ELF Monitoring Goes Global

Mapping storm activity across the globe at time scales ranging from minutes to years is an important element of measuring and forecasting climate change. The WERA system is being used to verify models of the influence of various types of solar activity on the lower layers of the ionosphere. We hope that one day it can also be used on Mars.

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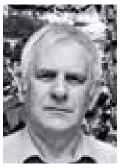

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The third station of the World ELF Radiolocation Array (WERA) system was brought online in Patagonia in Argentina on 27 March 2016, inaugurating the first intercontinental system of radiolocating sources of radio waves using extremely low frequency (ELF) electromagnetic waves. The first station – Hylaty in the Bieszczady Mountains in southern Poland – was launched in 2005, with Hugo in Colorado following a decade later. WERA works at frequencies from 0.03 to 300 Hz and it monitors electrical discharges in Earth's atmosphere. Using directional antennas at each station makes it possible to pinpoint the discharges, while analysis of the waves reveals the details behind the process.

Why ELF?

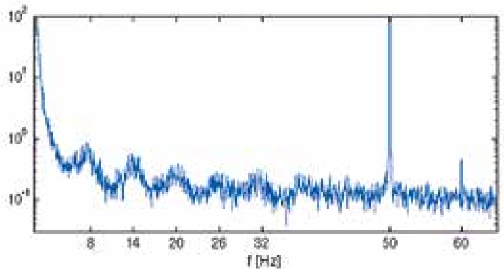
ELF waves move in a confined cavity, or waveguide, delimited by the Earth's surface and the lower layers of the ionosphere, up to the altitude of around 75 km. The ionosphere's reflective properties in this frequency range mean that the Earth–ionosphere waveguide has extremely low attenuation rate. For example, the energy of waves at a frequency of 10 Hz is halved only after travelling a distance of 10,000 km.

The long range of the waves and the well-known parameters of the waveguide makes this frequency range suitable for studying global electromagnetic activity. Additionally, only a few observatories are needed to conduct highly accurate measurements on a planet-wide scale.

Since low frequency alternating currents have been readily available since the late 19th century, it may seem surprising that the ELF wave range had not been studied before, perhaps soon after the first experiments on radio waves conducted by Heinrich Hertz in 1887. The major obstacle was the difficulty in constructing effective broadcasting antennas, which need to be hundreds of meters in size. Detection is significantly easier: the American engineer Arthur Edwin Kennelly attempted to observe ELF waves emitted by the Sun as early as 1890. He constructed a receiver comprising a coil several kilometers long, encircling ore deposits in New Jersey and connected to a phone receiver. His results were negative because of the Earth's ionosphere (its existence was unknown at the time), which deflects the Sun's radiation in this wavelength range. Another unsuccessful

attempt, this time at transmission in the ELF range over large distances, was made by Nicola Tesla in Colorado Springs in 1899. These early setbacks meant that research into ELF was abandoned. It wasn't until 1952 when Winfried Otto Schumann noted that the spherical shape of the Earth–ionosphere waveguide creates a massive resonance cavity which should support the propagation of electromagnetic waves at very low frequencies. The theory was confirmed through observations conducted by researchers from MIT in 1960. That year marks the start of systematic research into the propagation of ELF waves; today the subject is studied at centers in the US, Japan, Israel, Hungary, and Poland.

The biggest obstacle to observing ELF waves is posed by manmade disturbances, making observations impossible in most places in Europe. Schumann resonance was first observed in Poland in 1992 in the Bieszczady; the mountains have since turned out to be a rare spot in this respect. To make the most of this, we formed a team of physicists and astronomers from the Jagiellonian University and the AGH University of Science and Technology to conduct regular research into ELF waves. In 1994, we commenced expeditionary observations using specially designed ELA equipment, leading to the creation of new generation aerials and receivers. In 2005, the project KBN3P04D 018 24 and a collaboration with the Lutowisko Forestry led to the construction of a permanent ELF wave observatory Hylaty, using the ELA7 system. We placed the aerials and receivers underground, since ELF waves are able to penetrate the ground. The observatory is located near the edge of the Bieszczady National Park, far from the national grid, which means it produces high quality data. We also conduct theoretical work in modelling ELF wave propagation in the ground–ionosphere waveguide and resonance phenomena in the Earth–ionosphere cavity. We have analyzed the influ-



JERZY KUBISZ

Fig. 1:
Patagonia. Preparations for placing magnetic ELF antennas underground. Dr. Janusz Młynarczyk from the AGH University of Science and Technology (foreground) setting up the antennas

Fig. 2, 3:
Receiver module of the Patagonia station shortly before being installed underground. It is located at a sufficient distance from the antennas so that its personnel do not interfere with the measurements. Jerzy Kubisz from the Jagiellonian Astronomical Observatory and Jacobo Salvador from UNIDEF conducting the first test observations.

Fig. 4:
UNIDEF geophysical station

Fig. 5:
The first five-minute long spectrum of the Schumann resonance registered on 27 March 2016 at the Patagonia station. As well as the resonance's maxima, the image shows spectral lines of electrical grids: 50 Hz (South America) and 60 Hz (North America).

ence of solar activity on the Earth–ionosphere cavity (2003), and designed novel methods of studying the cavity's physical properties and mapping the movement and intensity of storm centers (2006-2015). We have also developed a new method of measuring the physical parameters of various types of discharges using inverse solutions (2010-2015). Today, the Kraków ELF research team is proud to be one of the most experienced in the world.

What can we see?

The most common source of ELF waves in the ground–ionosphere waveguide is negative atmospheric discharges, taking the form of lightning striking the ground. This occurs when negative charge accumulates at the base of a thundercloud, leading to an electrical discharge between the cloud and the ground. A typical discharge, lasting several microseconds, is an electrical pulse with an intensity of tens of thousands of amperes flowing in a plasma channel around two to three kilometers long. This generates an ELF field impulse within the ground–ionosphere waveguide, clearly discernable up to a thousand kilometers away. Beyond that it merges with similar impulses formed as a result of similar discharges around the globe.

At any given point in time the Earth has over a thousand active thunderstorms, mainly in the tropical zones, generating around 50 negative discharges per second. The waves travel in all directions, leading to interference with waves around the planet and the formation of resonance. The Schumann resonance is visible as constant atmospheric noise with spectral maxima around the frequencies of 8, 14, 20, 26 Hz, etc., corresponding to successive resonance modes of the Earth–ionosphere cavity.

Each station from the WERA system is constantly observing seven maxima. Measuring them makes it possible to conduct ongoing research into the inconsistencies of cavity parameters under the influence of changing solar UV and X-ray emissions and high-energy protons from cosmic rays, reaching the lower layers of the Earth's atmosphere.

A second, more powerful type of atmospheric phenomena involves positive discharges between the clouds and the surface. They are formed when positive charge accumulates in the upper layers of large mesoscale storm systems, leading to electrical discharges towards the ground. They release significantly greater charges via plasma channels up to 12 kilometers long. They generate powerful ELF field impulses, the most powerful of which, known as Q-bursts, orbit the globe and can be observed several times before they fade into background noise. The energies of positive discharges are hundreds of times more powerful than the ordinary energies of negative discharges. Preliminary observations of the WERA system reveal that there are around a dozen or so such powerful discharges on the Earth per hour.

Even more powerful discharges, caused by electrical breakdowns between the ionosphere and the clouds, co-occur with optical phenomena known as transient luminous events (TLE). The best known kind, called a sprite, occurs above mesoscale storm systems and is usually triggered by powerful positive discharges between the clouds and the ground, releasing the positive charge from the cloud. Sprite discharges are around 50 kilometers long, and they involve the flow of positive charge from the ionosphere to the cloud. They last up to a few hundred milliseconds and they are accompanied by charge flows comparable to powerful positive discharges. Since the discharges flow along such long channels, the ELF field impulses they generate are visible all over the globe.

The most powerful TLE discharges of all are known as gigantic jets. Their duration is usually shorter than that of a sprite, but they release vast amounts of energy, equivalent to explosions of several tons of TNT. Such phenomena are extremely rare: just a single gigantic jet was registered in Europe in recent years, occurring in 2009 near Corsica.

How did WERA become intercontinental?

Before the WERA system was constructed, Poland conducted tests on the Hylaty-Wigry-Karonosze (HWK) system, designed in 2014 as part of the NCN-2011/01/B/ST10/06954 project. New-generation AA1130 wideband antennas and ELA10 receivers are prepared for many years of operation in containers placed underground. The equipment uses low power technologies, and it can operate for up to two months without charging.

Thanks to the management of the Wigry and Karonosze National Parks, the HWK system was able to operate in optimal environmental conditions. In 2015, working with the Brody Forestry, the observations were repeated across the distance between Hylaty and the Augustów Forest (the HA system). They provided important information on the operation of the equipment under field conditions and produced data on storm activity in Europe.

Searching for suitable areas in the Americas was difficult. Potential sites had to be uninhabited while being within range of researchers who work with us. A suitable location for a WERA station was found through the NCN-2012/04/M/ST10/00565 Harmonia project alongside our partners Earl Williams from MIT, Marek Gołkowski from the University of Colorado and Eduardo J. Quel, director of the Unidad de Investigacion y Desarrollo Estrategico Para Defensa in Buenos Aires.

The final location and installation of the Hugo and Patagonia stations was made together with our team members Dr. Janusz Młynarczyk from the AGH University of Science and Technology and Jerzy Kubisz from the Jagiellonian Astronomical Observatory. The first tests confirmed that the data quality is as high as that generated by the model Hylaty station.

What else can we learn?

The WERA system can be used to conduct geophysical, meteorological, and climate research, and also for astronomical studies (i.e. space weather). Using precise measurements of the Schumann resonance provided by the three stations allows us to map global storm activities at time scales ranging from minutes up to many years. The data play an important role in assessing and forecasting the changing climate on our planet. The multipoint measurements of the Schumann resonance also make it possible to study the physical parameters of the Earth–ionosphere cavity and to verify models of the effect of the Sun's activity on the condition of the lower layers of the ionosphere.

One of the key features of WERA, distinguishing it from other systems, is its ability to measure the parameters of various types of discharges. Its global reach makes it possible to study the frequency and dispersion of the parameters of powerful positive discharges generating Q-bursts and follow the distribution and course of sprite discharges and gigantic jets. Measurements of wave impulses generated by individual discharges also provide important information on the condition of the lower layers of Earth's ionosphere along their route.

ELF waves in the ground–ionosphere waveguide mostly come **from negative atmospheric discharges** (lightning striking the ground).

The three WERA stations are also involved in studying the influence of Earth's electromagnetic interference on the LIGO gravitational wave detectors in the US and VIRGO in Italy.

Experience gained from using WERA is transferrable to other planets and moons, providing they have at least residual ionospheres (the ELF range is not picky in this respect). Our team has recently started designing a similar system to be constructed on Mars. The Martian ionosphere–surface waveguide exhibits significant dampening, since the waves penetrate deep beneath the surface. The project includes the construction of state-of-the-art equipment, as well as designing inverse solutions for studying the planet's tomography.

Andrzej Kułak

Further reading:

http://www.oa.uj.edu.pl/elf/index/projects3.htm