Atmospheric magnetic noise overview

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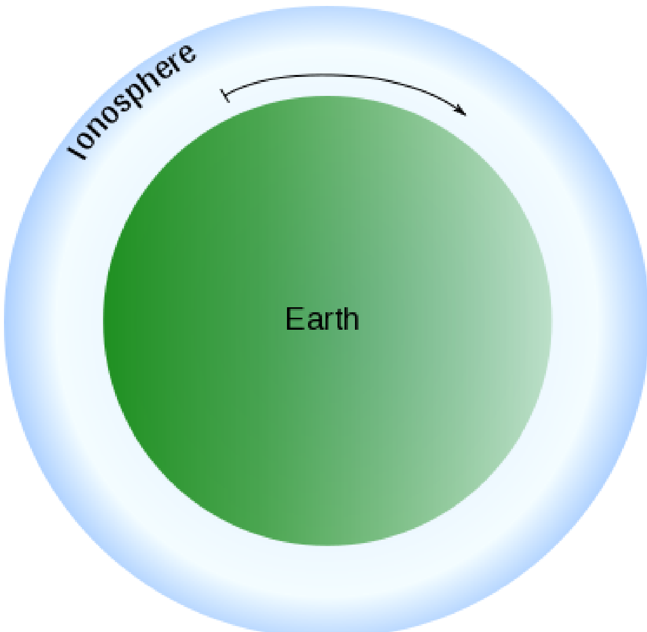
Introduction – ELF radio waves

ELF = Extremely Low Frequency range.

ELF waves = electromagnetic waves (radio waves) with frequencies below 3 kHz

- **The main natural source of ELF electromagnetic waves are atmospheric discharges**



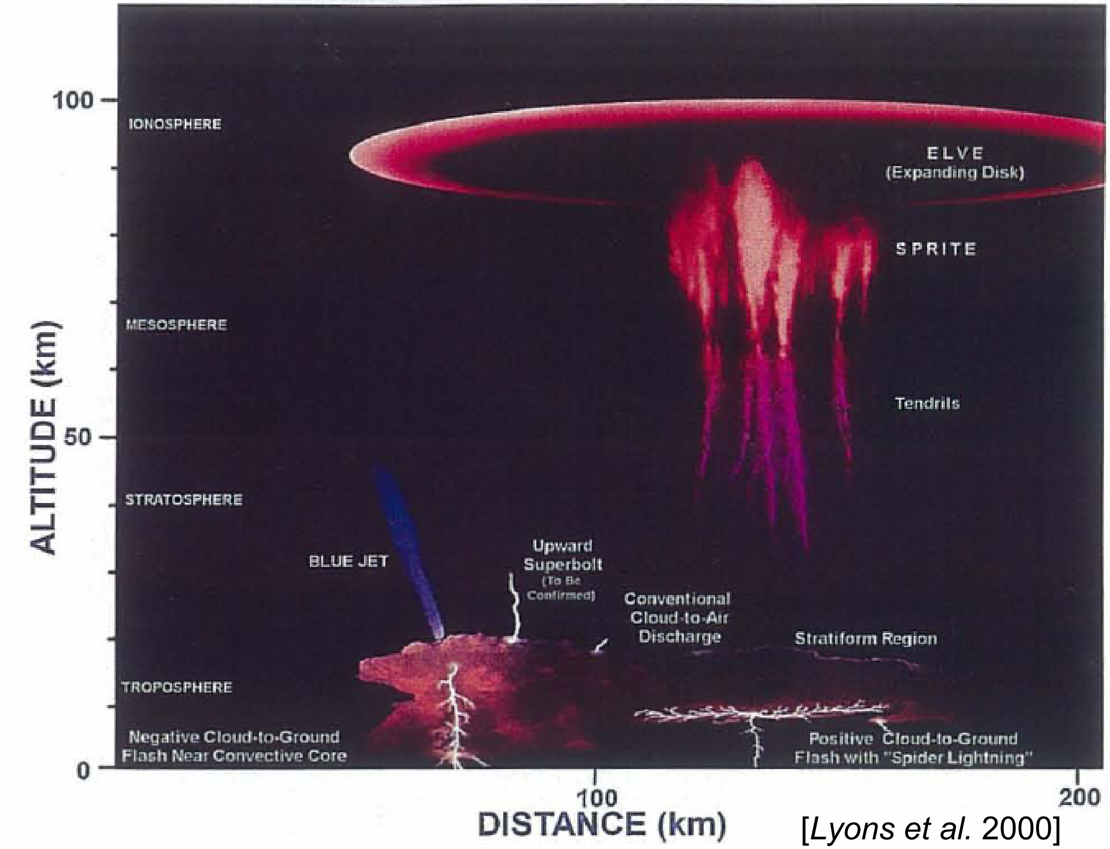
Earth-ionosphere waveguide

How do they propagate from the source?

- The ionosphere refracts radio waves in a broad frequency range, including ELF. The ground in the ELF range can be treated as a perfect conductor. Therefore, in the ELF range the space between the ground and the ionosphere form a waveguide
- ELF electromagnetic waves generated by lightning propagate in this Earth-ionosphere waveguide over long distances due to a very small attenuation rate (~0.25 dB/Mm at 10 Hz, ~1.3 dB/Mm at 100 Hz; 1 Mm=1000 km)

- The actual range of observation of individual lightning discharges depends on their charge moment, local electromagnetic noise, and daily variations of the Schumann resonance background

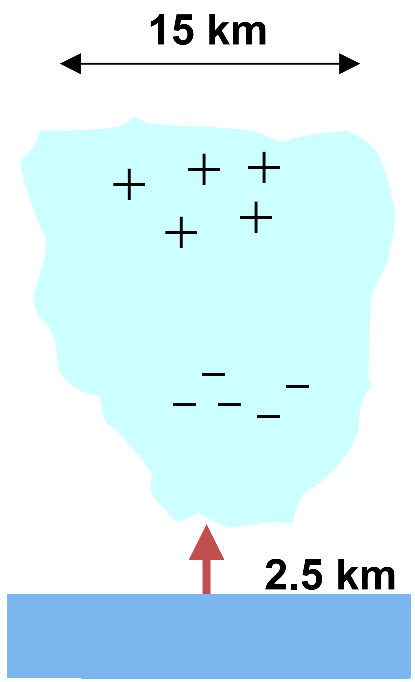
Common lightning discharges



[*Lyons et al.* 2000]

- Negative cloud-to-ground discharges (-CG); effectively transport negative charge from the cloud to the ground; they account for about 90 percent or more of global cloud-to-ground lightning [*Rakov and Uman*, 2003]
- Positive cloud-to-ground discharges (+CG); less common but more powerful than –CGs
- Cloud discharges (IC), which include intracloud, intercloud and cloud-to-air discharges
- Cloud-to-ionosphere discharges associated with Transient Luminous Events (TLEs): Sprites, Elves, Blue Jets, Gigantic Jets. Cloud-to-ionosphere discharges are often triggered by strong +CG discharges.

Typical negative cloud-to-ground discharge (-CG)

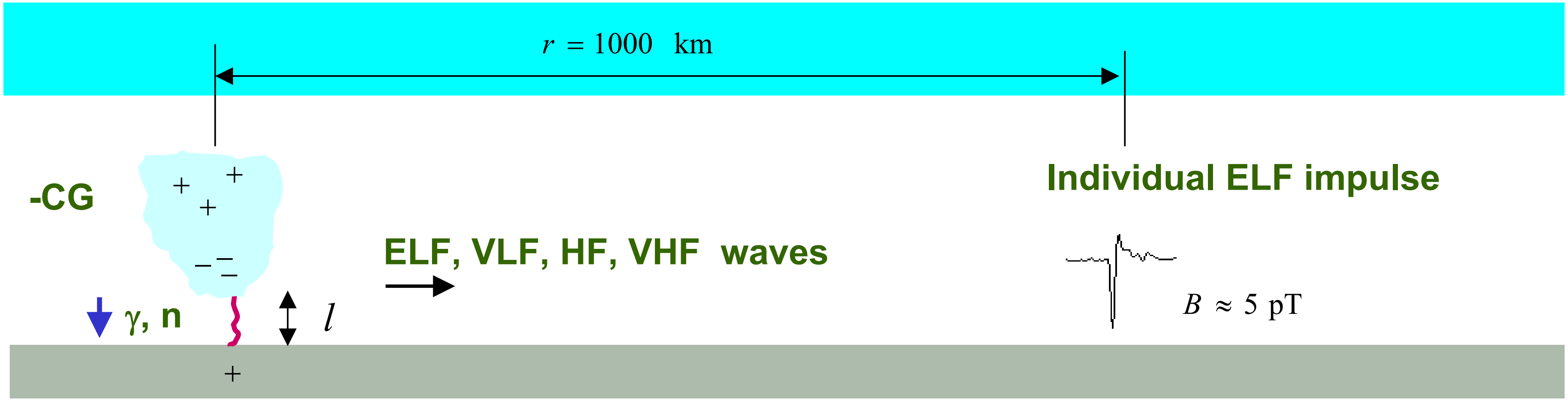


A simplified cloud electrification model

[*Rakov and Uman*, 2003]

- Inside a thundercloud the negative and positive charge separate. The negative charge accumulates in the bottom part, which leads to a large potential difference between the cloud and the ground. This leads to a breakdown and an abrupt discharge of the cloud (leader - return stroke sequence)
- Typical thundercloud can generate lightning discharges every few seconds
- There are about 1500 thunderstorms constantly active on Earth; they produce about 50 negative cloud-to-ground discharges per second

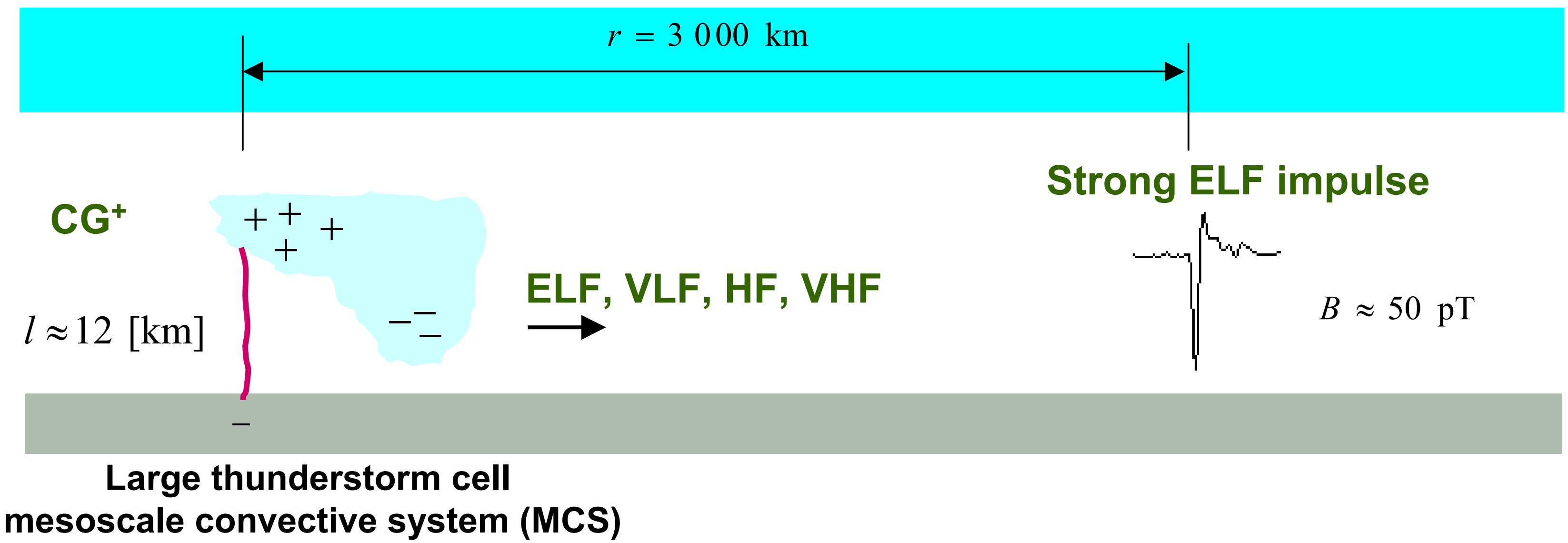
Parameters of typical negative cloud-to-ground discharges (-CG)



Typical parameters of −CG discharges:

$q = 2.5$ [C]	**charge transfer**
$l = 2.5$ [km]	**discharge channel length**
$I_{max} = 20\,000$ [A]	**peak current**
$\tau = 75$ [μs]	**current duration to half peak value (return stroke)**
$R_l \approx 350$ [Ω]	**channel resistance**
$r \approx 1-2$ [cm]	**channel radius**
$W = 20$ [MJ]	**accumulated electrostatic energy**
$P_{em} \approx 1000$ [GW]	**instant radiated power in the entire EM range (impulse power)**
$P_{ELF} \approx 100$ [W]	**instant power radiated in the ELF range**

Parameters of typical positive cloud-to-ground discharges (+CG)

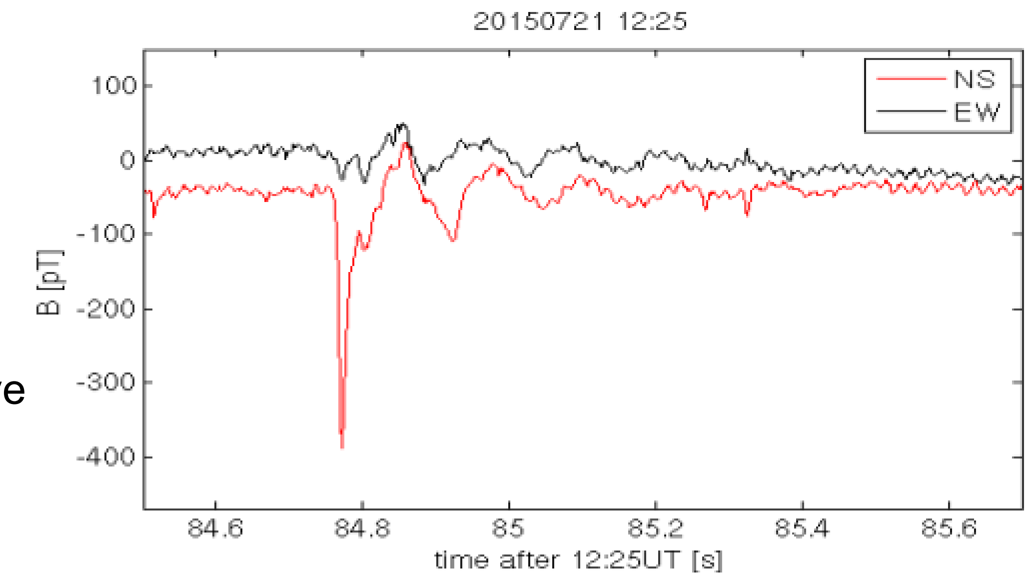


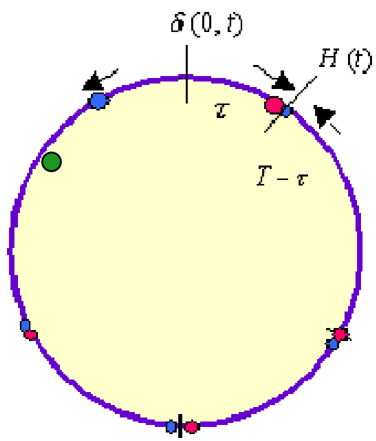
Typical parameters of +CG discharges:

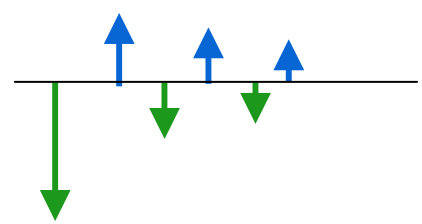
$q \approx 15$ [C]	**charge transfer**
$l \approx 12$ [km]	**discharge channel length**
$p = ql \approx 180$ [C km]	**charge moment (dipole moment)**
$W \approx 100$ [MJ]	**energy**
$\tau \approx 300$ [μs]	**current duration to half peak value (return stroke)**

Very strong +CG discharges

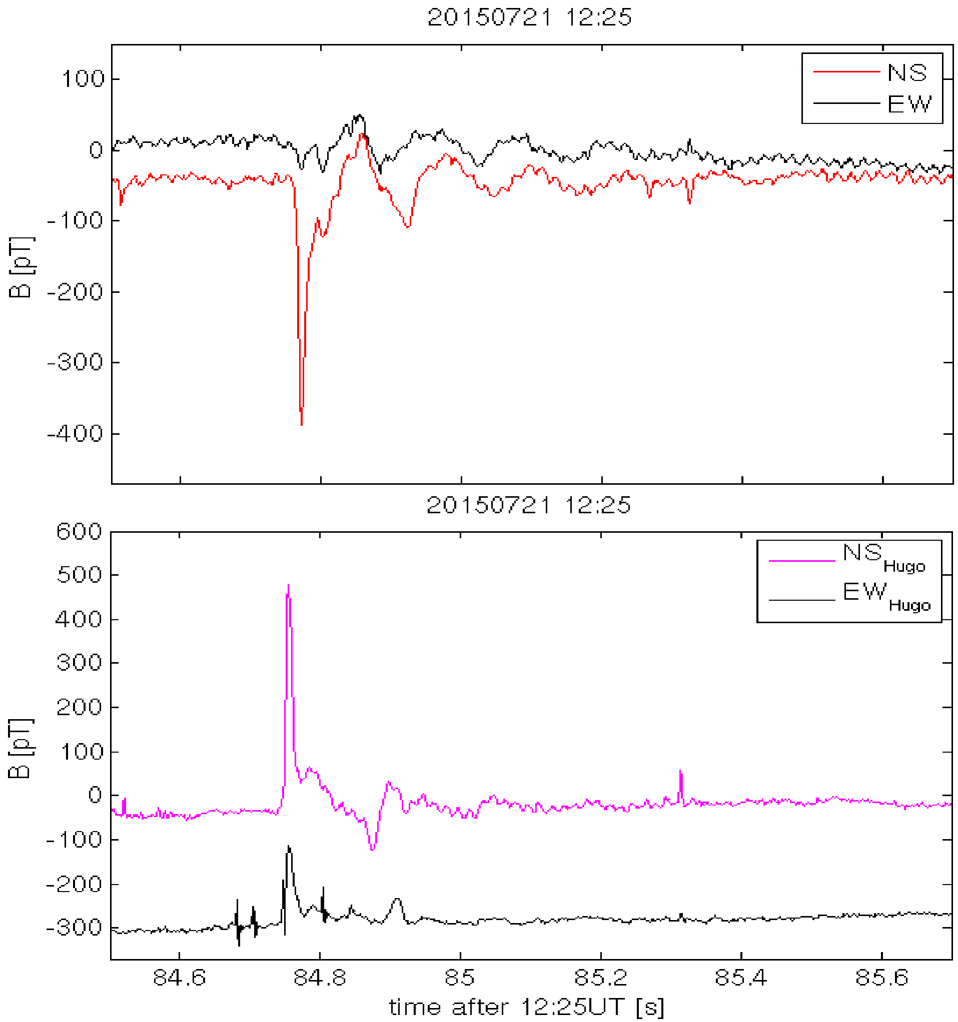
Some of the positive cloud-to-ground discharges are particularly strong. Their ELF waveform consist of a very strong first impulse, associated with the wave propagating directly from the source by the shortest path, a weaker peak in the opposite direction associated with the wave that propagated by the longer path, and then several weaker peaks resulting from the round-the-world propagation of these two waves.





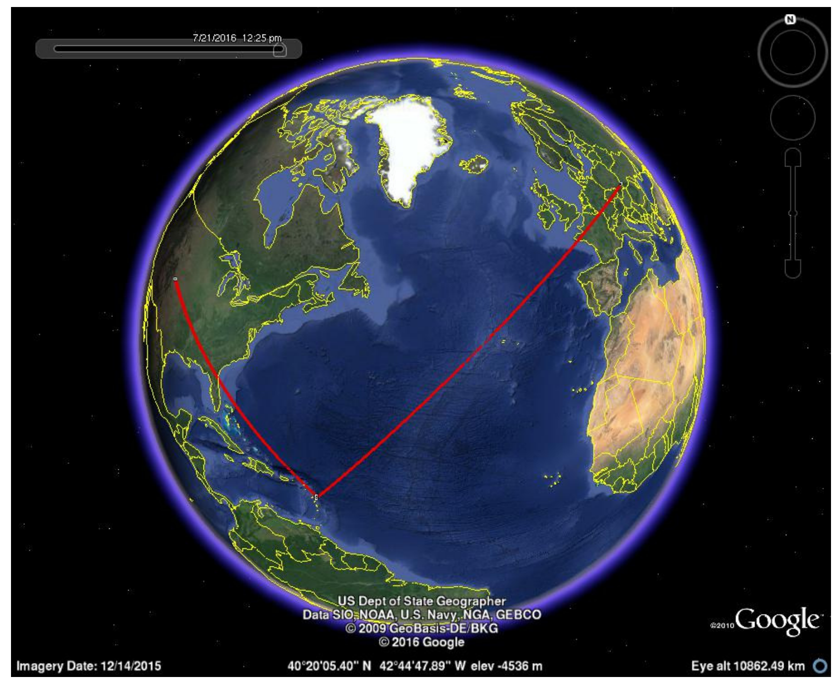


Radiolocation of ELF pulses recorded by the Hylaty and Hugo stations



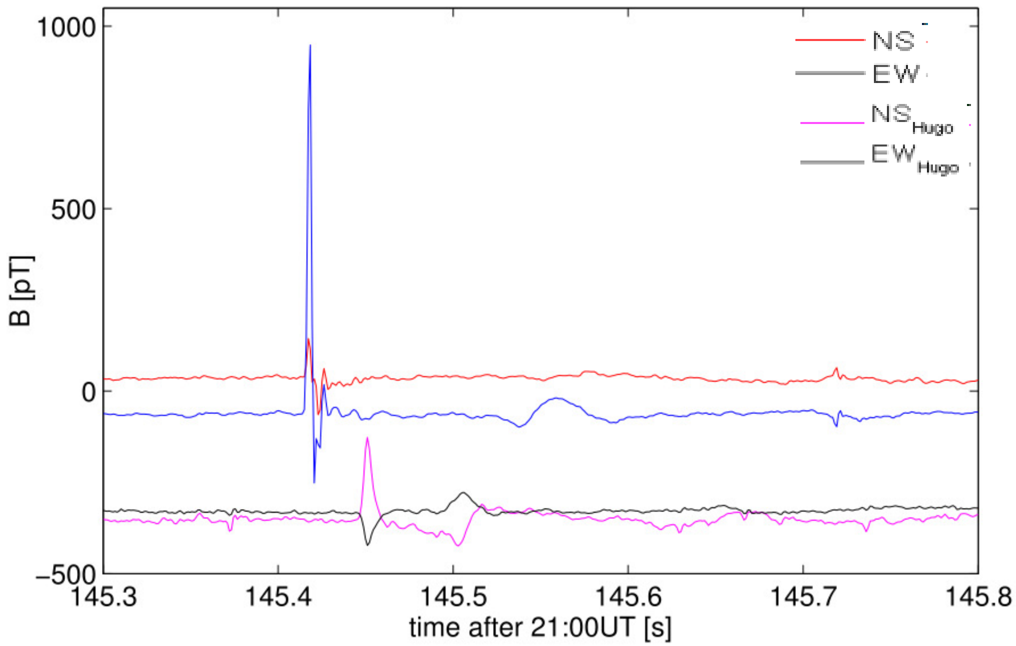
The magnetic field component of the ELF electromagnetic pulse recorded on 21 July 2015 at 12:25 UT by the NS and EW antennas at the Hylaty station (red and blue lines) and at the Hugo station (magenta and black lines) [*Mlynarczyk et al.*, AGU 2016]

Location of our two ELF stations
and the great circle path

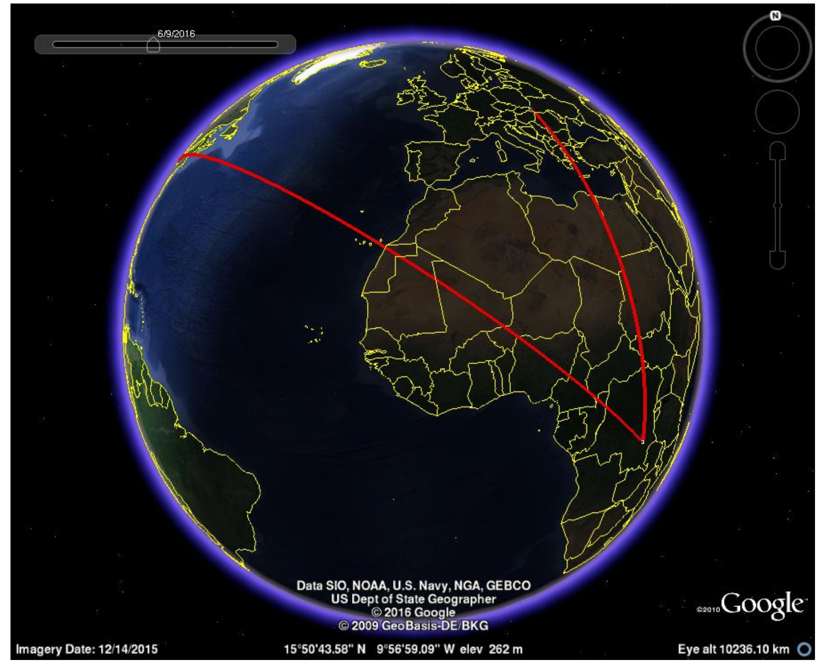


Calculated location of the discharge

Radiolocation of ELF pulses recorded by the Hylaty and Hugo stations

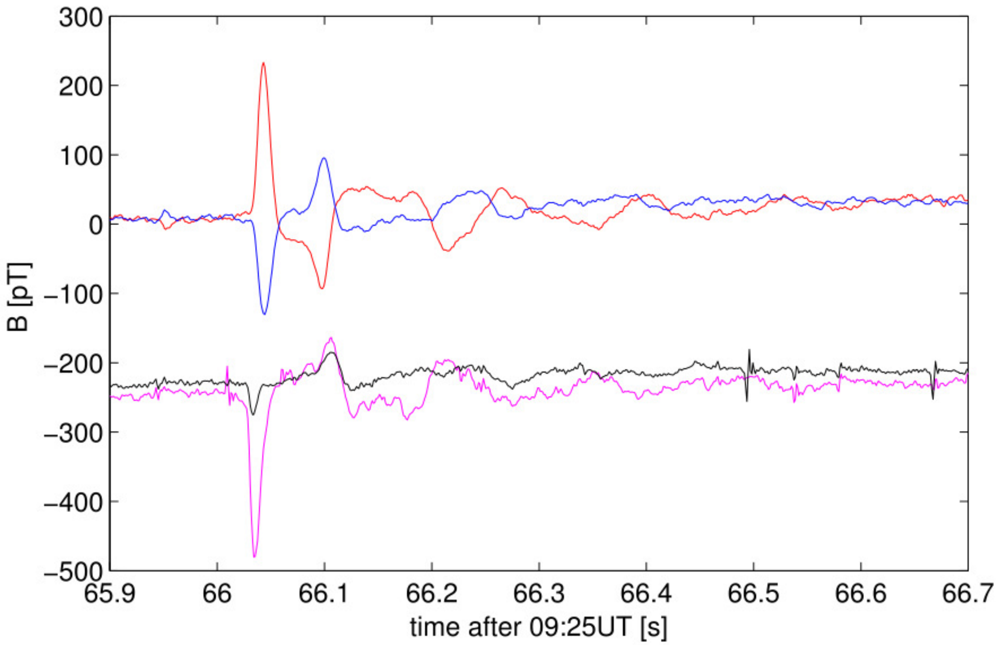


The magnetic field component of the ELF electromagnetic pulse recorded on 9 June 2015 at 21:00 UT by the NS and EW antennas at the Hylaty station (red and blue lines) and at the Hugo station (magenta and black lines, shifted on the y-axis to improve reading) [*Mlynarczyk et al.*, Mikon 2016]

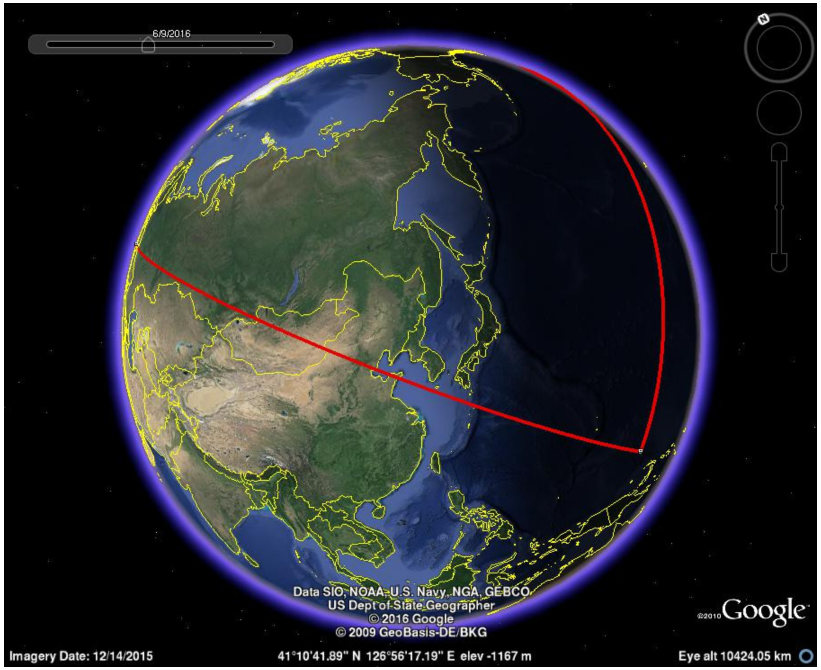


Calculated location of the discharge

Radiolocation of ELF pulses recorded by the Hylaty and Hugo stations



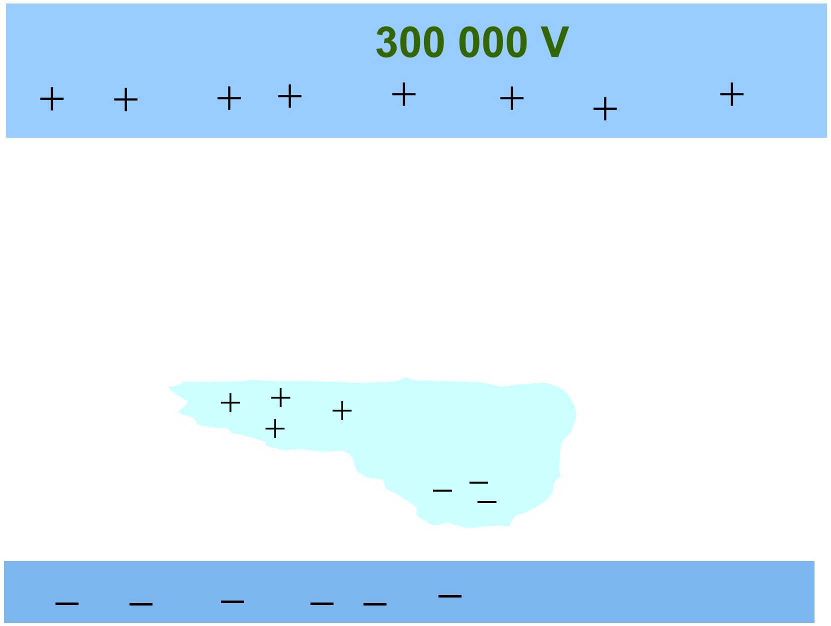
The magnetic field component of the ELF electromagnetic pulse recorded on 9 June 2015 at 9:25 UT by the NS and EW antennas at the Hylaty station (red and blue lines) and at the Hugo station (magenta and black lines, shifted on the y-axis to improve reading) [*Mlynarczyk et al.*, Mikon 2016]



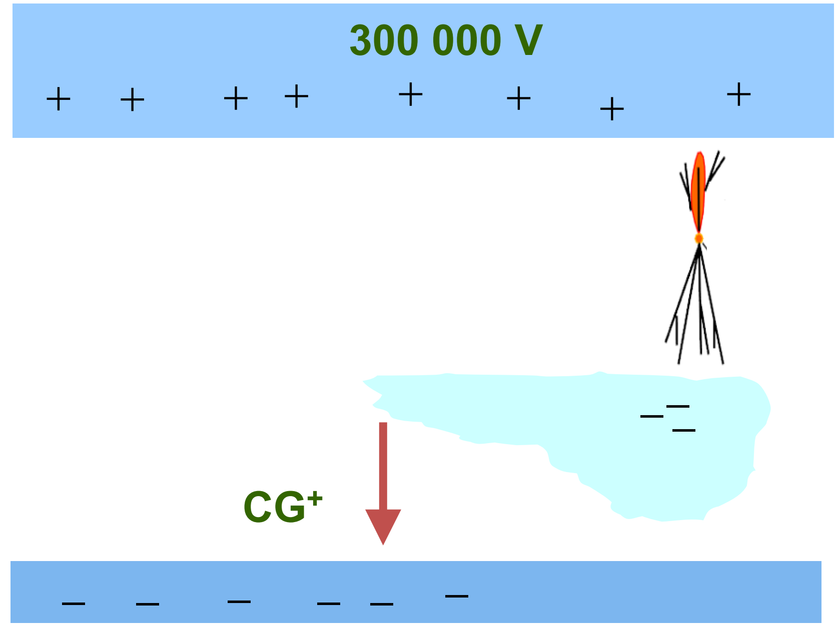
Calculated location of the discharge

Simultaneous recording at the Hylaty and Hugo stations enable us to locate strong +CG discharges that occurred anywhere on Earth

Cloud-to-ionosphere discharges

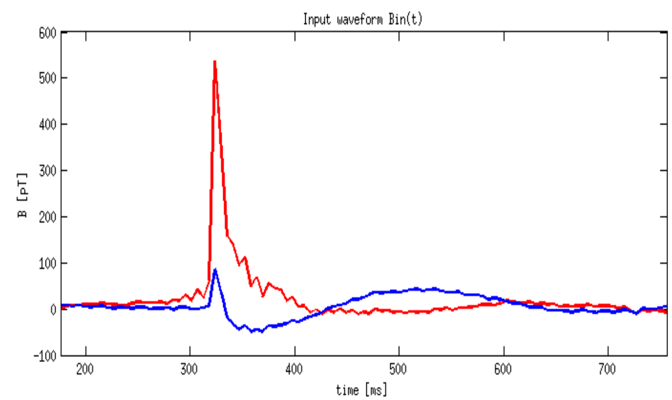


Mesoscale convective system
before the discharge



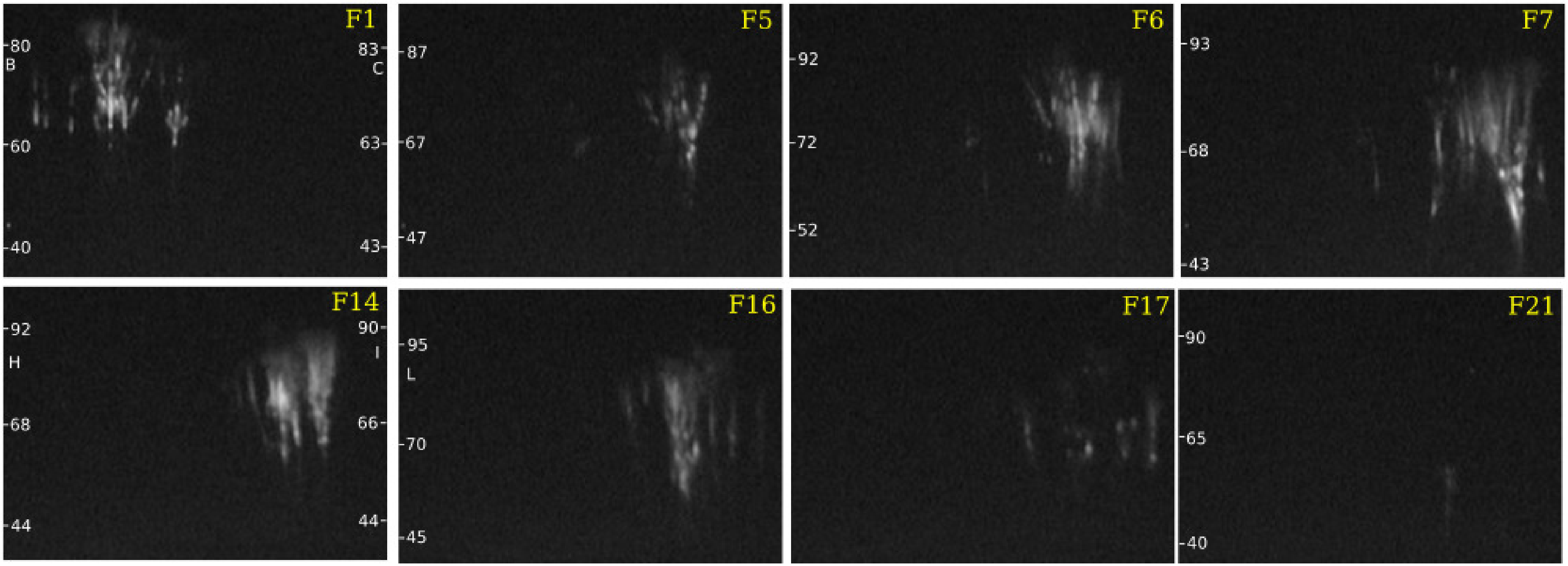
CG+ followed by a cloud-to-ionosphere
discharge associated with a Sprite

Sprite captured from Nydek
by Martin Popek

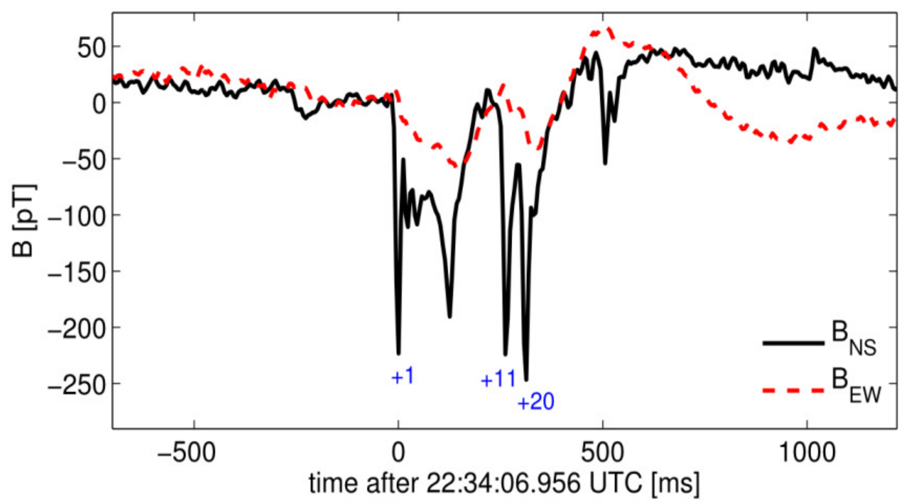


The magnetic field component recorded
at the Hylaty station

Sprites in rapid succession



Sprites in rapid succession. Selected video fields recorded at Sopron on 8 August 2013 at 22:34 UTC



The magnetic field component recorded at the Hylaty station

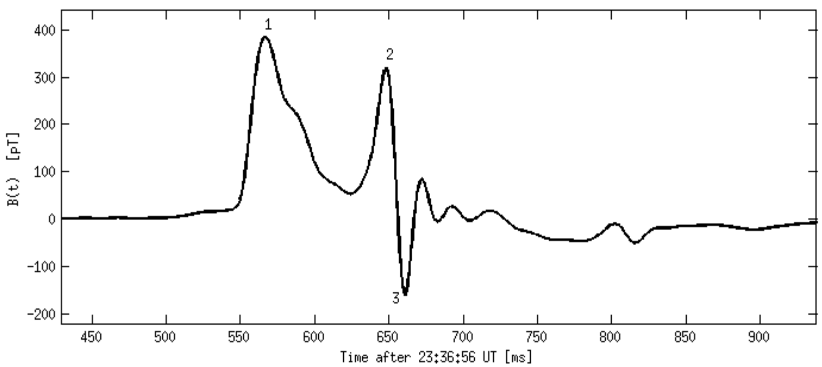
Calculated charge moment change of the sprite event: **13200 C·km** (first part 7900 C·km, second part 5300 C·km)

[*Mlynarczyk et al.*, JGR, 2015]

Gigantic Jet (GJ)

A rare type of TLE. In Europe, it was recorded for the first time in December 2009 near Corsica

[Ferruccio Zanotti, IMTN, 12/12/2009]



The magnetic field component recorded by the Hylaty station 1400 km away from the source
[*Kulak and Mlynarczyk*, JGR, 2012]

Charge moment change	$p \approx 11800\,[\mathrm{C\,km}]$
Channel length	$l \approx 60\,[\mathrm{km}]$
Charge	$q \approx 200\,[\mathrm{C}]$
Energy	$W \approx 6\,[\mathrm{GJ}]$
	$W \approx 1.5\,[\mathrm{kt\ TNT}]$

Conclusions

- We have a unique intercontinental system for measurement of ELF pulses generated by atmospheric discharges. It consists of two ELF stations, each equipped with a broadband receiver (0.03 - 300 Hz) and two magnetic antennas, north-south and east-west. We plan to install the third station in the southern part of Argentina soon.
- Our system can be used for worldwide geolocation of strong atmospheric discharges.
- We can help validate the signals recorded by the gravitational detectors by excluding their ELF origin (impulse signals and Schumann Resonance background)