequency electromagnetic field measurements

Z. Nieckarz [1], A. Kułak [2,3], J. Kubisz [2], A. Michalec [2], S. Zięba [2], M. Ostrowski [2], J. Młynarczyk [3]

1 - Institute of Physics, Jagiellonian University, Kraków, Poland
2 - Astronomical Observatory, Jagiellonian University, Kraków, Poland
3 - AGH University of Science and Technology, Department of Electronics, Kraków, Poland

Email: zenon.nieckarz@uj.edu.pl

22nd Cartographic School, Geoinformatics and Atmospheric Science, 6-9 May 2014, Walbrzych-Książ, Poland

Plan of presentation

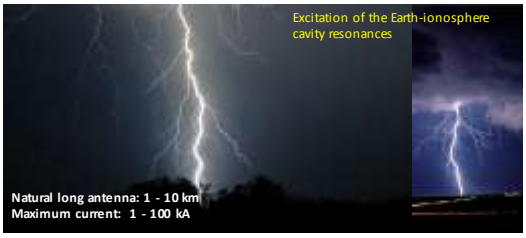
1. Connection between thunderstorms and lightning
2. The measurements of the ELF waves
3. Power spectrum of electromagnetic waves
4. Earth–ionosphere cavity and Schumann Resonance (SR)
5. Indexs of global continental activity (I_{RS})
6. Analysis of the ELF impulses
7. Method of the arrival azimuth determination of the ELF impulse
8. Conclusions

Thunderstorm and Lightning

Thunderstorms can occur inside warm, moist air masses and at fronts.

They are always connected with lightning.

Lightnings are sources of wide range of electromagnetic waves.



Scales of observations

Local scale (to few hundreds km) –

all cloud to ground discharges (CG):
individual location of lightning and its intensity;

Regional scale (to few thousands km)-

medium and strong intensity cloud to ground discharges (CG):
individual location of lightning and its intensity;

Global scale (for whole globe) -

only strong intensity cloud to ground discharges (CG):
individual location of lightning and its intensity ,

all discharges : global and continental activity;

„running" waves called ELF impulses

resonance waves called Schumann Resonance

The measurements of the ELF waves

- Where is location our ELF station?
- How we detect these waves?
- What are the components of the station?
- What data are collected?

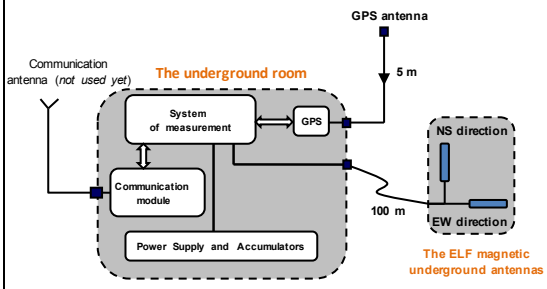
Location of the ELF Hylaty station

The Bieszczady Mountains, the Hylaty stream valley

View entry into the room

Map of location of the ELF Hylaty station

Diagram of the ELF Hylaty station



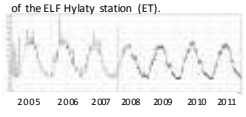
Design, manufacture and installation of stations in the Bieszczady Mountains, Obserwatorium Astronomiczne UJ : dr A. Kułak, inż. J. Kubisz, dr A. Michalec

Basic parameters

Parameters	Value
Location	(22.5 E, 49.1 N) / SE Poland / Europe
Sampling per channel	176 Hz
DAC resolution	16-bit
Type of analog input	Integral (**B** vector)
Band	0.03 Hz – 55 Hz
Anti-aliasing filter	55 Hz
Power supply	DC independent
Memory	Flash Card 32 GB

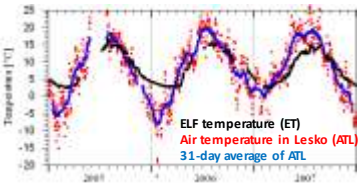
Control of working conditions of the ELF Hylaty station

A graph of the air temperature in the underground room of the ELF Hylaty station (ET).



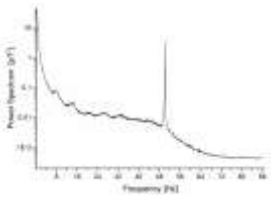
Binary data format (2.5 MB / 1h)

Graph of measured every 5 minutes Hylaty station (black) and the course of the average daily air temperature at the station synoptic Lesko (red). The blue shows the course of the moving average 31-day calculated from measurements of the average daily air temperature at the station synoptic Lesko.

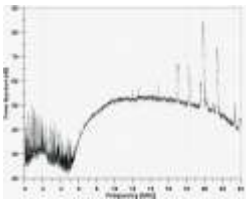


Power Spectrum of Lightning

ELF range



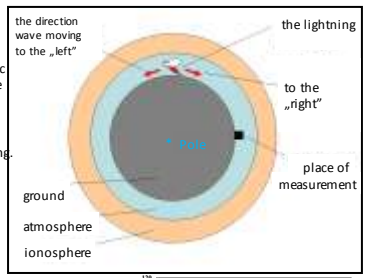
VLF range

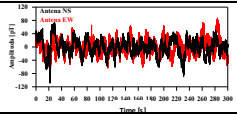


Schumann Resonance (SR)

A simplified diagram of the formation of electromagnetic wave and Schumann Resonance phenomenon.

The waves are emitted isotropically around the lightning.

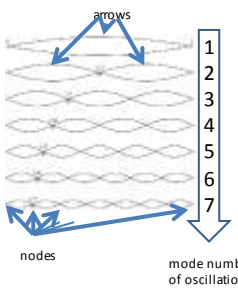




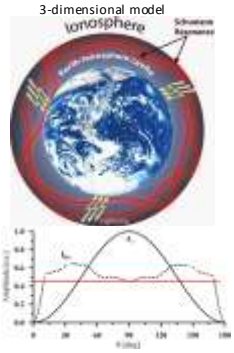
Waveforms recorded at the measuring point (station Hylaty) in two perpendicular magnetic antennas arranged in directions NS i EW (*Date: 4 Oct 2007 Time period from 01:00 to 01:05 UT*)

SR - it can be showed also that

1-dimensional model



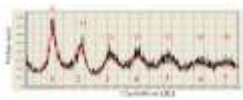
3-dimensional model



I_{RS}^{Global} - indicator of global activity

$$W = noise + \sum_{n=} \frac{A_n \bullet (1 + \varepsilon_n \bullet (f - f_n))}{(f - f_n)^2 + \Gamma^2}$$

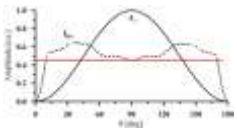
$$I_{RS} = \frac{1}{6} \cdot (A_1 + A_2 + A_3 + A_4 + A_5 + A_6)$$



Example of power spectrum

Each antenna can independently determine the number of I_{RS}^{EW}, I_{RS}^{NS}

$I_{RS}^{Global} = I_{RS}^{EW} + I_{RS}^{NS}$



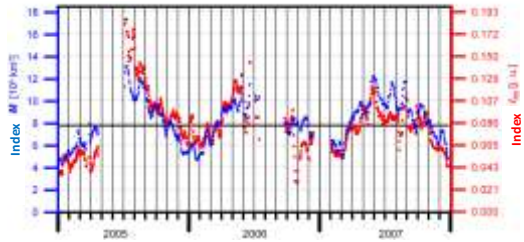
Where: W – power spetrum;
f - frequency ; f_n –frequency of n mode;
Γ_n - full width at half maximum of n mode;
ε_n – asymmetry parameter of n mode;
N – number of observed resonances;

$$I_{RS} = \frac{1}{N} \sum_{n=1} = \frac{K}{\tau} \cdot const \approx freq$$

Comparing indices

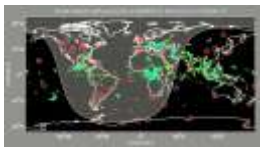
M vs. I_{RS}^{Global}

M – area of land covered by the storms calculated on the basis of ground-based observations of storm days [Nieckarz , IGGP UJ, 2009]

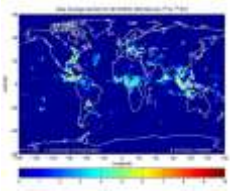


Source of lightning activity on a global scale

World Wide Lightning Location Network (wwlln.net)



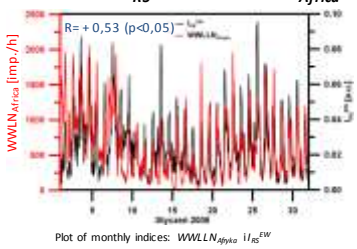
Red asterisks in white circles are active WWLLN lightning sensor locations.



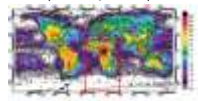
WWLLN Daily Average Density

Research indicates that detection efficiency for strokes is below 30% globally.
The detection efficiency is very different over globe.
This network register only very strong lightnings.

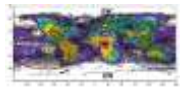
Results of comparison between I_{RS}^{EW} and $WWLN_{Africa}$



The selected area for the VLF analysis (20W 60E ; 20N 90S)



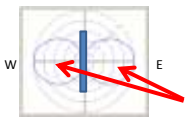
The selected area for the ELF analysis



index $WWLLN_{Afryka}$ – number of lightning registered by WWLLN per hour over selected area;

index I_{RS}^{EW} - hourly index of lightning activity calculated based on the EW antenna, this antenna detects mostly from the African thunderstorm centre;

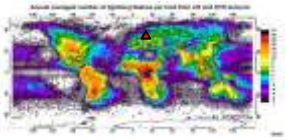
The method for determining the continental indicators of storm activity



Directional characteristics of the magnetic antenna

Direction (area) obseved by NS antenna

NS magnetic antenna

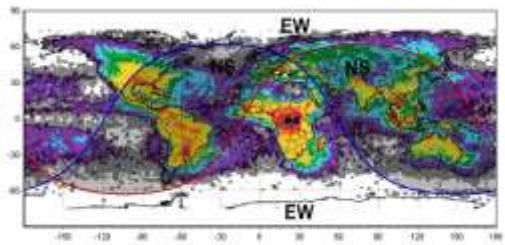


Location the ELF Hylaty

Land distribution over globe

Spatial distribution of lightning

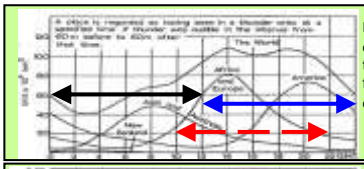
The Earth survey and the ELF magnetic antennas



Division of global distribution of lightning for antennas of the ELF Hylaty stations.

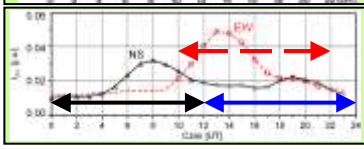
(Map of lightning activity from Christian et al., J. Geophys. Res., 2003)

How do we measure continental storm activity?



Plot of average diurnal area of land covered by thunderstorms calculated from meteorological observations

[Chalmers 1967]

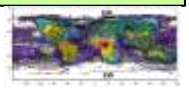


Plot of average diurnal indices I_{RS}^{NS} i I_{RS}^{EW} during period 2005-2007

[Nieckarz Z., IGGP, UJ, 2009]

I_{RS}^{Asia}=average(I_{RS}^{NS}) $I_{RS}^{America}$=average(I_{RS}^{NS})

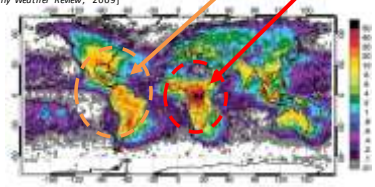
I_{RS}^{Africa}=average(I_{RS}^{EW})



Analysis of activity of the continental storm centers on the basis of daily indices I_{RS}

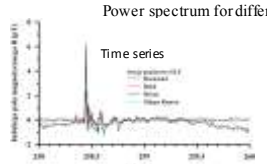
Index	Average	STD	Coefficient of variation	Procent of global activity
I_{RS}^{Asia}	0.0257	0.0110	0.46	28.6
I_{RS}^{Africa}	0.0351	0.0128	0.36	42.3
$I_{RS}^{America}$	0.0241	0.0125	0.52	29.1
I_{RS}^{Global}	0.0829	0.0294	0.35	100

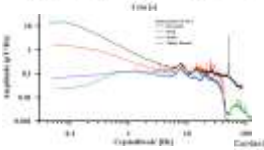
[Nieckarz et al., *Monthly Weather Review*, 2009]



The four ELF stations on the globe

Power spectrum for different location of ELF station





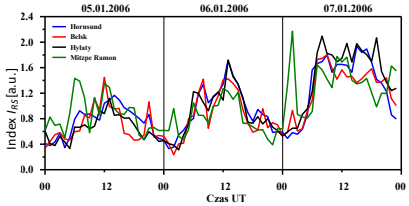
4 ELF station

Hornsund, Belsk, Hylaty, Mitzpe Ramon

Date: 07.01.2006

Time period: seconds from 22:45 UT

The four I_{RS}^{Global} indices

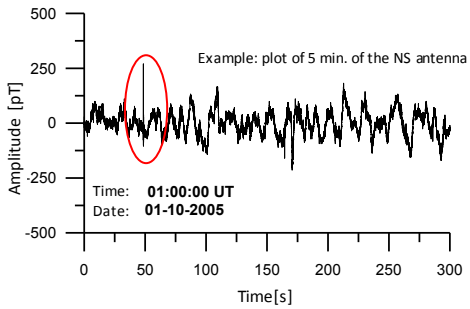


	Hornsund	Belsk	Hylaty	M. Ramon
Hornsund	-	0.89	0.92	0.79
Belsk	0.89	-	0.89	0.66
Hylaty	0.92	0.89	-	0.69
M. Ramon	0.79	0.66	0.69	-
R_{av}	0.86	0.81	0.82	0.63

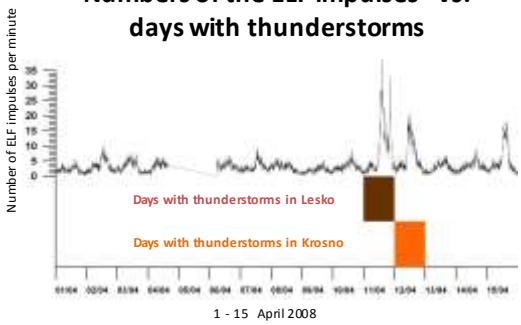
Analysis of the ELF impulses

1. Short time impulses
2. Magnetic component

Example of impulse with large amplitude

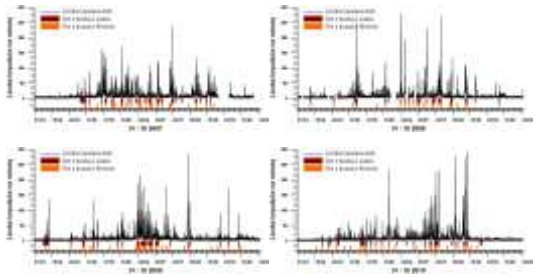


Numbers of the ELF impulses vs. days with thunderstorms

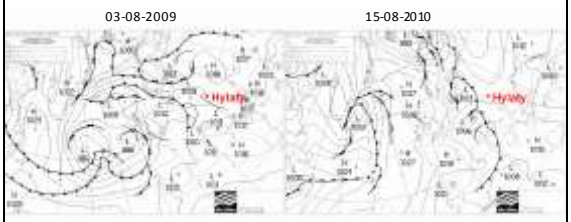


1 - 15 April 2008

The ELF impulses vs. days with thunderstorms in Lesko and Krosno



Synoptic maps



Extreme daily number of impulses registered by the ELF Hylaty station

Period 2007-2010 :

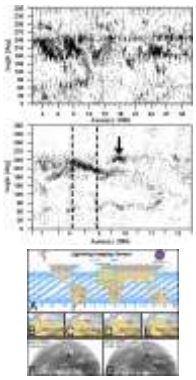
27-05-2007 (69781 impulses),

15-08-2008 (84760 impulses),

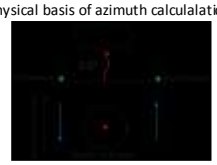
03-08-2009 (98143 impulses),

15-08-2010 (119564 impulses).

The arrival azimuth determination

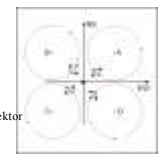


Physical basis of azimuth calculalation



$$|B|_i = \sqrt{B_{iNS}^2 + B_{iEW}^2}$$

From the Ampère's law



$$V_{angle} = B_{angle} - 90^o$$

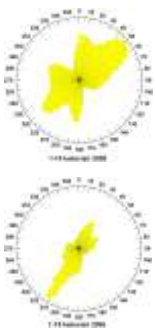
B_{angle} – the azimuth of B vektor

V_{angle} – the arrival azimuth of wave propagation

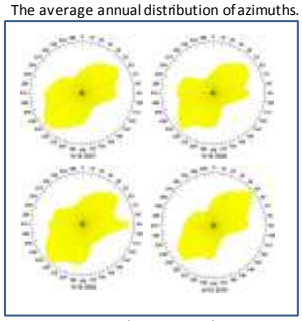
[Nieckarz et al., *AIP Conf. Proc.*, 2009]

Distribution of azimuths

The imprint of direction of atmospheric fronts.



The average annual distribution of azimuths.



Only warm period

Conclusions

The ELF measurement can be used for monitoring:

1) Local and regional lightning activity by analysis impulses in ELF dataset

2) Global and continental lightning activity by analysis the continues measurements ELF signal

3) Results obtained from the ELF correspond well with another known method

4) The ELF method is relatively cheap in use