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Same night observations of spread-F by the Jicamarca Radio Observatory in Peru and CUPRI in Alcântara, Brazil

Wesley E. Swartz

School of Electrical Engineering, Cornell University, Ithaca, NY 14853

Ronald F. Woodman

Jicamarca Radio Observatory, Lima, Peru

Abstract. 50-MHz echoes from equatorial spread-F were observed on several nights by both the Jicamarca Radio Observatory (JRO) in Peru and the Cornell University Portable Radar Interferometer (CUPRI) in Alcântara, Brazil. Although little detailed correlation is expected between sites separated by such large distances, the night of October 17, 1994 shows some remarkable similarities between Peru and Brazil. On this night spread-F commenced at both Jicamarca and Alcântara as thin bottomside layers situated near 320 km altitude at nearly the same local times. Later, major plumes erupted that reached to over 1000 km altitude at both sites. Since plumes normally drift west to east, these are obviously not the same structures but the similarities indicate that conditions for spawning them must have been coincidentally very similar on this night. The next two nights which produced plumes over Brazil, but only bottomside layers over Peru, emphasize that local conditions on the same night can be very different at the two locations. The importance of having a sufficiently wide beam for exploring spread-F over a large altitude range at the Alcântara site is also explored.

Introduction

Equatorial spread-F is a class of plasma irregularities in the ionosphere that have profound effects on radar backscatter [*Woodman and LaHoz*, 1976], radio beacons [*Basu and Basu*, 1985; *Basu et al.*, 1986], and rocket and satellite in situ instrumentation [*Kelley et al.*, 1981, 1986; *Basu et al.*, 1983; *Hanson and Bamgboye*, 1984]. Considerable progress has been made in our understanding of this phenomena particularly as a result of the clustering of a number of different instruments in two previous NASA rocket campaigns called Project Condor in Peru [*Kelley et al.*, 1986], and the CRRES/EQUIS project on the Kwajalein Atoll in the western Pacific [*Hysell et al.*, 1994c]. The most recent such clustering of instrumentation for the study of spread-F occurred during September and October, 1994, as part of the NASA Guará Dip Equator Sounding Rocket Campaign in northern Brazil [*Pfaff et al.*, 1997]. Real-time backscatter radar support for this campaign was provided by the Cornell University Portable Radar Interferometer (CUPRI). On a number of nights while CUPRI was stationed in Brazil, the Jicamarca Radio Observatory also acquired spread-F data. Such data sets from two widely separated locations should allow some separate identification of the global and local effects that trigger equatorial spread-F. Here we will give examples from just two of the 18 nights of coincident observations. For theories regarding the structure of spread-F, the reader is referred to *Fejer and Kelley* [1980], *Hysell et al.* [1994a,b] and *Hysell and Farley* [1996] and references therein.

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Experiments

CUPRI was moved to the Centro de Lançamento de Alcântara, Brazil (2.3°S, 44.4°W) in August 1994 for the NASA Guará sounding rocket campaign. The large main transmit/receive antenna consisted of 16 parallel COCOs (Coaxial-Colinear arrays) aligned east-west magnetically to allow repointing of the beam in the magnetic meridian by adding progressively longer phasing cables to the feeds of the individual sections. A second similar COCO array was located 58 m to the east for one leg of the radar interferometer. Providing for a shift in pointing of the large COCO arrays was important because the configuration of the Earth's magnetic field above Alcântara placed some unusual constraints on a radar making measurements of coherent echoes over a large spread of altitudes. Since spread-F backscatter is received from only those regions where the radar line-of-sight direction is perpendicular to the magnetic field to within 0.03°or less [*Farley and Hysell*, 1996], the beam width in the magnetic meridian should normally be as narrow as possible to maximize the signal-to-noise, especially for such a small radar as CUPRI. Above Alcântara, however, there is a very pronounced altitude dependence of the loci of perpendicularity. This is shown in Figure 1. Although the contours corresponding to electrojet heights are directly over Alcântara, optimum pointing to the 1000 km altitude contour would have required a beam displacement of 7°off-axis to the magnetic north. For probing 300 km the displacement would be 2°. (The Guará electrojet experiments used the on-axis positions as described by *Swartz* [1997]). Hence, a fixed narrow beam could not probe the entire altitude range of interest. A suitable compromise was achieved with a displacement of 4°, and with the two-way half-power beamwidth of a little over 3°we were still able to get echoes from over 1000 km without loosing bottomside spread-F. The first spread-F echoes were obtained at Alcântara during the evening of September 15;

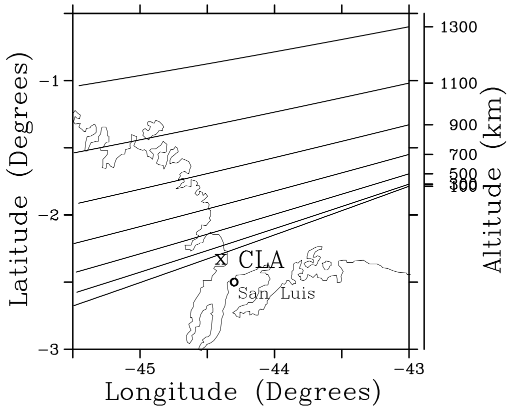

Figure 1. Contours where the CUPRI radar beam was perpendicular to the Earth's magnetic field at selected altitudes above the Centro de Lançamento de Alcântara (CLA) in northern Brazil.

the last on October 20 just before final disassembly for shipment back to The United States. The CUPRI radar was run in its spread-F mode during 30 nights in this period of which all but 5 had some spread-F activity. Half of the nights had plumes. The Jicamarca radar (12.0°S, 76.9°W) also must be directed perpendicular to the Earth's magnetic field to acquire spread-F data. However, the altitude dependence of the required pointing directions over Peru is not as strong as over Alcântara and so the highly aspect sensitive echoes can be received from 100 to over 1200 km altitude even with its smaller beam. Typically the Jicamarca beams are moved to about 3°off-axis to the magnetic north for these measurements. Other parameters from the CUPRI and Jicamarca radars are compared in Table 1. The longitude difference corresponds to about 2.2 hours in local time. Note that a longer pulse length and narrower receiver bandwidth were used for CUPRI to maximize spread-F detectability to high altitudes, a key criteria for the launch of the NASA Guará spread-F sounding rocket. Both radar systems used an interferometer configuration and recorded raw samples to tape for later processing.

Table 1. Comparison between CUPRI and Jicamarca Radars in Typical Spread-F Modes.

Parameter	CUPRI	Jicamarca
Latitude	2.3°S	12.0°S
Longitude	44.4°W	76.9°W
Radar Frequency	46.90 MHz	49.92 MHz
Transmitter Power	40 kW	1 MW
Antenna Beam Width	3.1°x3.5°	1.2°x1.2°
Range Resolution	15 km	5.25 km
Interpulse Period	5-10 msec	10 msec
Pulse Length	100 sec	35 sec
Time Integration	16-32 sec	16 sec
Interferometer Base Line	58 m	208 m
Relative S/N	-19 dB	0 dB

Results

The most spectacular night of spread-F that we observed at Alcântara was on October 14, the night of the launch of the high altitude spread-F rocket [*LaBelle et al.*, 1997], but there were no Jicamarca data taken this night. The second best night of spread-F at Alcântara was October 17 which is shown in Figure 2. Figure 3 shows this was also a night of intense spread-F activity above Jicamarca, and one where both radars saw a number of similar structures in spread-F development commencing with tongues of bottomside echoes between 300 and 340 km. At Alcântara the tongue formed at about 19:04 LT while at Jicamarca it began at 19:33 LT. These layers remained relatively constant for 30 to 50 minutes, respectively, before rising sharply to about 400 km and erupting into the first of several major plumes. The separation of the largest plumes was about 1.5 hours, while CUPRI saw a few intervening plumes as well. The second major plume at Jicamarca split above 600 km, and the last plume over Alcântara hints at a similar split. Both sites received echoes from plumes that extended to over 1000 km altitude, and the roughly 2.5-hour difference in occurrence times is close to the 2.2-hour difference in longitudes. The maximum signal-to-noise ratios were 26 dB and 38 dB for CUPRI and Jicamarca, respectively. This 12 dB difference is less than the 19 dB difference in sensitivities (Table 1) but neither radar has an absolute calibration and of course there are the differences in the plumes. Fine details evident in Figure 3 are not resolved in the CUPRI data with its coarser resolution (Table 1).

CUPRI and Jicamarca operated in spread-F modes for the next two nights; however, the echoes lacked the similarities of the October 17 data. During both of these nights there were plumes of spread-F above Alcântara, but only bottomside echoes above Jicamarca. As an example of these differences, we compare data from the two radars taken on the night of October 19 in Figures 4 and 5. The CUPRI echoes did not reach as high in altitude as on the nights of October 14 and 17, and the early tongue of echoes started earlier and was rising more rapidly in contrast to the 30- to 50-minute period of little movement on the other nights. At 2100 LT at Jicamarca there was only a thin and weakening layer in contrast to the plume activity over Alcântara.

Solar activity was steady for this period with an F10.7 index of about 90. Geomagnetic activity was very quiet

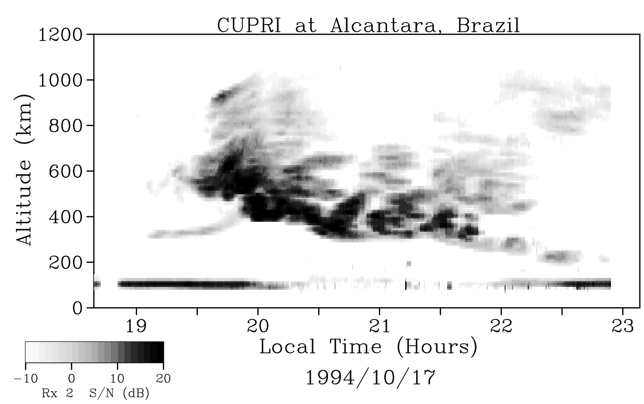

Figure 2. An RTI obtained with the Jicamarca radar during the same night as Figure 1.

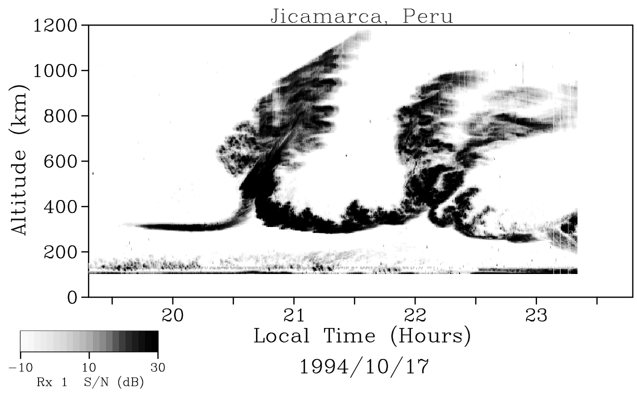

Figure 3. An RTI obtained with the Jicamarca radar during the same night as Figure 1.

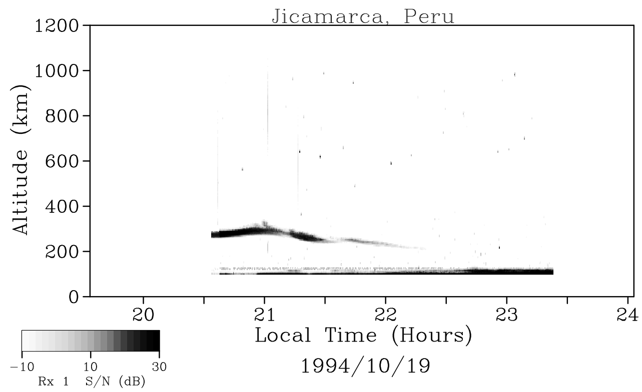

Figure 5. A Jicamarca RTI from the night of 1994 October 19.

with Kp values at or under 2 from late on the 15th through mid-day on the 19th after which they reached 3+. Even with these small differences, the negative correlation between spread-F and magnetic activity [*Calvert*, 1962; *Kelley and Maruyama*, 1992] relates to substantial differences in the vertical velocities which produced large swings in the altitude of the F-layer during the night of October 17 but not on October 19. This is shown in Figure 6. Although the peak of the F-layer reached its highest altitude before spread-F was detected on October 17, the two subsequent sharp rises are close to the times of the plume eruptions. While the second eruption occurred at the time when the F-layer was highest, it is curious that the first occurred some 20 minutes after the corresponding F-layer rise and at a time when the F-layer had returned to its pre-rise altitude. This plume must have developed well to the west and subsequently drifted into the radar beam.

Woodman et al., [1985] reported spread-F like irregularities that appeared in the daytime. It is likely that these were remnants of plumes that have traveled large distances. At typical drift speeds of about 100 m/s, it would take 8 to 10 hours for plumes to travel from Jicamarca to Alcântara. In fact such transport was the mechanism invoked by *Calvert* [1962] to explain morning spread-F over Natal following evening spread-F over Huancayo. (If Huancayo had no evening spread-F, he found no morning spread-F at Natal.) However, we observed no significant spread-F activity after midnight in Alcântara that could have been a candidate for a plume traveling such a large distance.

Both the Brazil and Peru data sets typically exhibit significant slants in active plume development and often show horizontal layering of irregularities at high altitudes after a major plume event, of which Figures 2-4 are good examples. This was not typical of the CUPRI Kwajalein data [*Hysell et al.*, 1994c] where we often saw a rapid succession of distinct plumes with no horizontal layering. There are a number of differences between these sites that might have contributed to this, the most notable being the fact that Kwajalein is 9.4°north of the magnetic equator, while both Jicamarca and the CUPRI Brazil location were very close to the dip equator. The age of the plumes as affecting the current state of turbulence could be another difference [*LaBelle et al.*, 1997]. Declination effects, the South Atlantic Anomaly and solar cycle differences may also play roles.

The small portion of spread-F data reported herein does not cover all the differences that can exist between the two sites. Coincident with 15 of the 30 nights of CUPRI spread-F operations at Alcântara, the Jicamarca Observatory was also operated in spread-F modes as part of the MISETA (Multi-Instrumented Studies of Equatorial Thermospheric Aeronomy) campaign for a total of 18 nights of coincident data. On seven nights when plumes developed over Brazil, only two lacked plumes over Jicamarca. On the other hand, of the eight nights with plume activity over Peru, five had

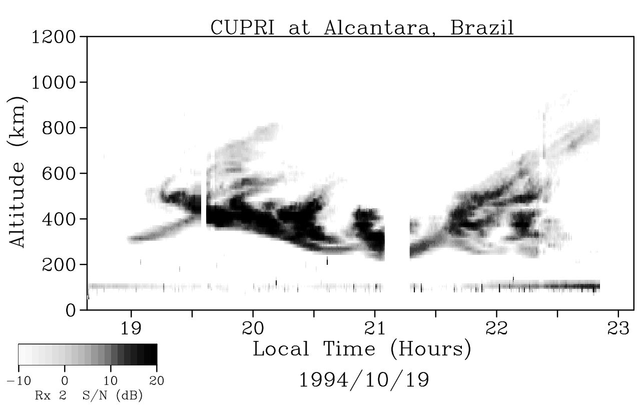

Figure 4. A CUPRI RTI from the night of 1994 October 19.

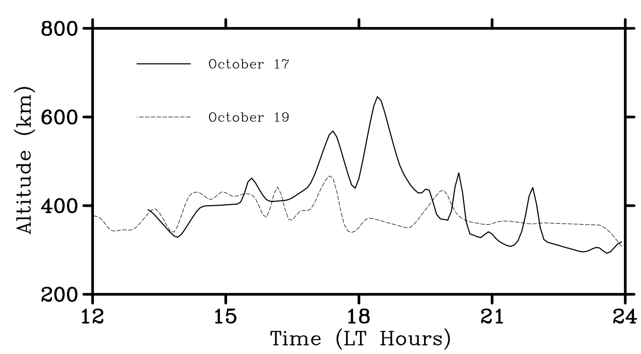

Figure 6. Time history of HmF2 for the two nights at Jicamarca.

plumes over Brazil, and two other nights had bottomside layers. The remaining night of plume activity over Peru, lacked spread-F over Alcântara. Since these data are the only existing high-resolution 50-MHz backscatter radar measurements of spread-F obtained at such widely separated locations, it will be of interest to pursue their statistical and morphological dependencies on other geophysical parameters.

Conclusions

The occurrence of spread-F is usually associated with a large pre-reversal enhancement of the eastward electric field which raises the F-layer to high altitudes. Such appears to have been the case on one of the nights at Jicamarca used in this comparison, with the actual plume eruptions correlated with secondary rises in the F-layer. The similar spacings of the plumes supports theories of initiation mechanisms tied to gravity waves [*Kelley et al.*, 1981], though other factors certainly play roles in these mechanisms. While one night exhibited strong plume activity at both sites, the other night described here had only plumes over Brazil. We have reported on only a small amount of the data collected during the Fall of 1994. This data set should be uniquely suited for distinguishing global and local mechanisms that trigger spread-F. Future work will look at more of the nights of simultaneous data to try and tie in the differences and similarities with layer height, upward drifts, and other observables that are available.

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W. E. Swartz, School of Electrical Engineering, 316 Rhodes Hall, Cornell University, Ithaca, NY 14853. (e-mail: wes@ee.cornell.edu)

R. F. Woodman, Jicamarca Radio Observatory, Apartado 13-0207, Lima 13, Peru (e-mail: ron@geo.igp.gob.pe)

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