A Global Network of VLF Antennas for Studying Pre-seismic Ionospheric Disturbances

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Abstract. In the framework of studying ionospheric variations, we present a system which records electromagnetic signals, in the Very Low Frequency (VLF: 3 kHz – 30 kHz) and Low Frequency (LF: 30 kHz – 300 kHz) ranges, 24 x 7 x 365. An individual system consists of a monopole antenna, a pre-amplifier, power supply, a central computer, a GPS unit, and a recording device (Galopeau et al., 2023). Several receivers will be implemented around the globe in a network. The first implementation of the system was done in Graz, Austria, the second one will be in Guyancourt (France), a third one in Réunion (France) and a fourth one in Moratuwa (Sri Lanka). Each reception device will allow a continuous daily monitoring of transmitter signals in the VLF and LF frequency bands. This network will be devoted to the study of ionospheric variations, in particular, those linked to the solar activity, but also those associated with seismic activity with the purpose of identifying electromagnetic earthquake precursors.

1. Introduction

Earthquakes (EQs) electromagnetic precursors have been reported and investigated since more than twenty years. Recent reviews of Parrot (2018) and Hayakawa (2015) emphasize on the space and the ground-based observations which are covering a large spectral domain, from few Hz and up to several hundred of kilohertz. We consider in this work electromagnetic (EM) precursors observed in two bands: Very Low Frequency (VLF, i.e. 3 kHz to 30 kHz) and Low Frequency (LF, i.e. 30 kHz to 300 kHz) by electric field experiment onboard satellites or on ground stations. One important feature of the seismic EM precursors is the study of the ionospheric disturbances observed above the earthquakes regions. The basic method consists to analyze the propagation of the transmitter subionospheric VLF/LF signal. Hence the transmitter signal is mainly reflected by the ionospheric D- and E-layers and detected by the ground station. Several investigations showed a drop of the amplitude of the transmitter signal few/several days before the earthquake occurrences using different methods in the treatment of the radio signal like the wavelet (e.g. Biagi *et al.*, 2019) and the spectral (e.g. Boudjada *et al.*, 2017) techniques. In the model of Molchanov *et al.* (2006) the pre-seismic ionospheric disturbances are linked to an upward energy flux of atmospheric gravitational waves generated by EQs preparatory zone. The size of the preparatory zone is derived from the well-known relationship between the radius of earthquake preparation zone ρ and the earthquake magnitude M (Dobrovolsky, 1979): ρ [km] = $10^{0.43M}$. The following Table lists the radius of the EQs preparation zone versus EQ magnitude (Pulinets and Boyarchuk, 2004).

Magnitude	3	4	5	6	7	8	9
EQ preparation zone radius [km]	19.5	52.5	141	380	1022	2754	7413

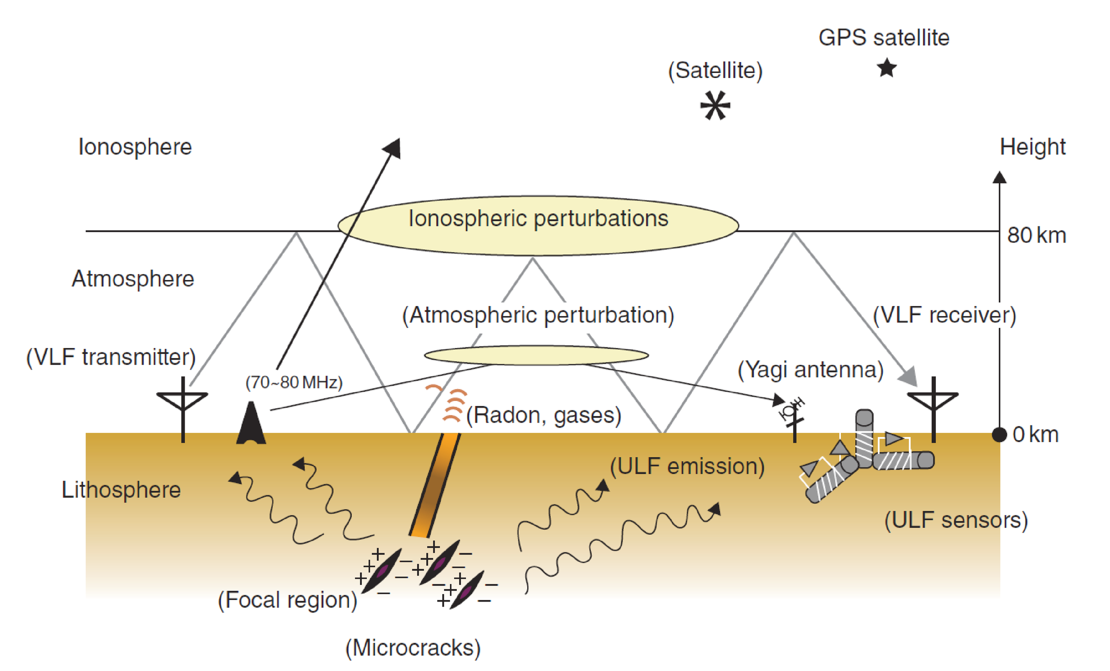

Figure 1. Conceptual general view of electromagnetic phenomena in possible association with Eqs and different radio techniques to measure those electromagnetic effects (from Hayakawa 2015).

2. Description of our VLF Facility

We introduce a VLF antenna system, to observe electromagnetic signals 24 x 7 x 365 and record data. Our system is simple in deployment and operation and cost effective compared to the other systems. The main objective of this project is to find special VLF signatures that might occur prior to earthquakes. In this currently ongoing project, we will be analyzing the collected data, locate special signatures and correlate those with the occurrence of earthquakes. For accurate location prediction we need multiple antenna systems around the globe working as a network.

The system we plan to use will consist of: a monopole antenna equipped with a preamplifier, a GPS receiver and a sound card to digitize the received signal. This device will be identical in all respects to the VLF reception system set up at the Space Research Institute in Graz in order to study the earthquake precursors. The receiving antenna (Procom BCL 1-KA) will be of monopole type (length 92 cm), omnidirectional, vertically polarized and provided for a frequency band 10 kHz - 100 MHz. It is equipped with a preamplifier that must be connected by a 50 Ω coaxial cable to a junction box that separates the DC-current from the 12 V power supply and the RF-signal. The radio signal will then be sent to a sound card to be digitized. The model used is Focusrite Scarlett 2i2, the sampling frequency of which varies from 44.1 kHz to 192 kHz, with a 24-bit output coding. A GPS receiver module with a PPS output (pulses per second) allows precise synchronization of the radio signal thanks to an update rate of 1 Hz. Finally the output of the sound card is connected (by a USB cable) to a PC running under a Linux operating system (CentOS). A specially dedicated software (UltraMSK) will provide the raw data. The system will deliver daily data files allowing to visualize the amplitude and the phase of the received signal.

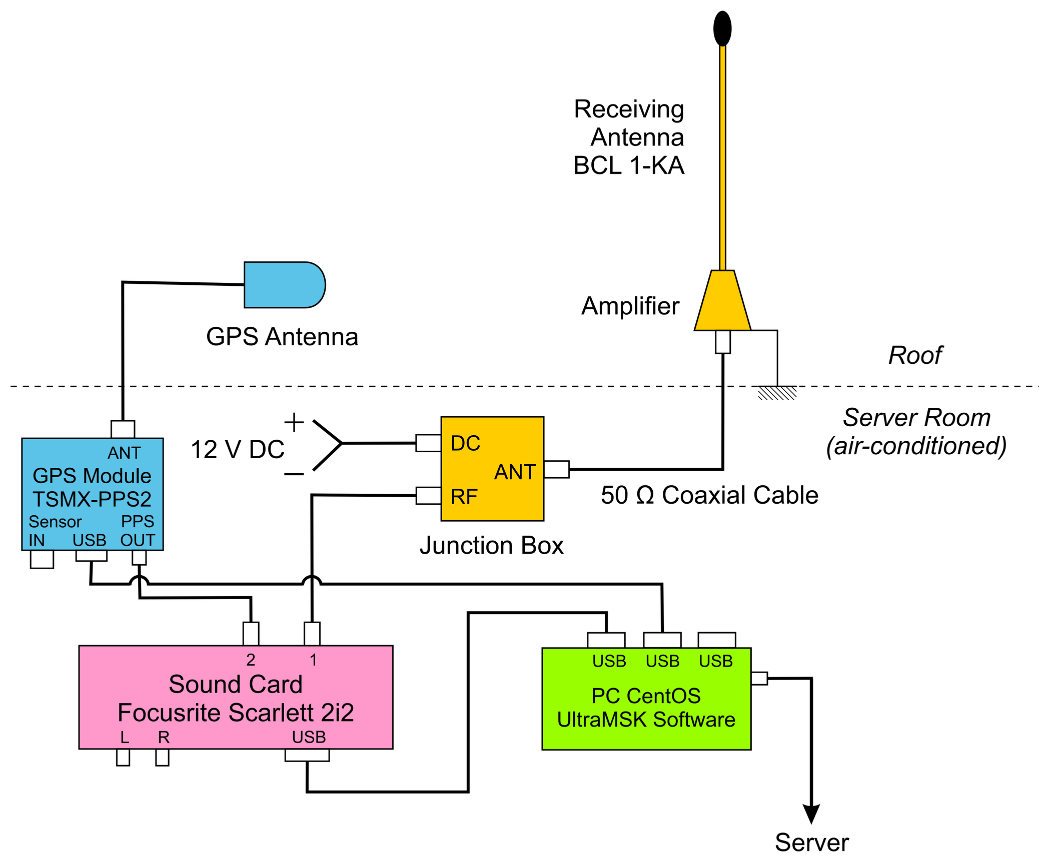

Figure 2. Schematic diagram of the VLF facility including the monopole antenna, the preamplifier, the GPS receiver and the sound card.

3. Example of VLF observations

We consider VLF observations recorded by this new system in Graz (Austria). We have selected one event recorded on March 20th, 2019, where solar flux has been detected.

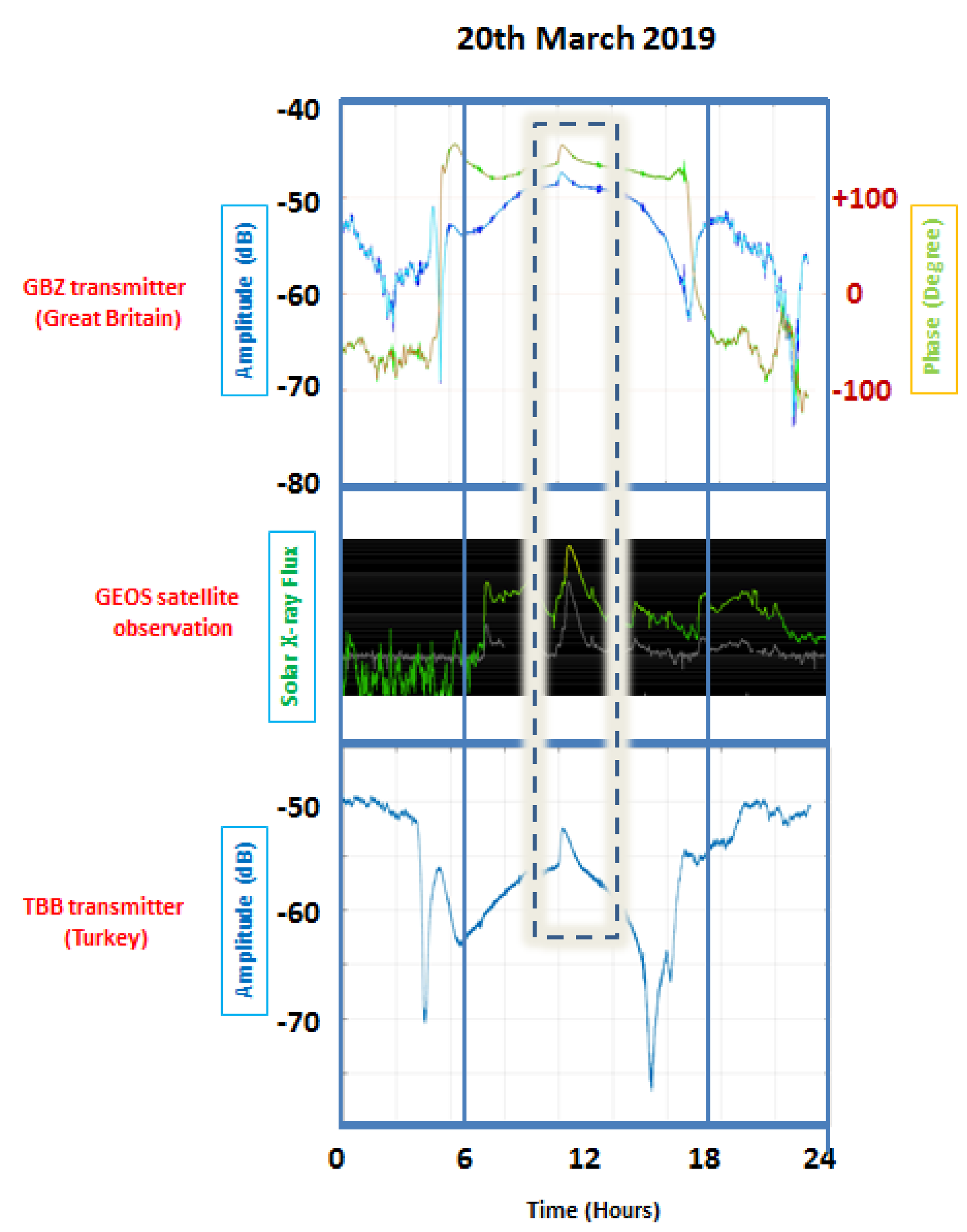

Figure 3. The first panel displays the variation of the amplitude (right-vertical axis) and the phase (left-vertical axis) versus the time (horizontal axis) for the GBZ transmitter. It is localized in Skelton (Great Britain) and its emission frequency is 22.1 kHz. The second panel shows the solar X-ray flux versus the time as recorded by GEOS satellite. The third panel displays the TBB transmitter signal emitted from Bafa (Turkey) at frequency of 26.7 kHz.

4. Deployment and site selection

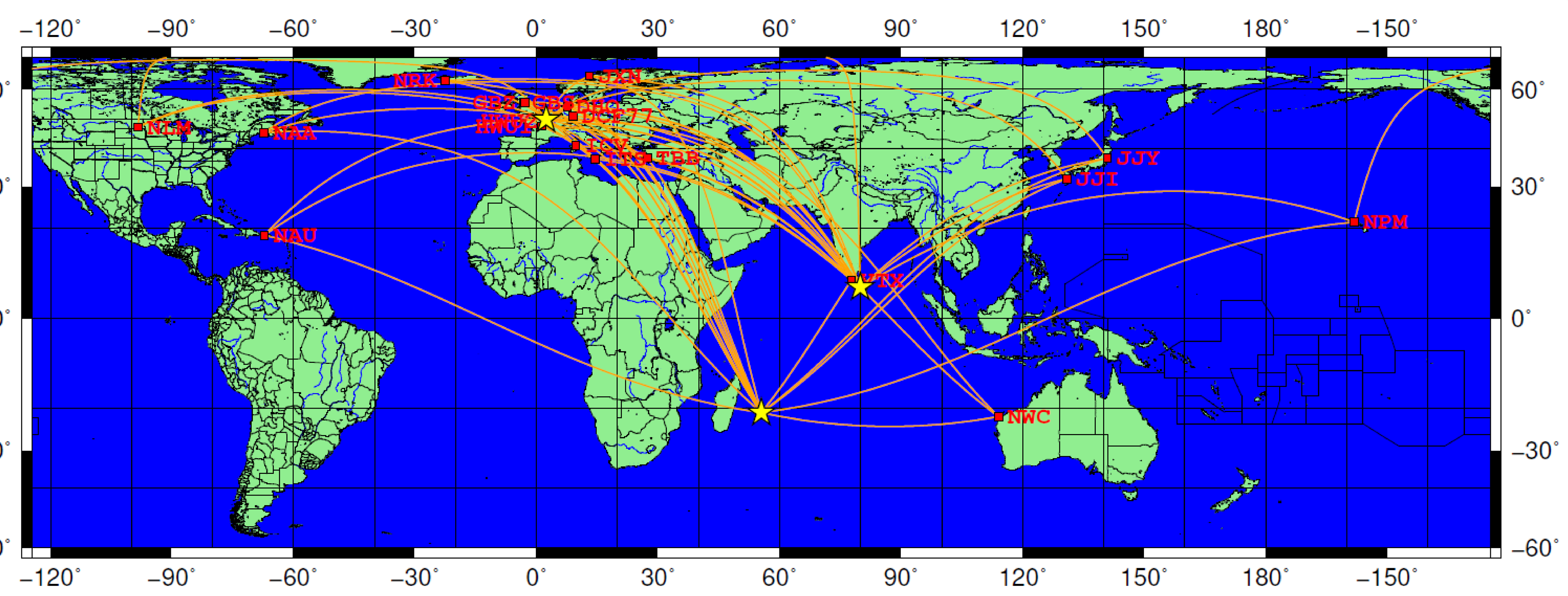

Figure 4. The map shows the location (yellow stars) of the new VLF/LF receiving facilities in Guyancourt, Réunion and Sri Lanka together with important transmitter stations (red squares) and their corresponding great circle paths (orange lines). The Sri Lanka station is particularly useful to sample the area close to the Sunda subduction zone with large earthquakes via the path to the NWC transmitter (19.8 kHz) in Western Australia. The facility in Réunion enables a broad range of paths over East Africa.

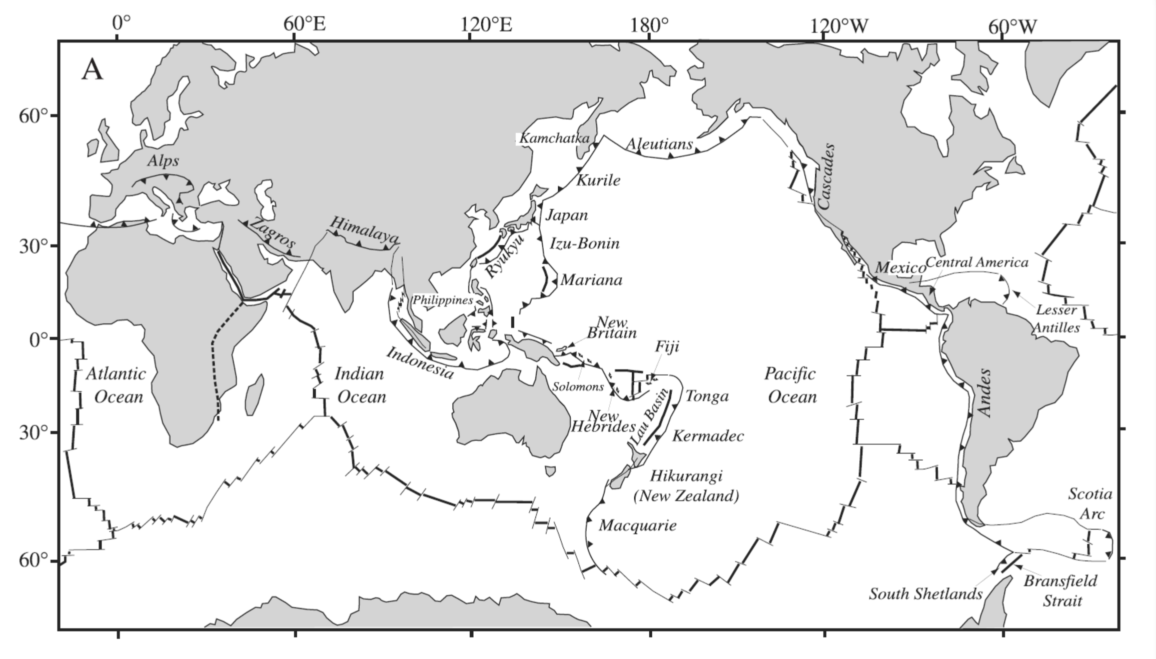

Figure 5. Subduction zones and convergent plate margins on Earth, from (Stern, 2002).

In addition to the first system implemented in Graz (Austria) and a second one planned in Guyancourt (France), completing the current network localized in Europe via the International Network for Frontier Research on Earthquake Precursors (INFREP, Biagi *et al.*, 2019), we propose a new location with two antennas in the Indian Ocean: the first one in the Southern Hemisphere (Réunion Island) and another one near the Equator (Sri Lanka). The Earth's seismic activity is mainly linked to tectonic activity and, in particular, to subduction zones where the lithosphere sinks into the terrestrial mantle. Thus many EQs occur at the boundary of convergent plates.

Setting up an antenna on Réunion Island, will be particularly interesting for the study of seismicity and volcanism along the East African rift system, linked to the progression of the Somalian plate towards the African plate. It will also lead to larger coverage of this region of the world and can be combined with other VLF networks in the Southern Hemisphere, like SAVNET in Brazil (Raulin *et al.*, 2009).

Another VLF/LF facility shall be set up in Sri Lanka, at the University of Moratuwa. Its proximity to the Equator provides accessibility to the equatorial region where the so-called equatorial electrojet occurs.

5. Conclusions

China Seismo-Electromagnetic Satellite (CSES) was launched in February 2018. This mission provides a new opportunity to investigate EQs electromagnetic precursors observed by satellite, and to combine space and VLF/LF ground-stations in Europe and Sri Lanka.

Capabilities of the VLF and LF reception system (i.e. antenna and receiver) lead to increase the spectral resolutions (i.e. time and frequency) needed for the detection of transmitter signals (amplitude and phase) for both VLF and LF frequency bands, and their associations to EQs EM precursors.

The new stations in France and Sri Lanka will allow, first, a better geographical coverage of seismic regions in particular those in the Mediterranean Sea and eastern Asiatic regions, and second, a complementary observations with the existing VLF European network INFREP (Biagi *et al.*, 2015).

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