# Observations of *E* Region Field-aligned Irregularities just Outside the Equatorial Electrojet Region

J. L. Chau[1,2], R. F. Woodman[1], and L. A. Flores[2]
[1]Radio Observatorio de Jicamarca - Instituto Geofísico del Perú
[2]Laboratorio de Física - Universidad de Piura

## Introduction

We have used the Piura VHF radar (5°12'S, 80°38W, ~7.5°N, dip latitude) just outside the equatorial electrojet (EEJ) region in northern Perú, to gather echoes from 3-m *E* region field-aligned irregularities (FAI). Similar irregularities have been intensively studied in the EEJ and auroral zones using ground-based radar systems and in-situ (rocket-borne) probes. Midlatitude *E*-region FAI have been the subject of far fewer experiments over the years, however this situation is rapidly changing and multi-instrument experiments are being conducted and planned [1]. On the other hand, at low-latitudes but outside the equatorial electrojet (EEJ), i.e., >3°, there have not been many radar observations, only those reported from a recent backscatter experiment in India [2], and the 1958 forward-scatter experiments in South America [3].

The Piura radar is part of a wind profiler network in the tropical Pacific. The main purpose of this system is to study the lower atmospheric dynamics. However, we interrupted the normal operations of the radar. Coincidentally, we can make our observations by using one of the pre-defined antenna-pointing positions.

Our observations are based on short campaigns of few consecutive days taken since 1991 at different times of the year. *E* region FAI over Piura are confined to the 95-120 km altitude and present spectral characteristics similar to type 2 EEJ echoes. However, despite of being at only 7°N dip latitude, they appear mainly at nighttime and early morning, and thus do not present a temporal similarity to the EEJ.

## Preliminary Observations

Observations of *E* region irregularities over Piura have been carried out since 1991, sporadically, few times a year. Woodman et al. [1999] [10] have presented the characteristics of these irregularities, based on the observations between 1991 and 1996. In Figure 1, we present the diurnal characteristics of

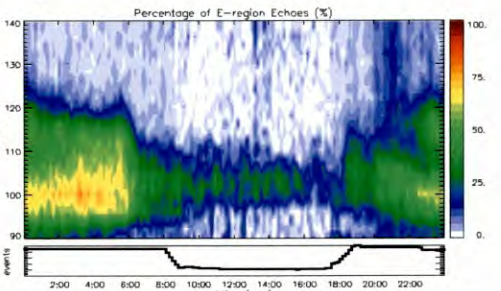


Figure 1. Percentage of *E* region echoes with a minimum of -6 dB SNR level. The time-altitude bin is 10 min x 2 km altitude. We have averaged data from: (1) July and December, 1995, (2) October-November, 1996, (3) July, October and November, 1998, and (4) February, April, July and October, 1999. The bottom plot shows the number of E region events observed at each time bin.

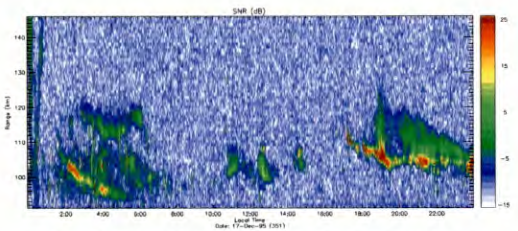


Figure 2. Typical signal-to-noise ratio (SNR) distribution of *E* region echoes observed on December 17,1995.

these echoes, but this time including data until 1999 [i.e., 1995 (25-Jul to 3-Aug, 15-18 Dec); 1996 (20-Oct to 4-Nov); 1998 (27-30 Jul, 10-21 Oct, 27-Oct to 5-Nov); 1999 (5-15 Feb, 8-14 Apr, 26-Jul to 2-Aug, 25 Oct to 1-Nov)] The main diurnal characteristics reported by Woodman et al., [1999] are again observed, i.e., (1) echoes are almost absent during the day, (2) there are mainly two echoing regions (lower and upper), and (3) the upper E region appears around 2300 LT and disappears around 0600 LT. In Figure 2, we show a 24-hour signal-to-noise (SNR) distribution. Note that echoes during the day are weak and sporadic.

## Quasiperiodic Echoes

As it has been recently observed at midlatitudes, we have also observed QP echoes over the Piura site, which is located in the equatorial (magnetic and geographic) region, but just outside the EEJ region. The first clear QP observations were obtained in 1998 (see Figure 3). At that time, the QP echoes presented mainly, striations with positive slopes. New systematic observations (taken over different seasons during 1999) have revealed the existence of negative, positive and vertical slopes. In Figure 4, we show an example of a QP with negatives slopes and with short striations. In Figure 5, we present a somehow complicated example of "QP" taken last October of coexisting striations with negative and positive slopes ("M" shape QP?).

| Site | Latitude, Dip angle (N) | QP slopes - | \| | + | Striation range km | Periods (min) | Mean Doppler | Freq. |
|---|---|---|---|---|---|---|---|---|
| **Shigaraki, Japan** Yamamoto et al. [1991] | 34.9°N, 48.6° | Yes | No | Yes | 95-125 | 2-10 | Negative | VHF |
| **Chung-Li, Taiwan** Pan and Tsunoda [1998] | 24.5°N, 35.0° | Yes | Yes | Yes | 100-110 | 5-10 | Negative | VHF |
| **Tanegashima, Japan** Tsunoda et al. [1998] | 30.4°N, 43.2° | Yes | No | Yes | 90-140 | 5-10 | N/A | HF |
| **Clemson U., USA** Hysell and Burcham [1999] | 34.7°N, 65.0° | Yes | No | Yes | 90-140 | 1-10 | Negative | HF |
| **Stanford, USA** Tsunoda et al. [1991] | 37.4°N, 61.3° | Yes | No | No | 90-140 | 5-10 | N/A | HF |
| **Tirupati India** Choudhary and Mahajan [1999] | 13.5°N, 12.5° | Yes | No | No | 102-116 | 2-4 | Negative | VHF |
| **Piura, Perú** Chau and Woodman [1999] | 5.2°S, 13.9° | Yes | Yes | Yes | 105-120 | 5-10 | Positive | VHF |
| **Salinas, Puerto Rico** Urbina et al. [1999] | 17.9°N, -49° | Yes | No | Yes | 90-120 | 1-2 | +/- | VHF |

Table 1. Characteristics of QP echoes at different latitudes.

## *E* vs *F* irregularities

In addition to the observations of the *E* region over Piura, we have also made observations of the *F* region irregularities. Moreover, these observations have been complemented with concurrent observations of the *F* region over Jicamarca (see Figure 6 for the location of Piura and Jicamarca with respect to the EEJ region). In Figure 7, we show the total power of a concurrent observation of spread *F* over Piura and Jicamarca. Note that the height coverage of spread *F* over Piura is smaller than over Jicamarca, and this is mainly due to less sensitivity (antenna size difference ~ -10 dB), pulse width difference ~-3dB). Preliminary statistics from these concurrent observations (see Figure 8) have shown that when *F* region irregularities are observed over Piura, the *F* region irregularities over Jicamarca are either bottomside or topside.

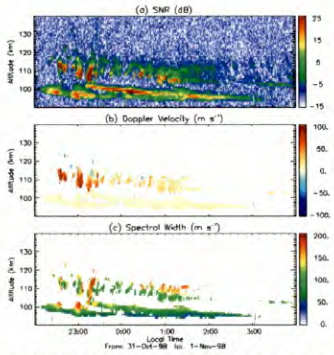


Figure 3. SNR, Doppler velocity and spectral widths of E region echoes over Piura. Note the QP striations with positive slopes.

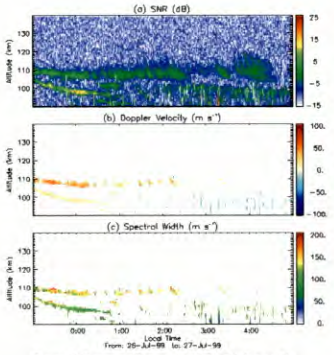


Figure 4. Same as Figure 3 but QP striations with negative slopes.

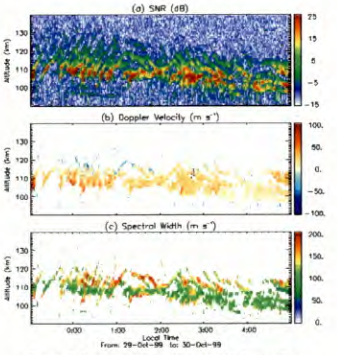


Figure 5. Same as Figure 3 but QP striations with positive and negative slopes (MQP?).

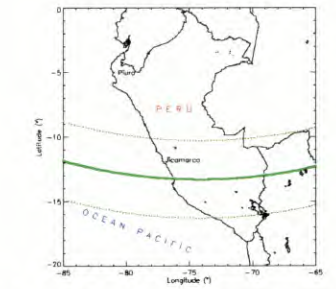


Figure 6. Map of Peru showing the location of the Piura and Jicamarca VHF radars. The EEJ region is delimited with green lines

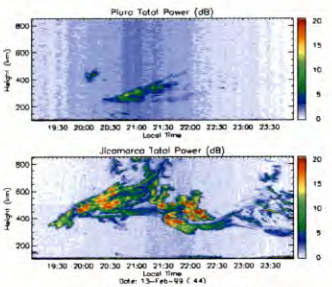


Figure 7. Total power of *F* region echoes over Piura (top) and Jicamarca (bottom).

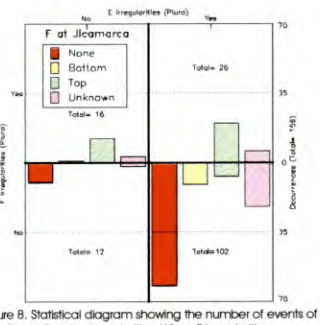


Figure 8. Statistical diagram showing the number of events of *E* and *F* region irregularities. When *F* irregularities are observed over Piura, "Top" *F* irregularities are observed over Jicamarca. When there are no *F* irregularities over Jicamarca, no *F* irregularities are observed over Piura

## References

[1] Fukao et al., Geophys. Res. Lett., 25, 1761, 1998.
[2] Krishna Murthy et al., J. Geophys. Res., 103, 20761-20772, 1998.
[3] Cohen and Bowles, J. of Res. NBS, 67D, 459-480, 1963.
[4] Yamamoto et al., J. Geophys. Res., 96, 15943-15949,1991.
[5] Pan and Tsunoda, Geophys. Res. Lett., 25, 1809-1812, 1998.
[6] Tsunoda et al.,Gephys. Res. Lett., 25, 1765-1768, 1998.
[7] Hysell and Burcham, J. Geophys. Res., 104, 4361-4371, 1999.
[8] Tsunoda et al., Geophys. Res., Lett., 26, 995-998, 1999.
[9] Choudary and Mahajan, J. Geophys. Res., 104, 2613-2619,1999.
[10] Woodman et al., Radio Sci., 34, 983-990, 1999.
[11] Chau and Woodman, Geophys. Res. Lett., 26 , 2167-2170, 1999.
[12] Urbina et al., Geophys. Res. Lett., Submitted, 2000.

# OBSERVATIONS OF *E* REGION FIELD-ALIGNED IRREGULARITIES JUST OUTSIDE THE EQUATORIAL ELECTROJET REGION

J. L. Chau[1,2], R. F. Woodman[1], and L. A. Flores[2]

[1] Radio Observatorio de Jicamarca, Instituto Geofísico del Perú, Lima
[2] Laboratorio de Física, Universidad de Piura, Piura, Perú

## 1. Introduction

We have used the Piura VHF radar (5°12'S, 80 °38'W, ~7.5 °N dip latitude), just outside the equatorial electrojet region, in northern Perú (see Figure 1) to gather echoes from 3-m *E* region field-aligned irregularities (FAI). Our observations are based on short campaigns of few consecutive days taken since 1995 at different times of the year. *E* region FAIs over Piura are confined to the 95-120 km altitude and present spectral characteristics similar to type 2 equatorial electrojet (EEJ) echoes. However, despite of being at only 7°N dip latitude, they appear mainly at nighttime and early morning, and thus do not present a temporal similarity to the EEJ. We observe the existence of two well-defined types of echoes: 1) lower *E* region echoes (95-105 km), and upper *E* region echoes (105-120 km). The lower echoes present a layering characteristic while the upper layer is more structured. In this latter region, the so-called quasiperiodic (QP) echoes have been observed with positive, vertical, and negative slopes and their characteristics are compared to those observed at mid latitudes. In addition, a relationship between concurrent *E* region irregularities over Piura and *F* region irregularities over Piura and Jicamarca is presented.

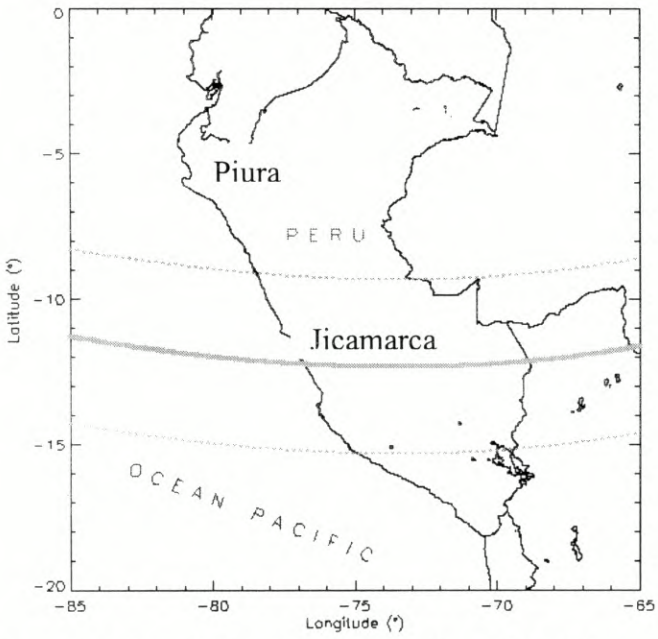


Figure 1. Geographic map of Peru indicating the location of the Piura and Jicamarca radars respect to the magnetic equator. The thick solid line represents the magnetic equator at 100 km. The dashed lines represent the typical latitudinal extension of the equatorial electrojet.

## 2. Results

### 2.1 Preliminary observations

Observations of *E* region irregularities over Piura have been carried out since 1991, sporadically, few times a year. *Woodman et al.* [1999] have presented the characteristics of these irregularities, based on the observations between 1991 and 1996. In Figure 2, we present the diurnal characteristics of these echoes, but this time including data until 1999 [i.e., 1995 (25-Jul to 3-Aug, 15-18 Dec); 1996 (20-Oct to 4-Nov); 1998 (27-30 Jul, 10-21 Oct, 27-Oct to 5-Nov); 1999 (5-15 Feb, 8-14 Apr, 26-Jul to 2-Aug, 25-Oct to 1-Nov)]. The main diurnal characteristics reported by *Woodman et al.*, [1999] are again observed, i.e., (1) echoes are almost absent during the day, (2) there are mainly two echoing regions (lower and upper), and (3) the upper *E* region appears around 2300 LT and disappears around 0600 LT.

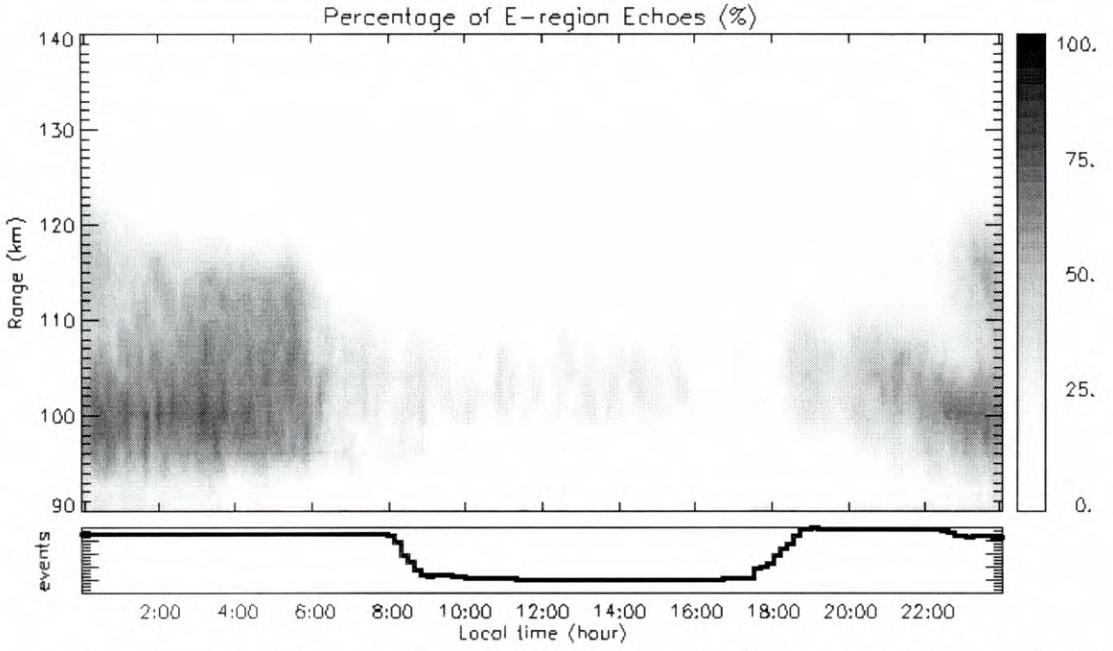


Figure 2. Percentage of *E* region echoes. The time-altitude bin is 30 min x 2 km altitude. We have averaged data between 1995 and 1999. Note that the occurrence of irregularities during the day is sporadic.

### 2.2 Quasiperiodic echoes

As recently observed at midlatitudes [see, e.g., *Larsen*, 2000 and references therein], we have also observed QP echoes over the Piura radar, which is located in the equatorial region (geographic and magnetic), but just outside the electrojet region. The first clear observations of QP echoes over Piura were obtained in 1998 and they have been reported by *Chau and Woodman*, [1999]. At that time, the QP echoes presented, mainly, striations with positive slopes. New systematic observations (taken over different seasons during 1999) have revealed a pronounced existence of striations with negative, vertical, and positive slopes. Moreover, the mean Doppler velocity in all occasions is positive, that is downward/southward. In Figure 2, we present a somehow complicated example of "QP" ("M" shape?) echoes taken in October 1999. Note the negatives slopes before 0130 LT and the positives slopes after that.

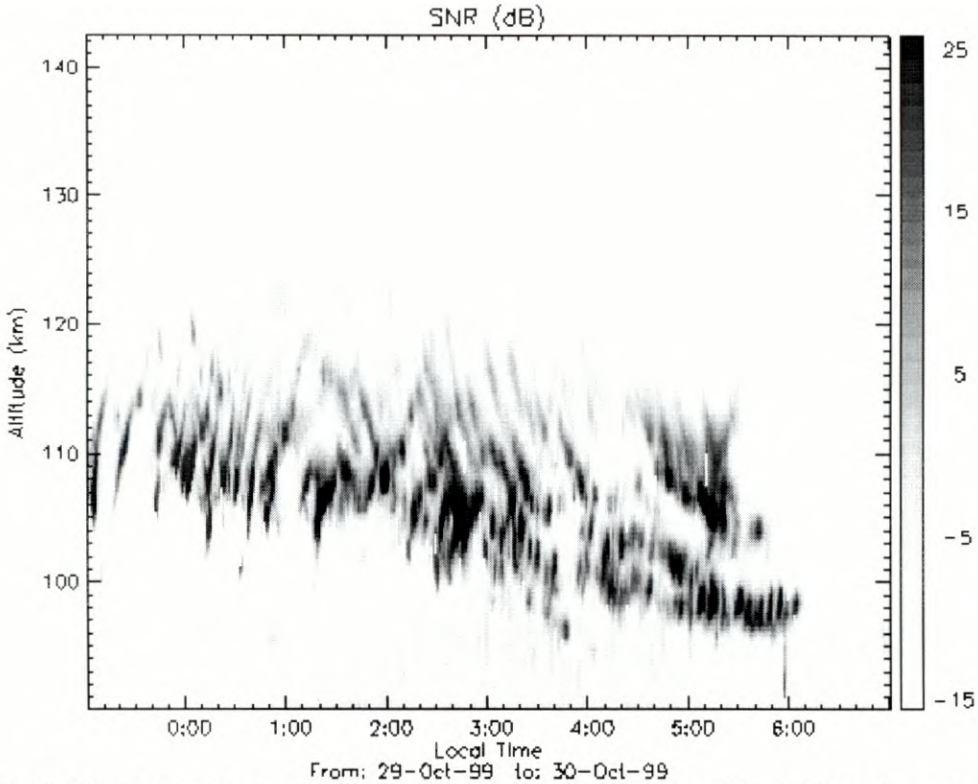

Figure 3. SNR altitude-time plot of *E* region irregularities over Piura. Note the presence of both negative and positive QP echoes.

## 2.3 *E* vs *F* region irregularities

In addition to the observations of *E* region irregularities over Piura, we have also made few observations of the *F* region irregularities. Moreover, most of these observations have been complemented with concurrent observations of *F* region irregularities over Jicamarca. In Figure 4, we show the total power of a concurrent observation of spread *F* over both sites. Note that the height coverage of spread *F* over Piura is smaller than over Jicamarca, and this is mainly due to less sensitivity (antenna size difference ~ -10 dB, pulse width difference ~-3dB). We have also found a way to measure at the same time *E* and *F* region irregularities over Piura. In the future, we plan to study this database in order to look for a possible correlation between them and see whether or not they are related to the seeding mechanism of equatorial spread *F*.

## 3. Future work

We are planning to continue observing these irregularities almost continuously by "stealing" *E* region signals when the Piura wind profiler is working in its normal atmospheric mode. These new observations will allow us to get the day-to-day and seasonal characteristics of these echoes. In addition, we will install new receiving antennas close to the radar to apply interferometry/imaging techniques and therefore try to better understand the scattering processes of these irregularities. For example, the new observations could help to verify the mechanisms on the generation of QP echoes [e.g., *Larsen*, 2000; Haldoupis "Recent studies of midlatitude *E*-region coherent radar backscatter" this issue] and also the understanding of the sporadic coexistence of lower and upper *E* region irregularities.

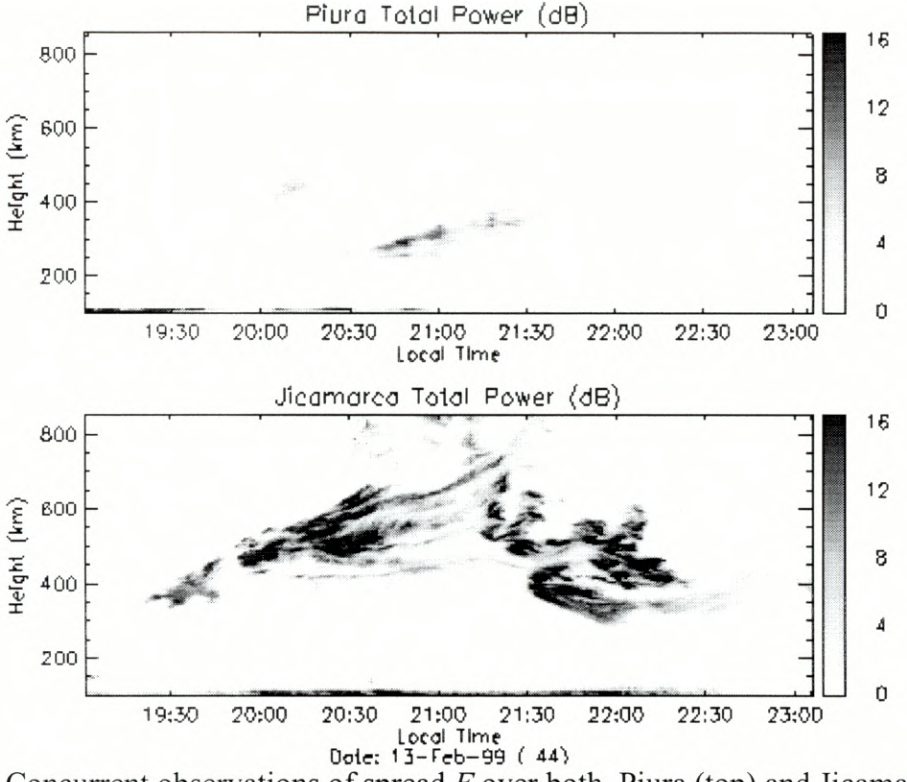


Figure 4. Concurrent observations of spread *F* over both, Piura (top) and Jicamarca (bottom).

## References

Chau, J. L. and R. F Woodman, Low-latitude quasiperiodic echoes observed with the Piura VHF radar in the *E* region, *Geophys. Res. Lett, 26*, 2167-2170, 1999.

Larsen, M. F., A shear instability seeding mechanism for quasi-periodic radar echoes, *J. Geophys. Res.*, in press, 2000.

Woodman, R. F., J. L. Chau, F. Aquino, R. R. Rodriguez, and L. A. Flores, Low-latitude field-aligned irregularities observed in the E region with the Piura VHF radar: First results, *Radio Sci., 34*, 983-990, 1999.