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Statistical studies of jovian decameter emissions observed during the same period by Nancay Decameter Array (France) and WAVES experiment aboard Wind spacecraft

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Abstract. Occurrence probabilities and polarization characteristics of the decameter jovian emissions (DAM) have been analysed by combined ground and space observations. We use the data observed in the same period by the Nançay decameter array (France) and the WAVES experiment on board Wind spacecraft. The ground observations cover the frequency range 10 to 40 MHz when the space experiment records the lower part of the spectrum from 1 MHz up to 13.8 MHz. Different observation conditions lead to a better description of the jovian decameter emissions where the ground-based and space observations are performed with distinct type of antenna and complementary receivers.

The combination of Nançay decameter observations and the WAVES/Wind data allow to analyse in terms of occurrence probability and polarization more than 200 events. After midnight and between 02:00 UT and 04:30 UT, 50% of these events are simultaneously observed from the ground and in space. In the Io-phase CML diagram, the ground observations are mainly related to Io-A and Io-B sources with right-hand polarizations and Io-C and Io-D sources with left-hand polarizations. For WAVES/Wind observations, the occurrences are related to Io-controlled (Io-C and Io-D) and non-Io-controlled emissions where we note the quasi-absence of Io-A and Io-B sources. The main differences in the occurrence probability between ground and space observations are interpreted as an effect of Earth ionosphere and receiver frequency coverages.

Key words: planets and satellites: individual: Jupiter – polarization – radio continuum: solar system

1. Introduction

1.1. Observational context

It is well known that two coordinates are of great importance when studying jovian radio emissions: the central meridian longitude (CML) which refers to the observer's position with respect to the planetary magnetic field and the Io's orbital position with respect to superior geocentric conjunction (Φ_{Io}). Bigg (1964) established for the first time that the jovian decameter emissions can be attributed to Io-dependent and Io-independent components. The first one depends on Io and appears only in certain positions of the observer with respect to the Io satellite. The second component appears wherever the observer is with respect to Io. On the CML and Φ_{Io} diagram several zones of enhanced occurrence probability have been labelled sources A, B, C, D (CML and Io phase coordinates for each source is mentioned in Carr et al. 1983). The Io-controlled emissions are more intense (Desch et al. 1975; Desch 1980) and have spectral characteristics like typical shape of arcs (Warwick et al. 1979; Boischot et al. 1981; Leblanc 1981; Aubier & Genova 1985). These arcs exhibit opposite curvatures and have been called vertex early arc (VEA) and vertex late arc (VLA) by Warwick et al. (1979).

The polarization of the jovian decameter emission (DAM) was studied by several authors. DAM is mainly polarized in the right-hand (RH) sense and sometimes in the left-hand (LH) sense. Kennedy (1969) reported a polarization analysis of A, B, C and D sources at fixed frequencies (10 MHz, 16 MHz, and 22 MHz). The first measurements of the Stokes parameters had been made by the spectropolarimeter associated to the Nançay Decameter Array (NDA) in a wide frequency band (Boudjada 1991). This receiver allows to analyse the linear and circular degrees of polarization of A and B sources (Lecacheux et al. 1991) and the orientation of the ellipse of polarization (Boudjada & Lecacheux 1991; Shaposhnikov et al. 1999). Using the spectropolarimeter data several authors characterized in more details the relationship between the spectral shape and the associated polarizations (Boudjada & Genova 1991; Dulk et al. 1992; Dulk et al. 1994; Leblanc et al. 1994; Boudjada et al. 1995).

1.2. Simultaneous space and ground observations

Jovian radio emissions have been recorded since a long time by several ground-based observatories and spacecraft. Such simul-

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taneous observations allow to estimate the beaming effect on the emission. The first direct evidence of such effect was reported by Poquerusse & Lecacheux (1978) which attempt to observe an Io-B source at 30 MHz simultaneously from Earth (Nancay observatory) and from the Stereo 5 experiment aboard MARS 3 spacecraft. The authors showed that the emission lobe is smaller than 15° and that a difference of 4° in Io phase makes emissions observable or not. Reyes & May (1981) compared the previous observations with those made at the same time in Chile, Florida, and Colorado and they suggested that Poquerusse & Lecacheux (1978) results may have been applicable only within a relatively narrow frequency range. The arc structures of jovian decameter emissions were analysed by Barrow et al. (1982) using Nançay observations and Voyager 1 and 2 data. They found a linear relationship between the central meridian longitude (CML) of Io-controlled source (Io-A) and the corresponding values of the Jovicentric declination of the Earth. Maeda & Carr (1984, 1988) made comparison of Voyager 1 data and Mizuho-cho Radio Observatory measurements and found a significant correlation with 42 min-lag between non controlled source (non-Io-A) observed from Voyager 1 and the Earth (due to different wave propagation times). This result was supported by Riihimaa (1986) using a jovian non-Io storm observed at the Oulu Observatory (Finland) in 1979 and which was compared with jovian emission observed at the same time from Voyager 1. More recently two groups of authors have compared data acquired from Wind spacecraft launched in 1994 and from Earth. Kaiser & Garcia (1997) compared Wind spacecraft data to Florida data obtained in the range 18-22 MHz during a different period of time (1968-72) when the Jovicentric declination of the Earth (D_E) was comparable. They found a greater number of intense controlled emissions (Io-C and Io-D), compared to what is usually reported, and interpreted their result as an effect of the Jovicentric declination of the Earth D_E which makes more visible the Southern hemisphere. Lecacheux et al. (1998) combined the Nançay Decameter Array observations with simultaneous Wind/WAVES observations which cover the frequency range from 1 MHz to 13.8 MHz. Using two representative Io-controlled events (Io-B/D and Io-C), they have shown that it is necessary to introduce refraction effects to explain the discrepancy between observations and the apparent emission angle deduced from a hollow conical radiation beam.

In this paper we report on statistical studies of jovian decameter emission observed from space and from ground in the same period when the meridian transit of Jupiter at Nançay (France) is mainly during the night. In Sect. 2 we introduce the characteristics of antenna and receivers used by the NDA and by Wind/WAVES. The data analysis of more than 200 events observed from ground and/or from space is discussed in terms of occurrence probability in Sect. 3. We focus our attention, in Sect. 4, on the morning events (observed from 00 UT to 06 UT) where occurrence probability from the NDA and Wind/WAVES are found to be similar around 03 UT. In Sect. 5, we discuss our results and we emphasize on the source occurrence areas in the diagram (Φ_{Io}, CML) which is totally dependent on several parameters as frequency of observation, the Jovicentric declination of the Earth and observation conditions. We conclude in the last section on the complementarity of ground and space observations.

2. Nançay survey receiver and Wind/WAVES experiment

Simultaneous observations of Jupiter radio emission are performed using WAVES experiment data aboard the WIND spacecraft and the Nançay observations. The two receivers cover a total frequency band of about 39 MHz (from 1 MHz to 40 MHz) with a common part between 10 MHz and 13.8 MHz. In the following more details on those receivers and the associated antennas are given.

2.1. Nançay Decameter Array (NDA)

The antenna array consists of two subarrays, one sensitive to the RHC radiation, the other one to the LHC (Boischot et al. 1980). Each subarray consists of 72 conical helix antennas (Erickson & Fischer 1974) with a gain of about 25 dB. The Nançay survey receiver is a spectro-analyser receiver with an instantaneous bandwidth of 300 kHz and a sweeping time of 0.5 second. The sensitivity near 30 MHz is $\Delta S \simeq 10^{-23}$ W.m^{-2}.Hz^{-1} (Dulk et al. 1994). The array can track Jupiter during 8 hours around the meridian transit in the frequency band from 10 to 40 MHz. A 20 MHz high pass filter can be added to limit human interference during the day time. Three other receivers can be connected to the antenna area. A polarimeter with 30 kHz bandwidth, which combines the output of the left and right arrays, allows to compute the complete state of polarization of the wave. The two other receivers have a high time resolution (few milliseconds): an acousto-optic receiver (Lecacheux et al. 1993) and a digital spectropolarimeter receiver (Kleewein et al. 1997) which are mainly used for millisecond radio burst observations.

2.2. The WAVES experiment on the Wind spacecraft

The Wind spacecraft is part of the International Solar Terrestrial Physics (ISTP) program. This satellite studies the dynamics of the interplanetary medium, the Earth's bow shock and terrestrial magnetosphere. The WAVES experiment is a plasma wave and radio instrument covering the frequency range from near DC to 14 MHz (Bougeret et al. 1995). Our analysis concerns the data recorded by RAD2 which is connected to two orthogonal electric dipoles, one of 100 m, the other one of 15 m tip to tip. The RAD2 receiver covers the frequency range from 1.075 to 13.825 MHz with a band pass of 20 kHz. The acquisition time is 20 ms with a standard cycle obtained every 16 seconds. The frequency band has been scanned over 16 channels in some periods of 1995. Since the end of that year a 256 channel mode was definitely adopted.

3. Data analysis and results

For the first time, Jupiter radio emissions in the frequency range 1-40 MHz have been observed from ground and space during the same period with comparable geometry. The NDA covers the range 10-40 MHz and the Wind/WAVES experiment records the lower part of the spectrum up to 13.8 MHz. For our study we have used the data from March 21 to July 08 in 1995 and from April 24 to August 12 in 1996. During those two periods the ground-based observations are performed mainly during the night and thus are less contaminated by man-made interference. The Jovicentric declination of the Earth and Wind spacecraft as seen from Jupiter lies between -3.4° and -2° for 1995 and 1996, respectively. Those values of D_E are quite different from those recorded before and after Voyager encounter where D_E was about +3°. Due to the fact that Wind spacecraft is at a distance from Earth smaller than 1.5 10^6 km the observation conditions (i.e. the observation time and geometrical corrections) are similar in the space and on the ground.

3.1. Data

The observations we report in our analysis are performed during the two quoted periods which correspond to a total of 221 days. We selected these periods because the meridian transit of Jupiter at Nançay (05:00 to 22:00 UT) is mainly during the night when the observation conditions are better. The NDA tracks Jupiter during 8 hours around the meridian time transit while Wind/WAVES observes continuously. In order to compare the two sets of data, we restricted Wind/WAVES's records to the interval of time when the NDA was observing which results in 1760 common observational hours. We establish a database which allows to characterize the observational parameters of each event: the beginning and the end of emission time, the frequency range, the main polarization, the arc curvature and a label from 0 to 2 for increasing intensity. A list of events had been first established and used by Kaiser & Garcia (1997) for each day associated to nearly the same period. The Wind/WAVES data had been reinvestigated to give the same informations than the NDA list during the same eight hours every day for all the events, even the faint ones, which were neglected by Kaiser & Garcia (1997).

3.2. Occurrence probability along the day

From the daily-8 hour observations performed by the NDA, in 1995 and 1996, we selected only 221 days. We rejected the data acquired when the meridian transit of Jupiter occurred during the day between 5UT and 21 UT. Thus we kept two periods (March 21, 1995 to July 8, 1995) and (April 24, 1996 to August 12, 1996) which correspond to 1760 hours of observations. During those periods, the meridian transit of Jupiter shifts each day by about 4 minutes. Fig. 1 shows the number of observations versus the universal time (UT) as covered by the NDA radiotelescope, each bin corresponding to half an hour. For the period considered in our study the number of observations occurrence per half-hour is greater than 100 when Jupiter is tracked between 21-05 UT. During this daily observation we recorded 221 events with the NDA corresponding to 216 hours. The duration of each event is highly variable from half an hour to a few hours with the NDA; the average duration of each event is about one hour. The Wind spacecraft recorded 252 events with a variable duration as in the previous case. The total duration of these jovian emissions recorded by Wind spacecraft below 13.8 MHz is 410 hours, leading to an average event duration of 1h 40 min. In the following we define the occurrence probability as the ratio between the emission duration and the observing duration for each half hour.

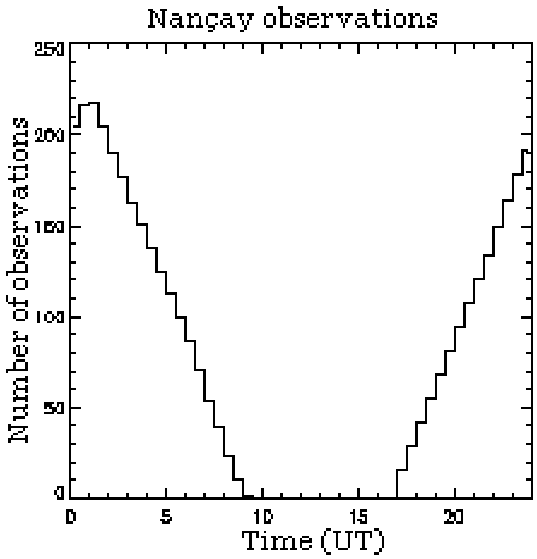

Fig. 1. Number of observations performed by the Nançay Decameter Array versus UT hours during the period from March 21, 1995 to July 08, 1995, and from April 24, 1996, to August 12, 1996.

The occurrence probability is found to be about 38% for the NDA (Fig. 2a) and Wind/WAVES (Fig. 2b) at the maximum of detection. This maximum occurs between 3 and 5 UT for the ground-based antennas whereas the occurrence evolves only slowly along the morning for Wind/WAVES observations. In the afternoon the occurrence probabilities are very different due to the great importance of man-made interference at Nançay station. Even if small percentage of detection is still possible, the efficiency of the NDA is smaller in the afternoon. However the NDA is more sensitive than the WAVES/Wind experiment but several facts diminish its capability. The attenuation produced by the ionosphere in the lower part of the spectrum, and the difference in the jovian emissions in the lower and higher parts of the spectrum as observed by each receiver. The result is an apparent equivalent capability in the early morning when the lowest frequencies are partly detectable at Nançay station.

3.3. Occurrence probability in the (Φ_{Io}, CML) plane for all events

We organised the data in the usual coordinates defined as function of the Io phase (Φ_{Io}) and the central meridian longitude (CML). Fig. 3 represents the sampling of the jovian plane (Φ_{Io}, CML) with NDA observations. The case of Wind/WAVES would lead to a better coverage of the plane but since we restrict the data to the same daily eight hours, as for the NDA, the same

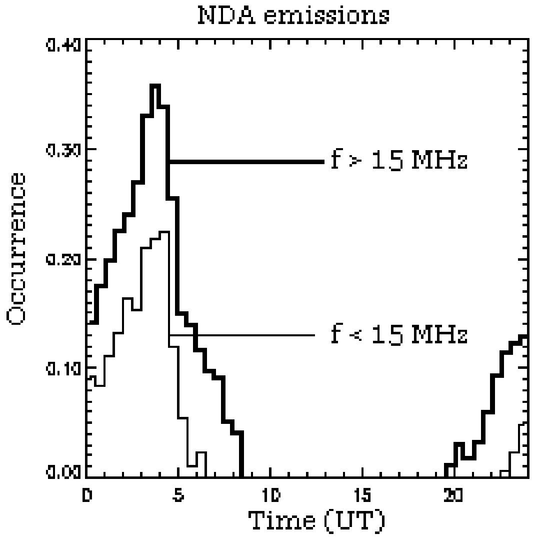

Fig. 2a. The NDA occurrence probability of jovian decameter emission versus UT hours for the period considered in our study. The thick and the thin lines are associated to emissions with frequencies smaller and greater than 15 MHz, respectively.

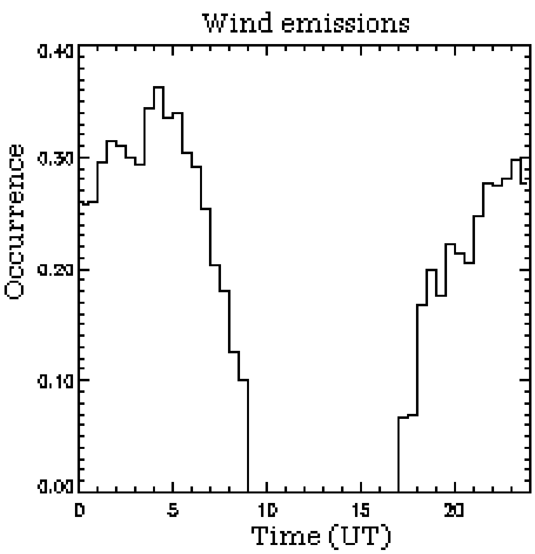

Fig. 2b. The Wind/WAVES occurrence probability of jovian decameter emission versus UT hours of the day for the period considered in our study.

slight modulation exists. However, the projection along the two axes is nearly uniform and thus it does not sidestep the issue. The diagram indicates a quite regular sampling of the plane. One can see that the A region as well as a part of the B region have been less sampled. We have to keep this in mind when considering the plane (Φ_{Io}, CML) as shown in Fig. 3. The (Φ_{Io}, CML) diagram of the emission recorded by Wind/WAVES and by the NDA are shown in Fig. 4 and Fig. 5, respectively. One must note that the appearance of the two diagrams are very different because the two receivers record events in two complementary frequency ranges. Even if the two bands superpose on 4 MHz,

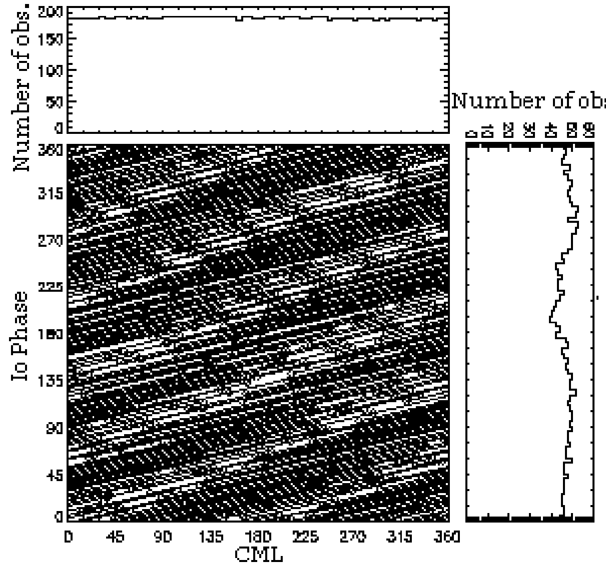

Fig. 3. The coverage by the NDA of the plane (Φ_{Io}, CML) with the corresponding coverage histograms in CML and Io phase observed in the periods from March 21, 1995 to July 08, 1995, and from April 24, 1996, to August 12, 1996.

the occurrence in the (Φ_{Io}, CML) diagram shows that we are partly dealing with different components of the jovian emission.

In Fig. 4 one can see that it is not possible to separate between the occurrence areas of controlled and not controlled sources observed by Wind/WAVES. However the Io-C and Io-B-D areas are slightly visible whereas the AA' sources are not visible. The occurrence probability as a function of Io-phase shows two major peaks recorded when Io-phase is equal to 95° and 250°. Each peak is the contribution of controlled and not-controlled emissions. The non-Io controlled emissions have a probability of occurrence of about 20% for all the values of Φ_{Io}. For two narrow ranges of values the occurrence increases up to 85% ($\Phi_{Io} \simeq 250°$) and to 72% ($\Phi_{Io} \simeq 95°$) corresponding mainly to the Io-C and Io-D/B, respectively. The occurrence probability evolves slowly in CML. It is found about 20% for all CML values and exceeds 30% when 100° $<$ CML $<$ 185° or 320° $<$ CML $<$ 10°. The maximum value is obtained when CML $\simeq$ 150°.

The Φ_{Io} occurrence in the NDA data (Fig. 5) is about 15% for all the values of Φ_{Io}. This occurrence reaches 44% when $\Phi_{Io} \simeq 250°$ and 46% when $\Phi_{Io} \simeq 95°$. Two small maxima are visible: 28% ($\Phi_{Io} \simeq 315°$) and 22% ($\Phi_{Io} \simeq 200°$). On the diagram one can localise the Io-A/A', C and B/D sources. The maximum around $\Phi_{Io} \simeq 315°$ is unusual whereas the other bumps results from D, B, A' and A/C sources. The NDA occurrence in CML is in average 10%. It reaches 32% when CML $\simeq$ 250° due to the contribution of non-Io-AA' emissions. It is around 20% in the CML range 120°-180°. The polarization occurrence probabilities obtained with the NDA are shown in Fig. 6a and 6b for the right-hand and left-hand polarizations, respectively. The main emissions with right-hand polarizations are associated to Io-B region and to another area with a CML between 200° and 270° corresponding to Io-A/A' and non-Io-

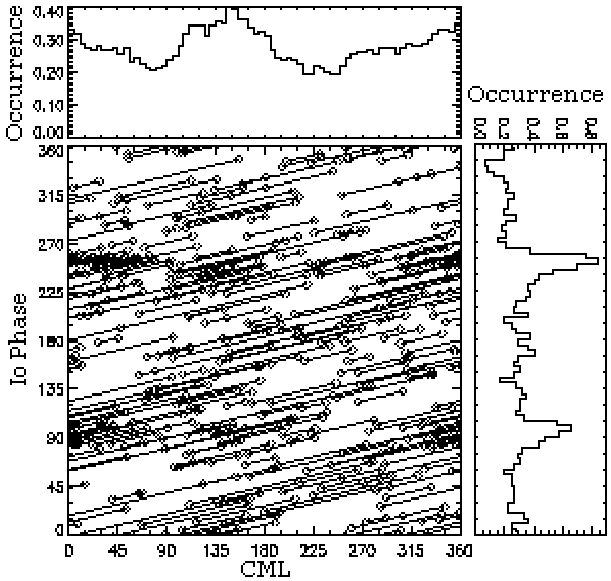

Fig. 4. The jovian decameter emissions observed by the Wind/WAVES in the plane (Φ_{Io}, CML) with the corresponding occurrence probability and for the same period as for Nançay observations.

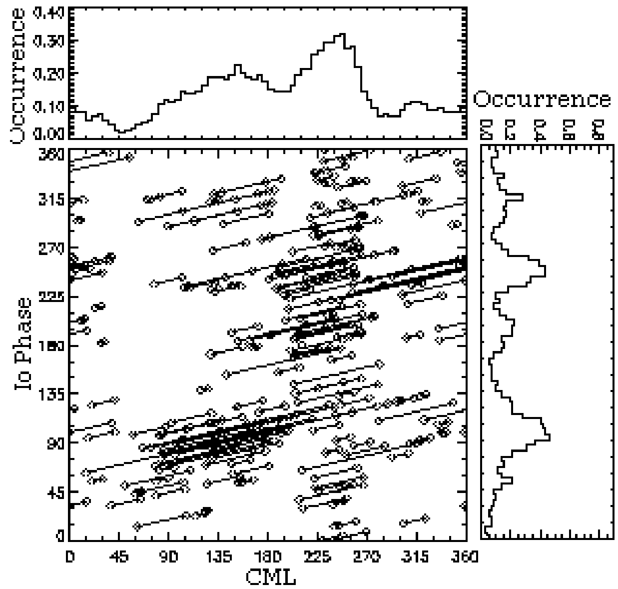

Fig. 5. The jovian decameter emissions observed by the NDA in the plane (Φ_{Io}, CML) with the corresponding occurrence probability.

A. The left-hand emissions have lower occurrence probability and they appear in Io-controlled (Io-C and Io-D) and non-Io-controlled (non-Io-C) regions. It is important to note the absence of Io-C emission with right-hand polarization (see Fig. 6a), only the left-hand component is observed (see Fig. 6b) contrary to previous studies (e.g. Boudjada & Genova 1991). The slight enhanced occurrence around $\Phi_{Io} \simeq 315°$ appears on both polarization diagrams.

From the analysis of the occurrence probabilities in the (Φ_{Io}, CML) diagram for the NDA and Wind/WAVES it appears that the two diagrams present some differences. The non-Io controlled emissions observed by Wind/WAVES are observed less often with the NDA. The occurrence areas of controlled emissions (Io-A/A' and Io-B) appear more clearly from ground observations than from space.

4. Characteristics of the events observed in the morning (00 UT to 06 UT)

The spectra recorded by the Wind/WAVES experiment have been analysed with respect to three criteria: intensity (percentage of very intense events), frequency range (percentage of events extending above 10 MHz) and curvature of arcs (percentage of vertex late arcs and vertex early arcs). We report in Table 1 the total number of events and corresponding percentage of events for the different characteristics in the case of all events (second column) and morning events (third column). In Table 1 the percentage of the very intense events are labeled as I=2. For NDA data the frequency range is separated in two parts (smaller/equal and bigger than 15 MHz), and another criterion has been added to describe the state of polarization of events with right-hand or left-hand polarization. A combined criterion (i.e. high intensity and left-hand polarization) is also given; the Table 1 is discussed in the next section.

When considering all the events observed from ground and from space between 17 UT and 09 UT (see Fig. 2a and 2b), more than 50% are recorded in the morning between 00 UT and 06 UT. From space the number of events recorded in the morning is not much greater than what is recorded during the whole observing period (58%), this is in agreement with what we expected. On the contrary for ground-based observations 77% are recorded in the morning. At low frequencies 91% of the events where observed in the morning. The proportion of events observed at low frequencies is greater (67%) in the morning set of data than in the all events set (56%). For the other criteria the percentage is about the same order in both columns. In particular the VLA-curvature is more common than the VEA (about 73% of VLA arcs).

5. Common events

5.1. Definition

We focus our attention on the events detected simultaneously by both receivers (NDA and Wind/WAVES). We consider as common events those observed simultaneously by both receivers, a gap of less than 30 minutes is accepted. We restricted the study to the morning data, so that the ground-based array is in the best conditions to record low frequency events as well. Among the events recorded in the morning about one half is observed by both radio receivers (52% for Wind and 47% for Nançay).

5.2. Properties of the common events

The common events are analysed as a function of the same criteria as the whole set of events. The results are summarized

Table 1. Spectral characterisation of the jovian events recorded during the same period by Wind/WAVES (1a) and the NDA (1b). The very intense events are those labeled as I=2 and the frequency listed refers to the highest frequency the event attained.

a

	All events	Morning from 00 UT to 06 UT
Number of events	252	147 (58%)
Intensity (I=2)	44 (17%)	24 (16%)
Freq. > 10 MHz	90 (35%)	56 (38%)
VEA	76 (30%)	37 (25%)
VLA	174 (69%)	108 (73%)
VEA and I=2	18 (7%)	8 (5%)
VLA and I=2	25 (10%)	16 (10%)

b

	All events	Morning from 00 UT to 06 UT
Number of events	221	170 (77%)
Intensity (I=2)	59 (27%)	49 (29%)
Freq. ≤ 15 MHz	125 (56%)	114 (67%)
Freq. > 15 MHz	206 (93%)	153 (90%)
VEA	36 (28%)	27 (26%)
VLA	94 (72%)	77 (74%)
LHP	71 (32%)	56 (33%)
RHP	144 (65%)	110 (65%)
LHP and f ≤ 15 MHz	52 (42%)	47 (42%)
LHP and f > 15 MHz	65 (31%)	49 (33%)
RHP and f ≤ 15 MHz	72 (58%)	66 (58%)
RHP and f > 15 MHz	135 (69%)	100 (67%)
LHP and I=2	23 (10%)	19 (11%)
LHP and VEA	12 (9%)	9 (10%)
VEA and I=2	22 (17%)	18 (19%)
VLA and I=2	34 (26%)	30 (32%)

Table 2. Morning common events recorded by Wind/WAVES (2a) and the NDA (2b).

a

	Common cases	Percentage*
Number of events	76	52%
Intensity (I=2)	7 (9%)	29%
Freq. > 10 MHz	27 (35%)	48%
VEA	21 (29%)	57%
VLA	52 (71%)	48%
VEA and I=2	2 (3%)	25%
VLA and I=2	5 (7%)	31%

b

	Common cases	Percentage*
Number of events	80	47%
Intensity (I=2)	26 (32%)	53%
Freq. ≤ 15 MHz	60 (75%)	53%
Freq. > 15 MHz	70 (87%)	46%
VEA	17 (34%)	63%
VLA	33 (66%)	43%
LHP	30 (38%)	54%
RHP	47 (59%)	43%
LHP and f ≤ 15 MHz	29 (36%)	62%
LHP and f > 15 MHz	31 (37%)	63%
RHP and f ≤ 15 MHz	29 (36%)	44%
RHP and f > 15 MHz	47 (59%)	47%)
LHP and I=2	13 (16%)	68%
LHP and VEA	6 (12%)	67%
VEA and I=2	11 (22%)	61%
VLA and I=2	14 (28%)	47%

* Percentage of common cases among the morning events for each criterion

in Table 2. In the following we compare for each parameter the last column of Table 1a/1b (morning events) to the first one of Table 2a/2b (morning common events). If the percentage in Table 2 is greater than in Table 1, the concerned criterion increases the probability to be a common event. We compute in the last column of Table 2 the percentage of common events for each selected criterion. When this percentage is greater than 52% in the case of Wind/WAVES and 47% for Nançay, the considered criterion increases the chance for one event to be observed by both systems.

In the case of Wind/WAVES data the arc curvature seems to be the only criterion which slightly increases this probability: in the last column of Table 2a 57% of the VEA are common. In the case of Nançay data several criteria play a role: the intensity, the frequency range (when emission is observed at frequencies lower than 15 MHz), the VEA-shape, the polarization (33% of the events have left-hand polarizations in the morning compared to 54% in the common data set). To evidence these results we have reported in the last column of Table 2, for all the criteria, the percentage of common cases among the morning events.

6. Discussion

We analyse the jovian decameter emissions observed from ground and space by the Nancay Decameter Array (NDA) and the Wind/WAVES experiment. For the considered period, March 21 to July 08, 1995 and April 24 to August 12, 1996, the maximum values of the occurrence probability from ground and space are comparable but the NDA sensitivity is found to be affected by the observing conditions in the lower frequency ranges. It is known that the observation conditions, on ground are modulated by the interference and ionosphere conditions in particular late in the afternoon and in the evening (17 UT to 24 UT). Such observational conditions were discussed by several authors (see Genova et al. 1987 and references therein) who showed the statistical occurrence bias due to the Earth's diurnal or annual rotation and by beats between these periods and the emission periodicities. From our analysis the occurrence probability at the NDA presents same features as reported by Genova et al. (1987) in their Fig. 77 with a maximum around 04 UT. For Wind/WAVES and NDA, the maximum occurrence of detection is found to be about the same order (38%) in the morning between 3 and 5 UT. In the afternoon the efficiencies of the two receivers are very different. It reaches 30% for Wind/WAVES but it is only a few percents of the NDA (less than 4% at fre-

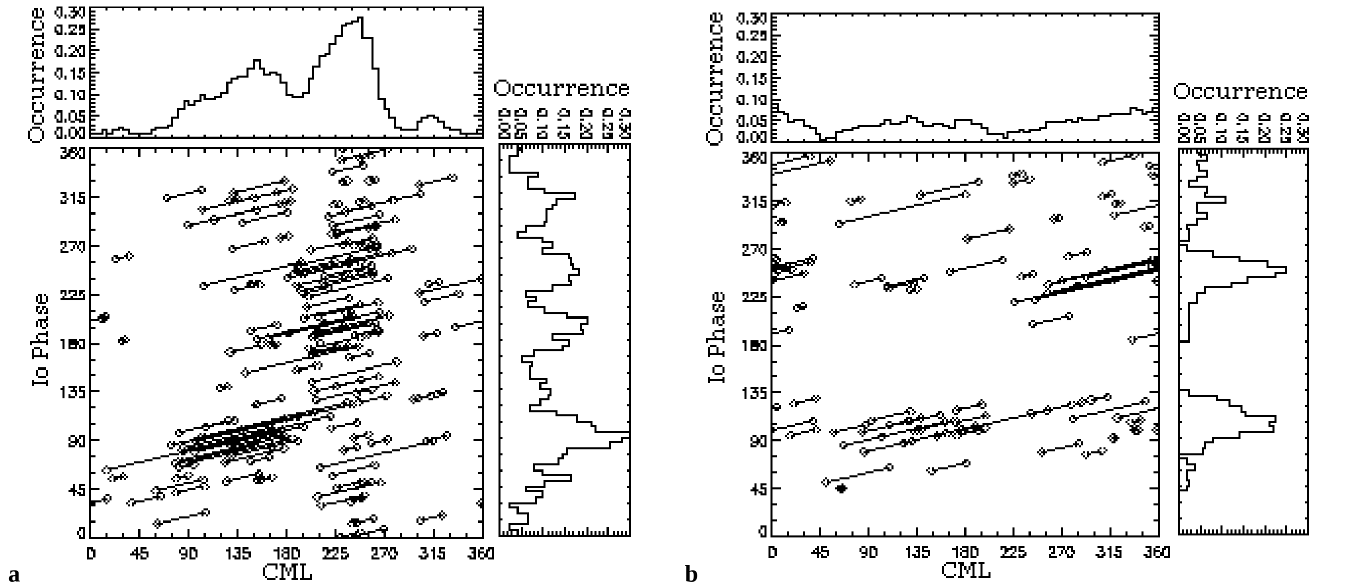

Fig. 6a and b. The jovian decameter emissions with the corresponding polarizations (Fig. 6a for right-hand and Fig. 6b for left-hand polarizations) as observed by the NDA radiotelescope in the plane (Φ_{Io}, CML) with the corresponding occurrence probability.

quencies lower than 15 MHz, and less than 12% for higher frequencies).

It is known that the occurrence area of sources in the Io-phase CML diagram are depending on two parameters: the Jovicentric declination of the Earth and the frequency of observation. Several authors had reported the Jovicentric declination of the Earth effect deduced from a long term observations of one jovian revolution (Boudjada & Leblanc 1992 and references therein). It appears that the change in occurrence probability could be explained as an effect of beaming of the escaping radiation varying with the Jovicentric declination of the Earth between -3.4° to +3.3° over Jupiter's 11.9 year solar revolution period. The weak occurrence probability of Io-A and Io-B sources as we find in our study is mainly due to the small values of the Jovicentric declination of the Earth which changed from -3.0° to -1.8° for the periods considered in our analysis. In previous studies the occurrence probability in the Io-phase CML diagram for Io-A and Io-B sources are found to be more higher; e.g. when the Jovicentric declination of the Earth was about +1° to 0° as reported in Figs. 4, 5 and 6 of Leblanc et al. (1981).

Otherwise we have found two maxima of occurrence probability at Io-phase equal to 95° and 250°. The same maxima were reported by Kaiser & Garcia (1997) using the Wind/WAVES data selecting the most intense events and they associated them to Io-D and Io-C controlled sources. They also showed that such sources are emitted from the Southern hemisphere which is more visible because of the Jovicentric declination of the Earth. From our analysis these maxima are due to the superposition of controlled and not controlled emissions in particular at Io-phase equal 90° and 250°. For the first maximum (Φ_{Io} = 90°) we distinguish three parts: first one when the CML is in the range 80° to 180°, the second between 170° and 360° and the last one for CML from 340° to 180°. Such distribution in CML is reported by Alexander et al. (1981) and Boischot et al. (1981) based on Voyager observations. The first and the third parts are associated to controlled emissions, Io-B and Io-D, respectively, when the second one is related to not controlled emissions, (non-Io-A and non-Io-C). Using the polarization measurements of Nançay data, it clearly appears that the Io-B source with right-hand polarization is shifted towards bigger values of Io-phase and covers part of Io-D source which has left-hand polarizations. In the same time, the second part, non-Io-A and non-Io-C are both observed with right-hand polarizations. For the second maximum (Φ_{Io} = 250°) nearly the same distribution in CML is found but with different type of emissions for each part. Thus the second one (170° to 360°) is related to Io-A (with weak occurrence) and Io-C and the third part (340° to 180°) is associated to Io-C region which is followed by non-Io-B area. The first part (80° to 180°) includes the non-Io controlled emission (non-Io-B). On the other hand, from the NDA observations, the same distribution in polarization is kept as for the first maximum. Such distribution in CML with the corresponding polarization shows that in spite of the decrease of the occurrence probability due to the Jovicentric declination of the Earth effect, we find again the same distribution as reported from Voyager data.

For the period considered in our study two Io controlled sources, Io-C and Io-D, are recorded with left-hand polarizations by the Nançay spectropolarimeter. Considering the hollow cone beam model (Dulk 1965) one finds that both sources are localized in the Southern hemisphere as derived also from Wind/WAVES data (Kaiser & Garcia 1997). According to more recent investigations based on composite Nançay-Wind dynamic spectra, Lecacheux et al. (1998) found significant discrepancies between the arc shapes associated to Io controlled emissions (Io-B, Io-C and Io-D) and the opening angle derived from the hollow cone model. The authors reported that such difficulty is observed at high and low frequencies which could be not associated to an inadequate magnetic field model. On the other hand the left-hand polarization emissions appear at Io-phase 90° and 270° when the right-hand ones are limited to CML range 180° to 300°. Our result is similar to those reported from ground observations (see Fig. 2 of Boudjada & Genova 1991). The main difference we have noted is the quasi-absence of the great arc of Io-C source which has right-hand polarization. Boudjada et al. (1995) have shown that the great arcs are related to other arcs with the same shapes (VLA) but opposite polarization. Such association was interpreted as an effect of source located in the same hemisphere but with opposite polarizations which is not in agreement with the hollow cone model. According to this model, the Io-controlled (e.g. Io-A and Io-C sources) and non-Io-controlled emissions are related to the Northern hemisphere because of their right-hand polarizations. However for the period considered in our analysis only Io-A source and non-Io-controlled emissions are observed but not Io-C source with right-hand polarizations. This result could be interpreted as a beam effect where the Northern hemisphere is less visible from the Earth because of the low Jovicentric declination of the Earth. If this assumption is correct, the non-Io-controlled emissions should also not be visible from the Earth because of the very high frequency of Io-C source which is usually higher than the frequency associated to non-Io-controlled emissions (see Fig. 3a and 3b of Genova & Aubier 1987). There is still only one explanation when considering that the Io-C emissions with right-hand polarizations come from the Southern hemisphere, from regions where the jovian latitude is smaller (than those of Io-D and Io-C with left-hand polarizations). In this case the hollow cone associated to Io-C with RH polarization should be outside from the ecliptic plane which makes it not visible from the Earth.

7. Conclusion

For the first time, we provide a statistical study of more than 200 events observed from space by Wind/WAVES experiment and from ground by the Nançay Decameter Array (NDA). We have found that more than 50% of these events are simultaneously observed, particularly after midnight; the occurrence probability around 02 and 04:30 UT is about the same. Our analysis was influenced by two effects: (a) the observation conditions (interference and ionosphere cut-off) were totally different between the spacecraft (quasi-continuous observations of the jovian emission) and the ground radiotelescope (the NDA can track Jupiter during 8 hours around the meridian transit), (b) the common frequency band (10 MHz to 13.8 MHz) was mainly affected by interference. According to the previous effects, it appears that the Wind/Nancay data are complementary. First in term of time coverage: after midday priority must be given to the spacecraft observations. The man-made interference cause saturation of the instruments, except for the spectro-numeric receiver (Kleewein et al. 1997), not used as routine receiver. The detection of a jovian signal falls to 4% of occurrence in Nançay for $f \leq 15$ MHz and 12% for $f > 15$ MHz. The frequency band 10-40 MHz is also affected: the transparency of the ionosphere is getting worse at the end of the day. The equality of the detection occurrences in the early morning indicates that the terrestrial equipment plays a determining role in the astrophysical studies. In particular the NDA due to its characteristics has a sensitivity about 100 times better than Wind/WAVES experiment. The sophisticated receivers that we can connect to the NDA requires computing power and enormous amount of data storage, not comparable with the space experiment constraints. The Wind/Nancay data are also complementary with respect to the frequency. The 4 MHz common to both experiments makes it possible to study in the whole decameter range the phenomenology of the jovian events. We found 50% of common events between 0 and 6 UT. It is thus possible to recreate tens of complete arcs as did Lecacheux et al. (1998).

In the Io-phase-CML diagram, the Wind/WAVES events are associated to controlled and not controlled emissions and it is not possible to separate between them according to their occurrence area. From NDA events, we report mainly the emissions related to Io-controlled occurrence area contrary to Wind/WAVES emissions. With regard to previous studies, we have found the absence of the great arc with right-hand polarization associated to Io-C regions. One could explain this disappearance by the Jovicentric declination of the Earth effect which allows to observe more the Southern hemisphere than the Northern hemisphere of Jupiter. If this assumption is true the other emissions (Io-A, Io-B and not controlled emissions with right-hand polarizations) should also be not visible from the Earth. The studies of the arc shapes (Lecacheux et al. 1998) and the emission occurrences reported in our analysis seem to be incoherent with the hollow cone model (Dulk 1965) and the polarization associated to each hemisphere.

In the future we will extend our analysis to the observations made in 1997 and 1998 by the Nançay radiotelescope and Wind spacecraft. From 1995 to 1998, the Jovicentric declination of the Earth changes from -3.0° to +1.5° which should allow a better knowledge of the occurrence probability in the Io-phase CML diagram in particular in the frequency range from 1 MHz to 40 MHz. The complementarity of space and ground observations should be the answer to avoid the Earth observation conditions in particular due to man made interference and the diurnal Earth effect. The high sensitivity of the NDA partly compensate the absorption produced by the ionosphere, since the occurrence is about the same order in the middle of the night.

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