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Microseismicity, meteorology and the solar cycle

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Abstract

The study of microseismicity and its relation to meteorology and the solar cycle is revisited. Pierre Bernard's important contribution is emphasized. ***To cite this article: J.-P. Poirier et al., C. R. Geoscience 341 (2009).***

Résumé

Microsismicité, météorologie et le cycle solaire. On réexamine les travaux anciens sur la microsismicité et ses rapports avec la météorologie et le cycle solaire. L'importante contribution de Pierre Bernard est mise en relief. ***Pour citer cet article : J.-P. Poirier et al., C. R. Geoscience 341 (2009).***

Keywords: Microseismicity; Atmospheric depression; Swell; Solar cycle

Mots clés : Microsismicité ; Dépression atmosphérique ; Houle ; Cycle solaire

1. Introduction

The study of microseisms, actively pursued in the end of the xixth and the beginning of the xxth century, has been somewhat neglected until very recently. Seismologists and climatologists now take a renewed interest in what they used to consider as noise [1,11,21,31]. It is, therefore, not without interest to remember the pioneering, generally unrecognized, contribution of Pierre Bernard (1915–2008), to the understanding of microseismic agitation and its relation to meteorology and solar activity.

2. Microseisms and meteorology

Microseisms are small, short period (less than 30 s), continuous vibrations of the ground, of an amplitude of the order of magnitude of a few micrometers, independent of local accidental causes (mechanical vibrations, etc.). Some can be caused by small magnitude earthquakes, but most have a meteorological origin, resulting from the non-linear interaction of ocean waves, caused by storms, travelling in opposite directions. The pressure pulse thus generated propagates to the sea-floor where it is transformed into seismic Rayleigh waves which can travel over long distances [11,26].

The first author to study microseisms systematically was the Barnabite monk Father Timoteo Bertelli (1826–1905) in the Collegio alla Querce, near Florence.

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Starting in 1867, he used an apparatus he had invented and named *tromometro*. The tromometer consisted in undamped pendulums, free to oscillate in different azimuts, each equipped with a stylum moving along a graduated scale and whose displacement was observed through a microscope. Bertelli thus recorded the amplitude of the microseisms over several years [2,3].

Microseisms were also recorded, using a tromometer, by the Italian seismologist Michele Stefano De Rossi (1834–1898) in his observatory at Rocca di Papa, near Rome [20].

George Darwin (1845–1912) and Antoine d'Abbadie (1810–1897) studied the variations of the vertical, the former with a bifilar pendulum, the latter by observing the reflection of cross-hairs in a pool of mercury 10 m below, in his château-observatory of Abbadia, on the Basque coast. Their observations were plagued by microseismic agitation. Darwin desisted [18], but d'Abbadie continued to study the agitation [16,17] and corresponded with Bertelli [30].

Bertelli had noticed that the microseismic agitation was correlated with barometric lows [2,3] and had drawn the conclusion, in line with the, still alive, pneumatic theory of earthquakes, that subterraneous gases escaped more easily when atmospheric pressure was low, thus causing microseisms.

In the early xxth century, several authors had noticed that microseismic agitation occurred when a cyclonic center travelled on the sea off a seismic station [10]. Progress in the early study of microseisms is, however, due, in a large measure, to Pierre Bernard.

In a 1937 paper, Bernard found that the variations of the intensity of the swell on the coast of Morocco were exactly identical to those of the microseismic intensity recorded in Strasbourg, far from the ocean, but which occurred later. At the dates of the maxima of agitation in Strasbourg, a deep atmospheric depression was present over the Atlantic. It was verified that the variable delay between the maxima in Strasbourg and the time of arrival of the swell in Morocco was due to the difference between the time of propagation of the swell away from the moving depression and the much shorter time of propagation of the microseismic waves through the solid Earth. Bernard concluded by ascribing the microseismic agitation to the action of the swell at its point of origin [4]. Microseisms consist mostly of Rayleigh waves, which propagate in the crust with a velocity varying from 1 to 3 km/s, while the swell propagates in the ocean with a velocity of about 60 km/h (or 0.017 km/s) [9].

On December 14 and 17, 1959, a seismograph installed in the Abbadia observatory detected a strong microseismic agitation, simultaneously with the Parc Saint Maur, near Paris, at the time when a strong depression centered south-east of Iceland reached its maximum. At both dates, the agitation due to the arrival of the swell was detected in Abbadia 32 hours later [7] (Fig. 1).

In 1941, Bernard [10] located the centre of a depression in the North Atlantic at the intersection of three hyperbolæ, loci of the differences in time of a sudden increase of microseismic amplitude between two stations (Fig. 2). A few years later, using tripartite stations consisting of three seismometers, distant by 2.4 km, at the apices of an equilateral triangle, Gilmore could calculate the direction of propagation of the microseismic waves. He was thus able to detect, locate and track hurricanes in the Caribbean (in one instance, 2 days before the hurricane was announced by the US Weather Bureau) [22].

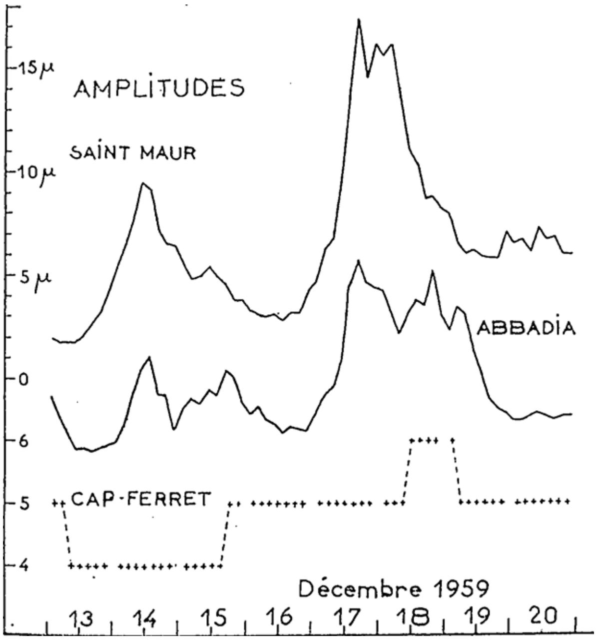

Fig. 1. Amplitude of the microseismic agitation in Saint Maur (near Paris) and Abbadia (on the Atlantic shore). Note that, on 14 and 17 December, the peaks of agitation, due to the propagation of sound waves through the crust, coincide in Saint Maur and Abbadia. Another peak, due to the impact of the swell on the shore, is present 32 hours later in Abbadia, coinciding with the state of the sea as measured in Cap Ferret, but is absent in Saint Maur [7].

Fig. 1. Amplitude de l'agitation microsismique à Saint-Maur (près de Paris) et à Abbadia (sur la côte Atlantique). Noter que le 14 et le 17 décembre, les maxima d'agitation, dus à la propagation des ondes sonores à travers le sol, coïncident à Saint-Maur et à Abbadia. Un second maximum, dû au choc de la houle sur la côte, est présent à Abbadia et absent à Saint-Maur ; il coïncide avec un maximum de l'état d'agitation de la mer au Cap Ferret [7].

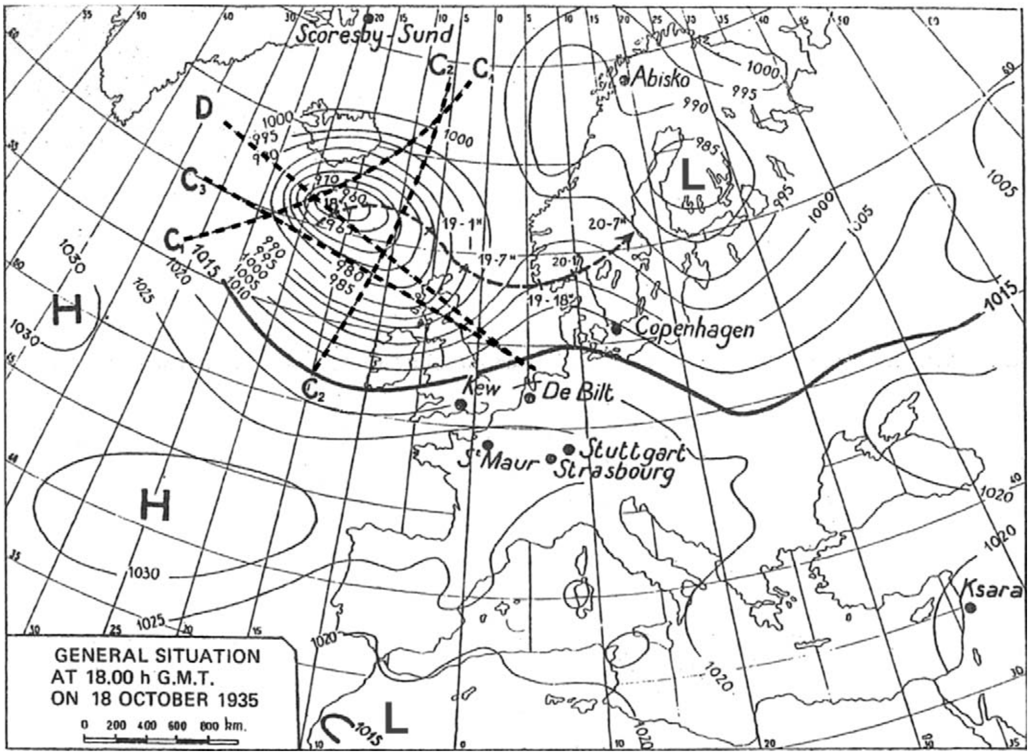

Fig. 2. Localisation of a strong depression in the North Atlantic by observations of microseismicity. The dashed curves are hyperbolæ, loci of the difference in time corresponding to a sudden increase of microseismic amplitude at two stations. C1: Scoresby-Sund and Ksara; C2: Abisko and Scoresby-Sund; C3: Copenhagen and W. Europe as a whole; D: median of the simultaneous stations, Saint Maur and Copenhagen. All curves pass near the center of the depression [10].

Fig. 2. Localisation d'une forte dépression dans l'Atlantique nord, au moyen d'observations de la microsismicité. Les courbes en tireté sont des hyperboles, lieux de la différence en temps correspondant à une augmentation soudaine de l'agitation à deux stations. C1 : Scoresby-Sund et Ksara ; C2 : Abisko et Scoresby-Sund ; C3 : Copenhague et l'ensemble de l'Europe occidentale ; D : moyenne des stations simultanées, Saint-Maur et Copenhague [10].

3. Microseisms and the solar cycle

It being established that microseisms have a meteorological origin, Bernard investigated whether the microseismic agitation might reflect an influence of solar activity on meteorology. He therefore searched for the undecennial variation of solar activity in a long uninterrupted series of microseismic recordings at Parc Saint Maur, starting in 1910, as well as shorter series at Eskdalemuir, Strasbourg and La Plata. He found two clear maxima in 1919–1920 and 1929–1930, two years after the maxima of solar activity (maximum number of sunspots) of 1917 and 1927, at the time of the fastest decrease of the number of sunspots. He then concluded that the frequency and intensity of atmospheric perturbations in the North Atlantic, and probably also in the South Atlantic, would have a periodic variation of 11 years, with a maximum during the decrease of solar activity [5,6].

Those results were confirmed by the analysis of more recent data from 13 seismic observatories in Europe, one in Rabat (Morocco) and La Plata (Argentina) [8]. The curve of the amplitude of microseismic agitation, smoothed by the linear filtering method of Labrouste, correlates rather well with the curve obtained by differentiation of the biannual mean of the Wolf numbers. The Labrouste harmonic analysis method consists in substituting, for every ordinate of the primitive graph, sums or differences of equidistant ordinates. The sums and differences eliminate composants of period shorter and longer, respectively, than the period one is interested in, thus favoring it [24].

Bernard [5] noticed that the curve of the microseismic agitation lags the curve of the Wolf number by approximately a quarter cycle (Fig. 3). In a brief discussion of the correlation between the number of sunspots and the amplitude of the microseismic agitation, he considered that increasing the area of

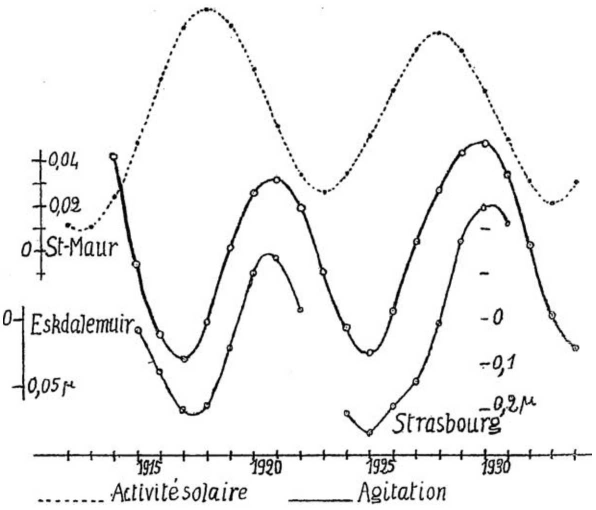

Fig. 3. Curves of the amplitude of microseismic agitation, smoothed with a Labrouste filter, at Saint Maur, Eskdalemuir and Strasbourg, lag the Wolf number curve, proxy of solar activity (dotted) by a quarter cycle [5].

Fig. 3. Courbes de l'amplitude de l'agitation microsismique, lissée par un filtre de Labrouste, à Saint-Maur, Eskdalemuir et Strasbourg. Elles sont déphasées d'un quart de cycle par rapport à la courbe du nombre de Wolf, représentant l'activité solaire [5].

sunspots reduced the solar irradiance (as thought at the time) hence, in someway, affected meteorological phenomena, in particular cyclonic perturbations. At the time of Bernard's study, solar activity was essentially characterised by the number of sunspots (or groups of sunspots), representative of the so-called magnetic close-field activity. However, the open-field activity, consisting in corpuscular ejection from coronal holes (solar wind), is also modulated by the 11-year Schwabe cycle, reaching its maximum toward the minimum of the sunspot cycle.

It is commonly argued that solar activity cannot significantly affect tropospheric phenomena – more precisely that the solar cycles cannot impose their print in those phenomena – due to the quite small variability of solar total irradiance (1‰) during a cycle. However, several mechanisms have been proposed which may circumvent this objection. Let us present only one of them, involving the so-called global electric circuit. The electric current density, J_z, that flows downward from the ionosphere through the troposphere to the Earth's surface, penetrates layer clouds and generates space charges at their boundaries, thus affecting the microphysical interaction between droplets and ice-forming and condensation nuclei [13]. Tinsley et al. [32] infer that "*mechanisms responding to J_z are candidates for explanations of sun–weather–climate correlations*". In particular, effects of changes in polar cap ionospheric potential and J_z, due to changes in the longitudinal component B_y of the polar wind, were observed in surface pressure at high latitudes by Mansurov et al. [27] and Page [29], and recently, with high statistical significance, by Burns et al. [12]. As already mentioned, the solar wind is modulated by the solar cycle. Changes in relativistic electron precipitation from the sun have been observed to affect the atmospheric vorticity [23,25,34], as well as the 500 hPa temperature and cloud cover.

Although we have no knowledge of J_z variations, or even of particular solar events at the time of the Atlantic depressions studied by Bernard, the correlation on decadal time scale he found between the number of sunspots and microseismic amplitude is not implausible. It is fair to say that the global circuit mechanism is not completely worked out at the present time. It is interesting to note that the importance of J_z current in cloud formation, through the ions it carries (small ions and big ions in the terminology of the time), was pointed out as early as the beginning of the xxth century [14,28].

Bernard [8] also found a correlation between the amplitude of microseismic agitation and the amplitude of the variation of the length of day, as given by Currie [15], which could reflect the fact that the rotation of the Earth is affected by the general circulation of the atmosphere linked to cyclonic perturbations. Evidence for an undecennial periodicity in both the microseismic agitation and the length of day again points to the influence of solar activity on meteorology. These studies would need to be confirmed.

4. Conclusion

Bernard's early observations on the meteorological origin of microseisms have been confirmed and theoretically accounted for. As remarked by Bromirski [11], the direct association of storm-driven ocean waves with microseisms shows that the solid earth is not independent of the global climate system. The correlations between solar activity and microseismicity and meteorology, pointed out in Bernard's pioneering papers, deserve to be investigated in more depth. Independently of its now considerable interest for seismologists, microseismic agitation seems to be a good proxy for cyclonic activity and the great number of seismic stations and networks now in operation provides a considerable corpus that could help obtain a better view of the influence of solar activity on meteorology. Note that correlations between solar activity and short-period meteorological phenomena need not be stationary over time spans of the order of a century [19,33].

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