Schumann Resonance Observations from the Central Pacific Ocean

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ABSTRACT: A one-year data set of calibrated magnetic Schumann resonance (SR) observations from the UPF field station in Tahiti, French Polynesia, has been analyzed in terms of resonant peak frequency, Q-factor and magnetic intensity. It is assumed that the global lightning activity is the main natural source of SR in the Earth-ionosphere waveguide. However, due to daily variation of solar heating, the location of the maximum lightning activity on Earth is “quasi-heliosynchronous” and varies with longitude, but occurs consistently in the late afternoon in local time. The analysis of the SR intensity on the UT scale shows maxima at about 09:00, 15:00 and 21:00 associated with afternoon thunderstorms over southeast Asia (Maritime Continent), Africa and the Americas. Assuming an ideal Earth-ionosphere waveguide, the angular structure of the amplitudes of the horizontal component of the magnetic field of the first three resonant modes presents nodes at 180, 90 and 60 degrees from the main source of SR excitation. Considering the three main tropical lightning centers, Tahiti is approximately located 90 degrees from both the Maritime Continent and South America and 180 degrees from Africa. Indeed, lightning activity over the Maritime Continent and the Americas, respectively west and east of Tahiti along great circle paths, is detected in the NS-oriented magnetic coil. The most prominent lightning center in Africa appears in the EW-oriented coil (and with a reduced intensity relative to the NS coil contributions), despite its quasi-opposite location. Furthermore, the spectrum analysis has put in evidence an unexpected fourth tropical lightning center located close to Tahiti, with a maximum in activity in late afternoon local time. More than the spectrum analysis, individual pulses produced by ELF Q-burst are carefully examined and associated with the three lightning centers thanks to the WWLLN data. Finally, the sensitivity of the magnetic coils to very close CG or IC flashes is also examined. The lightning waveforms are often not saturated and can have durations exceeding 1second.

INTRODUCTION

The lowest frequencies (<100Hz) of the electromagnetic spectrum radiated by lightning can propagate several times around the Earth in the Earth-Ionosphere guide, resonate and behave as quasi-standing waves predicted by Schumann in 1952 (Schumann, 1952) and commonly called Schumann Resonances (SR). Global descriptions of the Schumann Resonance phenomena have been published in Voland [1984], Nickolaenko and Hayakawa, [2002], Rakof and Uman, [2003], Price et al, [2007], Satori et al, [2009]. The resonance-frequencies have been

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deduced from spectral analysis by Balser and Wagner [1960]. The resonance-frequencies have been measured by means of electromagnetic sensors located on Earth: 8, 14, 20Hz for the first three modes. Because of the finite conductivity of Ionosphere and asymmetry of the wave-guide thickness due to day/night fluctuations, those resonance-frequencies values are slightly smaller than the theoretical ones calculated with an ideal spherical wave-guide. According to the standing-wave theory, the measurement of the SR amplitude depends on the distance between the source and the detector. Assuming an ideal wave-guide, the angular structure of the amplitude of the magnetic field of the first three TM normal modes is represented in Fig.1. One of both poles is a suitable location for a magnetic sensor in order to record the global lightning activity which mainly takes place in the inter-tropical belt. Indeed, the analysis of the SR intensity on the UT scale shows maxima at about 09:00, 15:00 and 21:00 associated with afternoon thunderstorms over southeast Asia (MC for Maritime Continent), Africa (AF), and the Americas (AM), commonly called the three chimneys. Thus, global lightning is mainly concentrated over land and oceanic lightning activity has a minor contribution. However, we have considered it interesting to place a magnetic sensor in Tahiti, located in the central Pacific. The first argument is that central Pacific is about 10Mm (90°) from two of the three chimneys and about 20Mm (180°) from the third chimney. The “drawback” is that Tahiti is located in a region where relatively intense lightning activity can be recorded. The seasonal cycle is the major source of weather variability on monthly time scales. It is composed of two main seasons. The wet season, from November to April, is associated with high rainfall amounts and high thunderstorm activity as the South Pacific Convergence Zone (SPCZ), source of deep convection, extends towards French Polynesia [Vincent 1994; Ortega and Guignes 2007]. The dry season extends from May to October and is characterized by low rainfall quantities consistent with the SPCZ being confined in the western part of the basin. So we paid attention to how the sensor is able to record SR with close lightning activity, especially during the wet season.

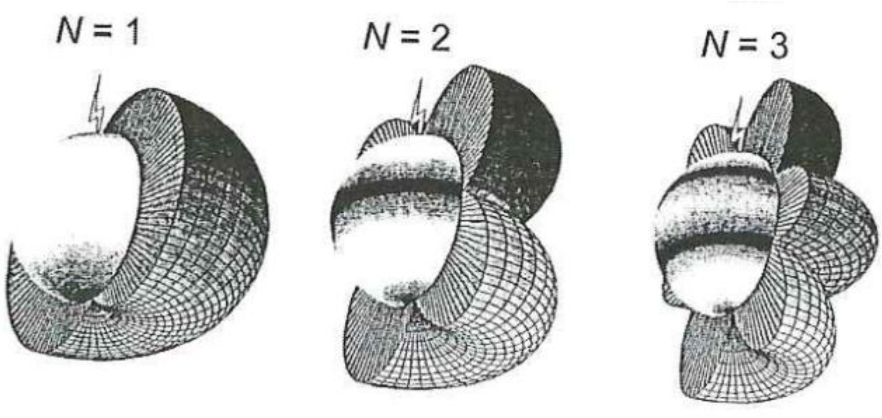

Fig.1 Amplitude of the magnetic field of the first three SR modes
(from Rakov and Uman [2003] adapted from Sentman [1996])

We first present the ability of the Tahitian sensor to detect the SR in the middle of the Pacific and discuss the coherence in regards to the standing-wave theory. Then, diurnal variations of the SR intensity are analyzed in comparison with the global lightning activity provided by the Wide World Lightning Location Network (WWLLN).

MEASUREMENT

The sensor

The detector (LEMI-30), provided by the University of Tripura (India) consists in two 1 metre long magnetic induction coils. They are set horizontally on a concrete slab and accurately North-South and East-West oriented. LEMI-30 is intended for the study of magnetic field variations in the frequency band 0.001-30 Hz. The setting must be done very carefully since the signal recorded is seven orders of magnitude smaller that the terrestrial magnetic field. Even if that magnetic field can be assumed to be constant, micro- vibrations transmitted to the coils can induce a detectable magnetic field variation.

The sensor location in Tahiti is 149.5°W 17.5°S. The data are continuously recorded with a 128Hz sampling frequency and stored every hour in a file. The SR features, spectrum, resonance-frequencies and Q-factors, are calculated with 10 minute segments of recorded data, according to previous analysis.

SR Spectra: 2013-01-22 (wet season)

Fig.2 shows four amplitude spectral densities (ASD) of one hour data recording from the two perpendicular coils (blue and green curves). A one hour time slot (one graph) approximately correspond to the maximum thunderstorm activity of one the three chimneys, 8-9h, 12-13h and 20-21h. Fig.3, where flashes detected during the same four time intervals are plotted on four separate world maps, confirms the assumption of the three chimney model. Indeed, although the global detection is nearly constant whatever the time of the day, the flash amount evolves from region to region, with a maximum over the MC at 8-9h, over South America at 20-21h and over Africa at 12-13h. Note that the amount of flashes over the three chimneys is reduced at 2-3h while active thunderstorms are detected in central Pacific. Thus, that fourth time slot, 3-4h, has been added in Fig.2 for discussion.

The first result is that the SR can be clearly detected from central Pacific, the Q-factor ranging between 2.5 and 5 for the first SR mode. During the austral summer, when global thunderstorm are located further south, according to the standing-wave theory and to the Tahitian sensor location, thunderstorms located in the tropical belt must show up in the NS component, with an attenuated contribution of AF which is located close to a node (180°). Indeed, at 8-9h and 20-21h, the thunderstorm activity increases over MC and AM respectively (Fig.3) lead to a high amplitude of the first SR mode (blue spectra). At 8-9h, the relatively high amplitude of the first mode can be attributed both to AF and MC activities according to Fig.3. We can note that, for that NS component, the peak amplitudes decrease for mode 2 and 3 (14 and 20 Hz) and this is in accordance with the standing-wave system described in Fig.1.

However, the thunderstorm activity increasing over AF does not induce significant signals in the EW oriented coils. This could be expected since, as previously mentioned, AF is located close to a node. It must be noted that, unlike the NS component, the peak amplitudes of the EW components (green spectra) increase with the mode 2 and 3 (14 and 20 Hz) especially at 8-9h and 3-4h. Indeed, as shown in Fig.1, the area of “zero field” around the node location is reduced when the mode increases.

The contribution of the central Pacific (CP) thunderstorms on the amplitude spectra is not obvious. First, those thunderstorms are also located close to a node and, at that time of the day, MC is still active and must show up in the NS component. Nevertheless, the fact that, first, the NS spectrum amplitude only slightly decreases with the mode and, second, that the spectral amplitude of the EW component increases at the second and third modes, implies that there is a minor, but existing contribution of the CP thunderstorms in the SR detected in Tahiti.

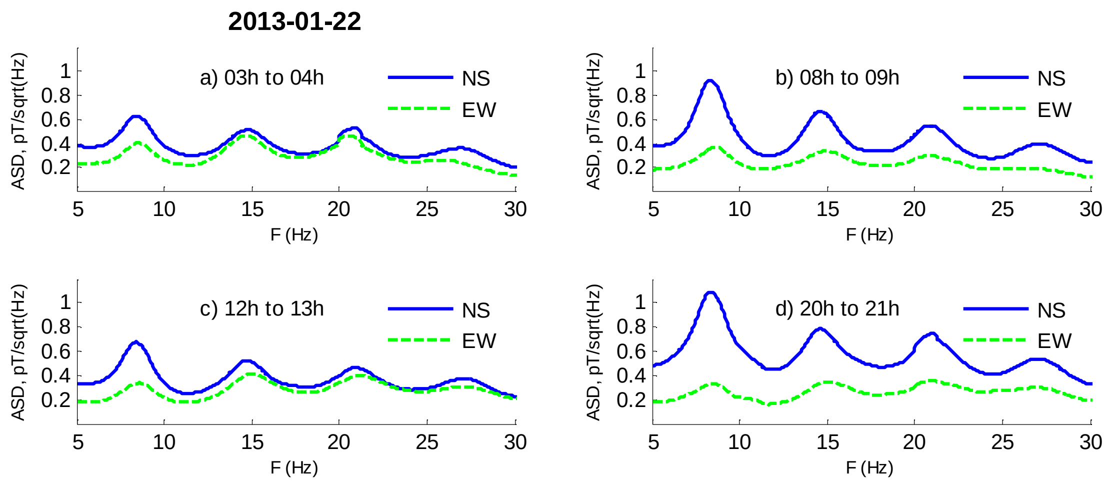

Fig2. Four amplitude spectral densities of one hour data recording of the day 2013-01-22 from the NS oriented coil (blue) and from the East-West oriented coil (red)

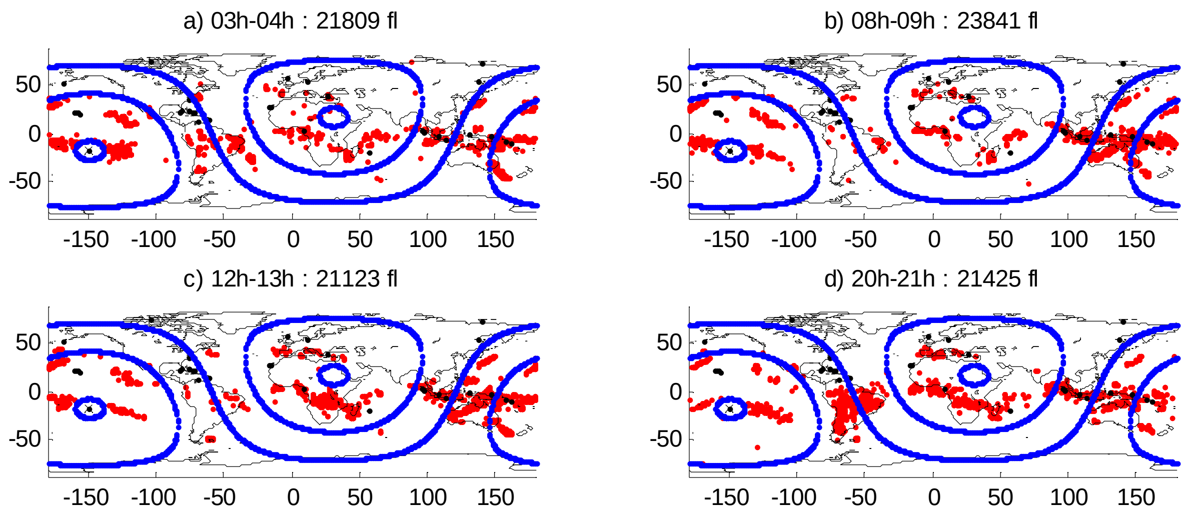

Fig.3: Worldwide flash distributions from the WWLLN corresponding to the time intervals of Fig.2 for the same day (2013-01-22). Blue lines are the equidistant points from Tahitian sensor (x) at 10°, 45°, 90°, 135° and 170°. The total amount of flashes is indicated in for each time interval

SR Spectra: 2013-07-06 (dry season)

Amplitude spectral densities and lightning distributions are shown in Fig 4 and 5 respectively for the day 2013-07-06 (dry season) with the same configuration than Fig. 2 and 3 (identical time intervals). The northward shift of the general thunderstorm activity can be clearly seen in both figures. The amplitudes of EW component are greater during that season which is sensitive to thunderstorms of North America (20h-21h and 03h-04h). Thunderstorms from Europe-Asia can be detected in the EW component between 12h and 13h.

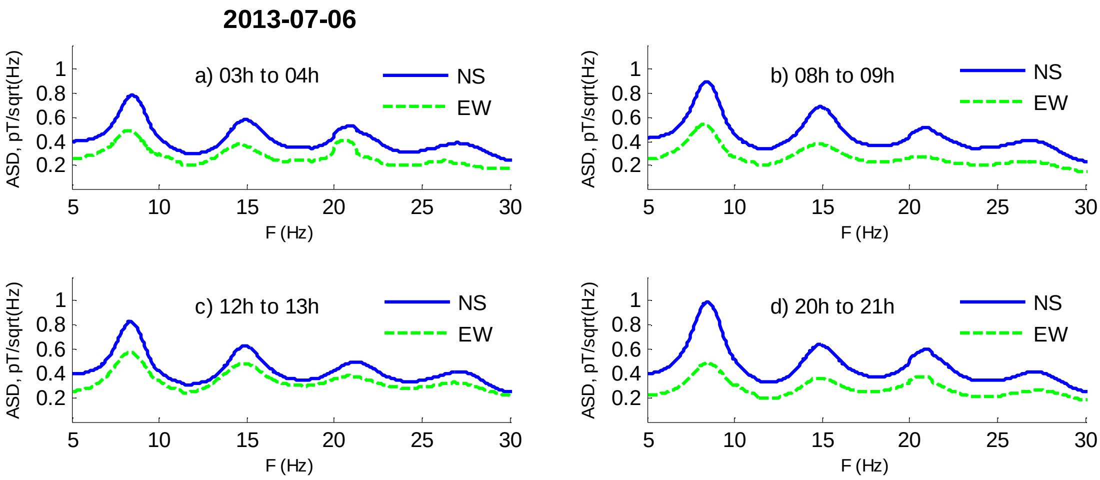

Fig.4: Four amplitude spectral densities of one hour data recording from the North-South oriented coil (blue) and from the East-West oriented coil (red) for four time intervals on the day 2013-07-06

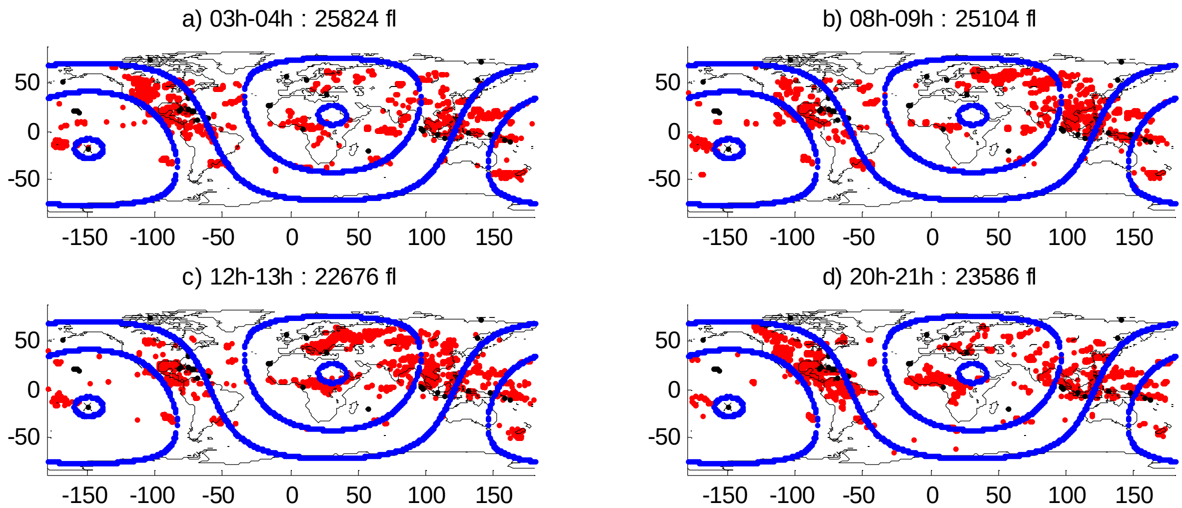

Fig.5: Worldwide flash distributions from the WWLLN corresponding to the time intervals of Fig.4 for the same day (2013-07-06). Blue lines are the equidistant points from Tahiti (x) at 10°, 45°, 90°, 135° and 170°. The total amount of flashes is indicated in for each time interval

Mean diurnal SR amplitude variations

From the estimation of the SR spectral amplitudes (first three modes), monthly mean variations have been calculated and plotted in Fig.6 for the months of January and July 2013. In January, the analysis done for one day in the previous section can be generalized to the month. The NS component shows the increased thunderstorm activity in both the MC (8h-9h) and AM (21h). The NS component is rather weak. The amplitude of the EW component has increased due to the northward shift of the general thunderstorm activity. In July, a shift of the two maxima in the NS component is noted, in the two intervals 8h to 11h and 21h to 22h. That correspond to a Eastward shift of the general thunderstorm. Both observations indicate that the general move is North-Eastward oriented. That tendency can be seen by comparing Fig.3 and Fig.5.

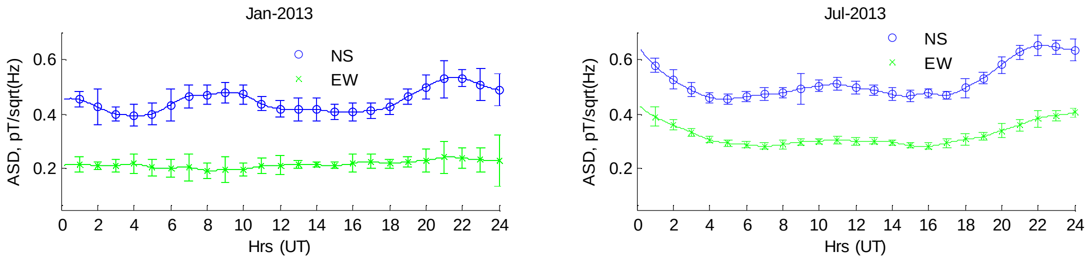

Fig.6: Monthly mean diurnal variations of the two magnetic component amplitudes for the first mode for January 2013 (wet season) and July 2013 (dry season), with corresponding standard deviations.

LIGHTNING ACTIVITY IN THE CENTRAL SOUTH PACIFIC

The WWLLN Management Team, led by R. Holzworth of the University of Washington, produces maps of global lightning climatology. Fig.7 shows the global lightning distribution calculated over 9 years. It is well known that global lightning is mainly concentrated over land [Christian et al 2003, Williams and Stanfill 2002, Hutchins et al 2013]. However, the central Pacific shows an area of high lightning density far from any continent. Four areas, corresponding approximately to the location of the maximum thunderstorm activity during austral summers, are drawn in Fig.7. Conventionally, only the three chimneys should have been considered, but a fourth area can be distinguished, located in the middle of the Pacific, shifted slightly southward from the equator. For that area, local late afternoon occurs at about 3h UT.

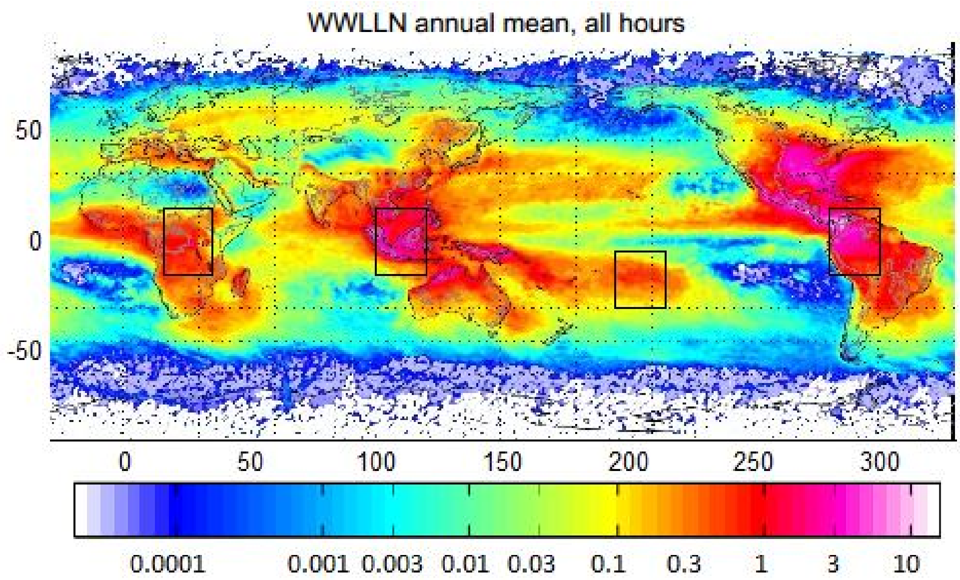

Fig.7: Global flash distribution calculated over 9 years (WWLLN)

For each area, we have calculated the mean daily flash distribution of March in the interval 2008-2013. The relative comparison of total flash detection per area cannot be exploited since the efficiency of the network is not homogeneous all over the globe. For the three chimneys, we can distinguish a clear maximum activity at 15-16h for Africa, 21-22h for South America and 9-10h for MC. For the fourth area, South Central Pacific (SCP) the distribution is more homogeneous although two maxima appear, one at about 02h-03h and the second around 12h-13h. Nevertheless, the three chimneys MC and AM are still active, more than CSP, and must be the dominant contribution of the NS signal even at about 03h.

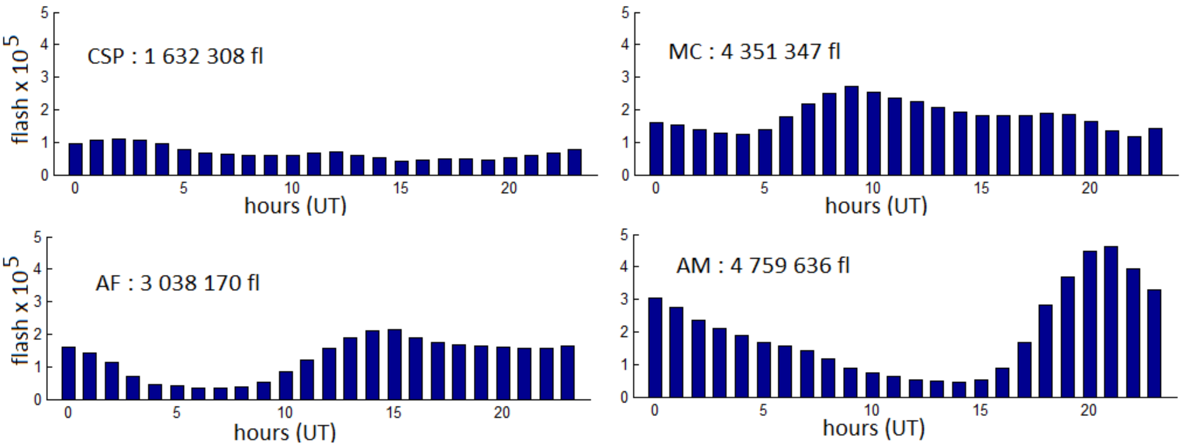

Fig.8: Daily WWLLN flash distributions for the four areas defined in Fig.7 and calculated for the months March in the period 2008 to 2013

THE INFLUENCE OF CLOSE LIGHTNING FLASHES ON SR DETECTION

If lightning activity in the CSP can be detected in the EW component of the SR amplitude spectra recorded in Tahiti, the influence of the close lightning must be analyzed. Fig.9 shows the amplitude spectra (NS and EW, first mode) deduced from the data recorded on the day 2013-01-13. It can be seen that between 20h and 23h, the spectrum is abnormally high. Fig.10 shows the flashes recorded by WWLLN on the day 2013-01-13, over a large area around the sensor location (180°W-120°W / 30°S-0°). 61 052 flashes have been recorded all day long. The flash distribution has been separated into two periods, 0h-20h and 20h-23h. Fig.10a shows the flashes recorded all over the area during the first period. Fig10b gives a zoom on Tahiti Island in the same period. In Fig.10c, the flash locations are plotted in the second period and Fig.10d, gives a zoom on the Tahiti Island (the SR sensor location is indicated by a blue dot). Flashes are located very close to the sensor. A quick analysis of the raw data from January 2013 has shown that out of a critical distance of 15 km from the sensor, cloud-to-ground flashes do not disturb the SR recordings. That criterion does not take into account the lightning peak current and a statistical study over a longer period is needed.

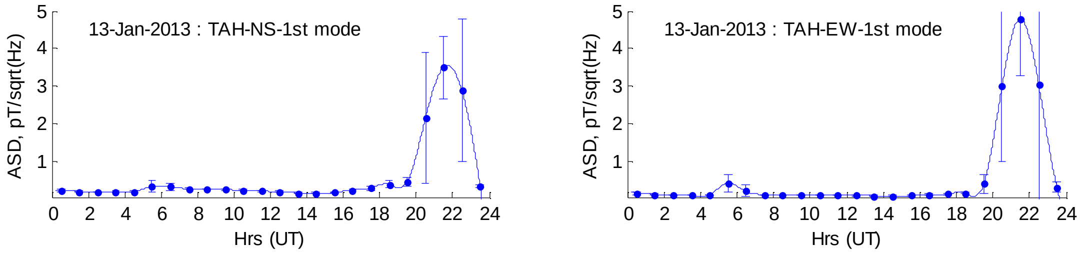

Fig.9: Diurnal amplitude spectral densities for both magnetic components on the day 2013-01-13

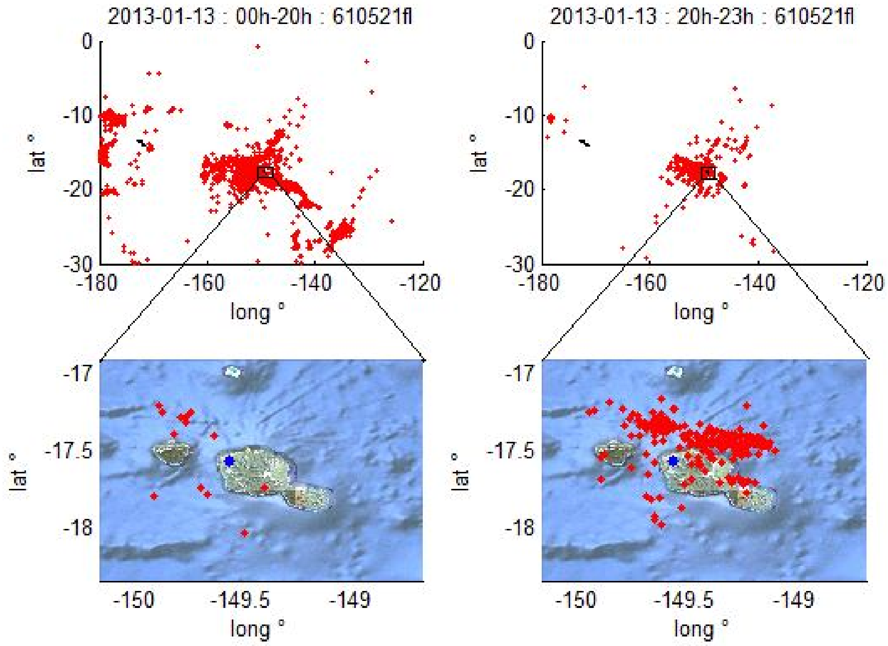

Fig.10: Flashes recorded on the day 2013-01-13 by the WWLLN over the Central South Pacific area. a) flashes from 00h to 20h00 b) same period and zoom over Tahiti; c) flashes from 20h00 to 23h00; d) zoom over Tahiti. The blue dot is the SR sensor location.

CONCLUSIONS

The Tahiti location provides for excellent detection of worldwide SR because Tahiti is remote from the three dominant lightning chimneys. During austral summer, the NS oriented coil allows MC and AM thunderstorm activity to be recorded while the signals produced by AF thunderstorms are weakly detectable due to their location close to a node. However, thunderstorms located in the Central South Pacific seem to have a contribution in the EW signal. That hypothetical fourth chimney could be detected either from Tahiti but with an electric antenna or from South America or West Australia (located at 90°) with magnetic antennas.

During austral winter, a northward shift of the global lightning activity makes the distinction among the different chimney less observable. North America thunderstorms can be detected in both components. The maximum of the diurnal SR amplitude can be associated with a global eastward shift of the general thunderstorm activity. Lightning closer that about 15km from the SR sensor seems to perturb the SR measurement.

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