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Azimuthal analysis of [SQUID]^2 signals for mesopause and sprites excitations

G. Waysand[1], E. Pozzo di Borgo[3], S. Soula[8], M. Pyée[6], J. Marfaing[2], J.-J. Bois[1], M. Yedlin[7], R. Blancon[3], S. Gaffet[1,4], P. Barroy[5], M. Auguste[1], D. Boyer[1], and A. Cavaillou[1]

[1]*Université de Nice Sophia-Antipolis, Observatoire de la Côte d'Azur, Laboratoire Souterrain Bas Bruit de Rustrel-Pays d'Apt (LSBB), 84400 Rustrel, France*
[2]*Universités d'Aix-Marseille, L2MP Faculté des Sciences de Saint Jérôme, 13397 Marseille, France*
[3]*Université d'Avignon et des Pays de Vaucluse, Dpt de Physique, Rue Louis Pasteur, 84000 Avignon, France*
[4]*Université de Nice Sophia-Antipolis, GéoSciences-Azur, 250 rue Albert Einstein, 06500 Sophia-Antipolis, France*
[5]*Université de Picardie Jules Verne, EA 2081 Phys. Mat. Cond., 33 rue Saint Leu, 80039 Amiens, France*
[6]*Université d'Orléans, LPC2E CNRS 3A, Avenue de la Recherche Scientifique, 45071 Orléans Cedex 2, France*
[7]*University of British Columbia, Dpt of Electrical Engineering 2356 Main Hall Vancouver, BC, V6T 1Z4, Canada*
[8]*Observatoire Midi-Pyrénées, Université Paul Sabatier, Laboratoire d'Aérologie, 14 Av. E. Belin, 31400 Toulouse, France*

Abstract. The physical meaning of the azimuth information provided by the ultra low-noise magnetometer instrument [SQUID]^2 is analyzed for mesopause and atmosphere electromagnetic signal sources. Consequences for a potential world-wide network of such instruments are evaluated.

1. INTRODUCTION

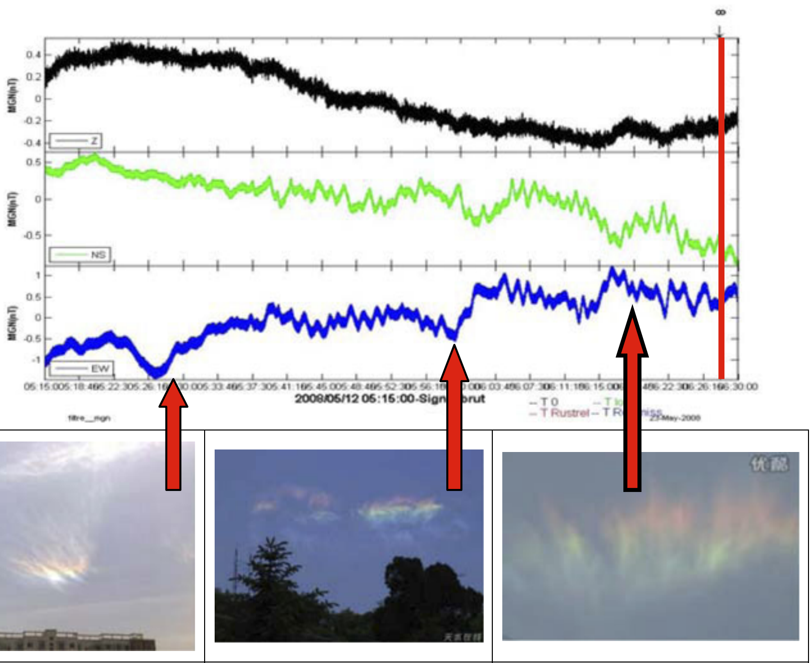
The combination of a low Tc Superconductor 3-axis SQUID magnetometer inside the LSBB capsule Shielding QUalified for Ionosphere Detection (=[SQUID]^2) provides a DC to 40 Hz bandwidth for the observation of magnetic fluctuations with a noise baseline with the present SQUID of 3fT/$\sqrt{\text{Hz}}$ at upper frequencies. Hence it has the potentiality to detect a variety of geomagnetic signals, as it is evident from the magnetometry session of this conference.

The present paper addresses the signification of the azimuth in two extreme cases:

- the first one is the mesopause precursor of the Sichuan-Wenchuan quake of May 12, 2008. It is an extreme nearfield situation because the period of the electromagnetic signal is of the order of 74 seconds.
- the second case, a high frequency one, hence a conventional propagating electromagnetic signal, is the magnetic detection of giant sprites on September 2, 2009 in the Golfe du Lion – about 200 km from LSBB.

2. EXTREME NEAR FIELD SITUATION: THE 12 MAY 2008 SICHUAN-WENCHUAN PRECURSOR

Each ground movement of the Earth shakes the air column above it. This acoustic wave can reach the ionosphere. In the case of Rayleigh waves the response is linear and has been observed initially by Doppler radar techniques. By principle, Doppler sounding needs a reflecting layer at the sounding frequency, thus a large enough charged particles density to reflect the signal probe. For P waves there is no need of active sounding and reflecting layer. With highly sensitive magnetometers shielded from noise sources, such as our [SQUID]^2 system, the collection of electromagnetic signals emitted by the mesopause is possible in spite of its low electron density.



60 minutes ago Baoji, 500 km from epicenter	30 minutes ago Tian-Shui, 450 km from epicenter	10 minutes ago Mei-Xian, 550 km from epicenter

Figure 1. Upper part: Raw signals of the 3 components of the magnetic field recorded by [SQUID]^2 in May 12, 2008 before the Sichuan quake. Black trace: vertical component, Green NS, Blue EW. The vertical red line marks the initial time of the quake. On the EW component, "jumps" of magnetic field are noticeable sixty, thirty and ten minutes before the quake, Each of them had been in time coincidence with "rainbow clouds" observed and video recorded by amateurs at different locations a few hundreds kilometers from the epicenter to be.

Separating the mesosphere from the thermosphere, the mesopause is 90 km above the ground without appreciable day-night variation of altitude. It is the coolest layer above our heads with a temperature around 90 K. As a result, thermalized molecules and charged particle in the mesopause emit a signal only if a collective excitation from an external source displaces them. Such is the case with a P wave, 300 seconds after its emergence when it reaches the mesopause. The response is not linear, the P wave excites a resonance mode of the mesopause. The period of this resonant mode is always between 60 to 90 seconds [1]. The corresponding electromagnetic wavelength is extremely large compared to any geographical distance on Earth. Wherever is the source, any detecting magnetometer is always in extreme near field situation.

In principle, this mesopause resonance mode can also be excited by an external electric field. Unexpectedly, this possibility has been provided by the Sichuan-Wenchuan seismic event of 2008. For one hour the Sichuan quake of May 12, 2008 ($M = 8.1$) has been anticipated by an excitation of the same mesopause resonance (period around 74 sec) [2]. Sixty, thirty and ten minutes before the quake "rainbow colored clouds" appeared each time at a few hundreds kilometers from the epicenter to be, in time coincidence with DC magnetic "jumps" extremely visible on the EW component of the [SQUID]^2 magnetic signals (Fig. 1). World-wide there was no major quake, those occurring with $3 < M < 5$ were not simultaneous to the magnetic jumps.

All over this hour the mesopause resonance excitation was observed by [SQUID]^2 as it appears (Fig. 2). Where the signals of the three components are filtered in the [0.01–1] Hz frequency band.

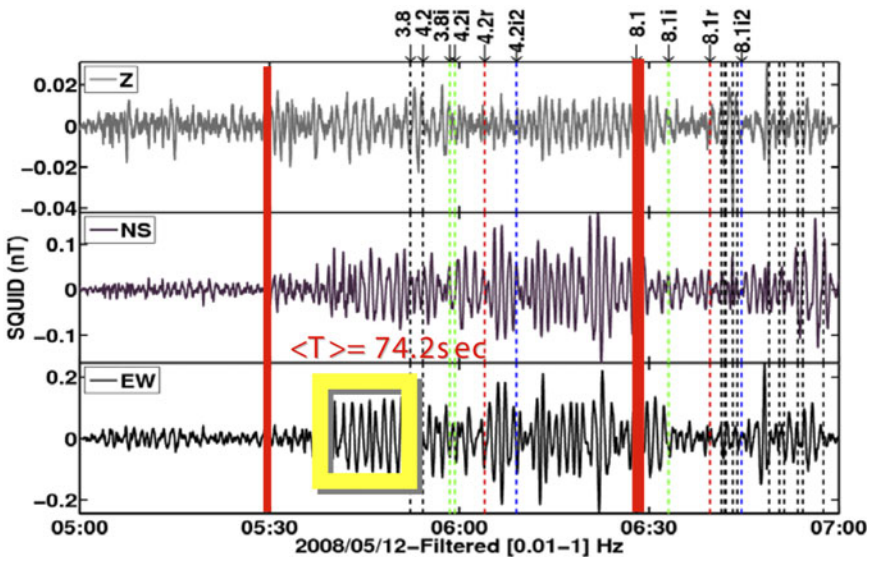


Figure 2. Filtered [SQUID]^2 magnetic components for the hour preceding the Sichuan quake. The excited regime appears immediately on the Z component at 05:30 and progressively on the horizontal ones. The average period of the excitation regime in the yellow frame is 74.2 seconds. The dotted lines indicate the few $M > 3$ world wide seismic events with the following convention: time zero: no index; time zero + 300 seconds, P wave arrival at the mesopause: index i; P wave arrival at Rustrel: index r; arrival time at Rustrel + 300 seconds: arrival of the P wave at the vertical of Rustrel: index i2. The dotted green line 8.1i indicates the arrival of the P wave of the initial Sichuan event at the mesopause. It coincides with the extinction of the excited mode.

There is one more coincidence: the resonance mode has been extinguished 300 seconds after the quake, the time it has taken for the Sichuan P wave to reach the mesopause. Thus four coincidences (the three magnetic jumps + the extinction by the Sichuan P wave) establish that the excitation of the resonance mode was a Sichuan precursor signal). Electric field effects associated with quakes and their visual observations is not unusual and there is an abundant literature about them. In the present case, the presence of electric field is established by the fact that the magnetic response to the first aftershock was recorded as a magnetic pulse by [SQUID]^2 (on the Z and EW components), a feature sometimes observed by [SQUID]^2 for seismic events near Greece and Turkey.

The oscillation amplitude of the resonance mode is not constant, presumably the result of intermittent electric field emissions but each bunch of oscillation has a constant amplitude over many periods. The NS/EW ratio when the signal looks constant over a few minutes gives the azimuth of the horizontal projection of the magnetic oscillation. This rough unfolding was done before any information was available on the seism mechanism itself. It had given an azimuth of $35 \pm 10°$. Fig. 3 compares this result to the USGS map of the seism fracture line. Clearly, as expected in a near field situation, the signal horizontal azimuth, at the rough precision of the unfolding, gives the source polarization. Indeed with a period of 74 seconds the phase shift from the epicenter to Rustrel is of the order of 0.1°. In addition let us note that the surface fault line is about 400 km long. Taking that length as a characteristic length for a dipolar electric field emission, is coherent with rainbow clouds observation at similar distances from the future epicenter.

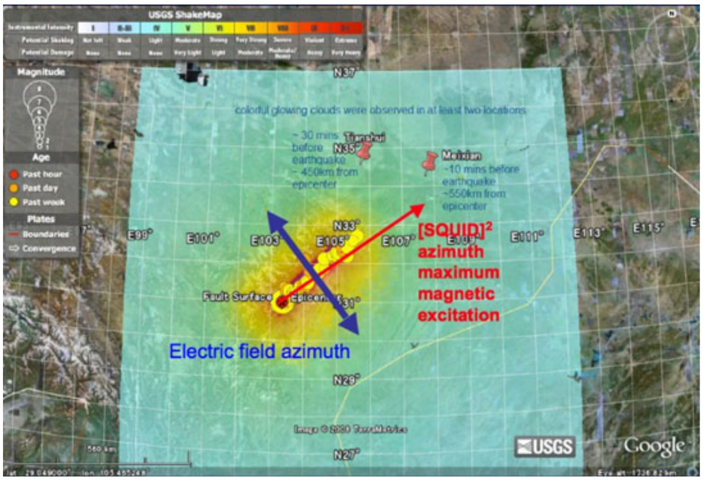


Figure 3. Sichuan fracture line orientation compared to $[\mathrm{SQUID}]^2$ response azimuth. The pin symbols indicate the locations of two of the video observations of rainbow clouds. The length of the surface fault line is about 400 km. "Rainbow clouds" observation at similar distances from the epicenter is coherent with a dipolar electric field emission of that length.

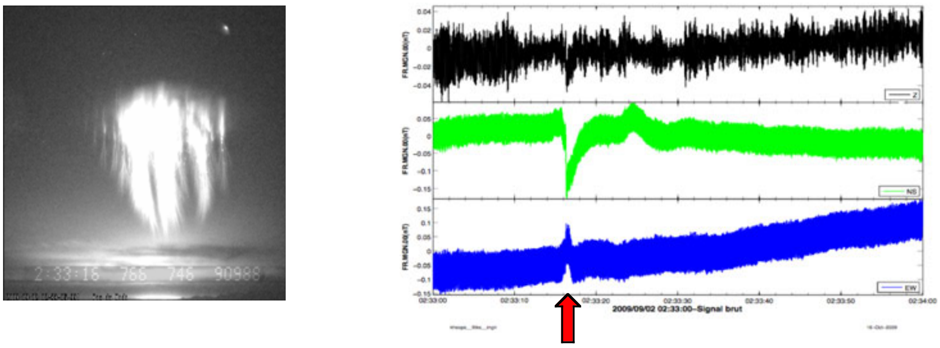


Figure 4. Left: camera frame from Pic du Midi of one of the TLE/right: $[\mathrm{SQUID}]^2$ LSBB magnetic detection of the same TLE at 02:33:16 TU. The ratio H_{NS}/H_{EW} of the peak values of the components defines the azimuth with respect to the EW axis. If the lightning is assimilated to a vertical current, the Ampere law means that the magnetic signal is essentially horizontal, hence the amplitude of the magnetic response is $(H_{NS}^2 + H_{EW}^2)^{1/2}$ and can be compared to the lightning current determined by a the conventional network of electric antennas detecting it.

3. PROPAGATION REGIME: SPRITES (TLE) IN GOLFE DU LION, SEPTEMBER 2, 2009

Sprites are Transient Luminous Events (TLE) triggered in the upper atmosphere by the discharge of positive lightning between the thunderstorm and the ground. They are not so frequent at our mid latitudes. A set of 9 TLE occurred at night in Golfe du Lion on September 2, 2009 and were optically

Table 1. The magnetic response of the 9 TLE detected by [SQUID]^2 the azimuths vary from 196 to 221° are compatible with the source thunderstorm.

event	TV	ΔH_{NS} p_T	ΔH_{EW} p_T	$\Theta°$	ΔH p_T	ΔH p_T total
1	02:33:16	−182	79.5	204	194	199
2	02:37:30	−173	51	196	180	
3	02:41:25	−164	67	202	177	
4	02:46:50	−115	77	214	138	
5	02:50:00	−200	87	204	218	
6	02:51:50	−76	54	215	93	
7	02:55:15	−8.5	4	201	60	
8	02:56:20	−139	103	217	173	
9	03:08:00	−236	205	221	312	318

detected by a highly sensitive camera from the Pic du Midi Observatory West of the Golfe and magnetically by [SQUID]^2 N,NE of the Golfe (Fig. 3).

Results for the set of TLE are displayed in Table 1. The span of the resulting azimuths is represented on Fig. 4. They are compatible with the thunderstorm location (a misalignment of 10°) of the magnetometer cannot be excluded [3].

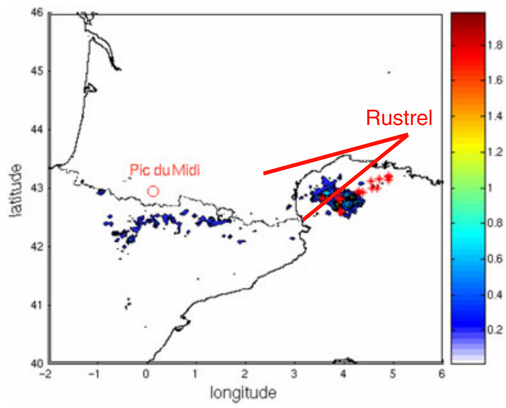


Figure 5. Map of the Golfe du Lion thunderstorm of September 2, 2009. The summit of the red angle is Rustrel, the red lines defines the span of the azimuths of the 9 TLE magnetically detected by [SQUID]^2. The color scale represents the ground flash density per km^2 [3].

Clearly we are in a conventional propagation regime. This is not a surprise, the lightning spectrum is a high frequency one. Even if one considers that the lightning magnetic response is limited at 40 Hz by the shielding, at this frequency the wavelength in the air is about 7500 km, assuming the distance from Rustrel to the thunderstorm to be of the order of 150 km, this gives a phase variation from the source to LSBB of 7°, this is no more a near field regime as for the Sichuan precursor.

4. CONCLUSION

The rough unfolding of the azimuth information offered by [SQUID]^2 in these two extreme situations illustrates the wide variety of signals that this kind of instrument can explore. In each case, even if the unfolding had been more cautious, the precision is limited by the fact that for the time being it is still a unique instrument of its kind. This calls for the creation of a world-wide network of such stations.

Even if they have not the same noise rejection quality, their time coincidence will provide a complementary tool for the study of natural hazards of societal importance.

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