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Preliminary Climatology of UHF Scintillation over the South American Equatorial Anomaly at Solar Minimum

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13. ABSTRACT *(Maximum 200 words)*

We have deployed two 250 MHz radio receivers in South America; one at the magnetic equator and another near the peak of the anomaly crest. These stations listen continuously to both an eastern and western communications satellite. The unique deployment allows for two measurements at common magnetic latitudes and one along a common field line. Data has been gathered for more than a year and statistical studies have been performed, which are compared to the popular Wide Band Scintillation Model (WBMOD). The preliminary results presented here show a persistence of scintillation several hours later into the evening than predicted by the model. The seasonal variation of the model matches the measurements quite well, however. The results elucidate both the strengths and weaknesses of our predictive capability. In addition to these statistical measures, we present results on east-west asymmetry in scintillation from the two stations. The equatorial station shows little asymmetry while the southern station exhibits a significantly stronger scintillation to the east than to the west. The asymmetry appears to have a seasonal dependence. The origin of this phenomenon is unclear, but a few possibilities are suggested. Simultaneous data from the common field line links are also compared. A brief presentation is made of the PL-SCINDA scintillation warning system, which uses the data from these stations for "now-casting" and scintillation forecasts. Work in progress on the deployment and utilization of GPS units in this effort is also discussed.

14. SUBJECT TERMS

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1. INTRODUCTION

Severe disruption in ground-to-satellite communications can be caused by *F*-region irregularities in electron density near the geomagnetic equator. The irregularities, commonly called equatorial spread *F* (ESF) instabilities, probably arise from a convective instability driven by gravity waves [*Kelly*, 1989]. They are composed of kilometer sized holes or bubbles in the plasma which are bunched together and stretch along field lines from the lower edge of the nighttime ionosphere to perhaps 1000 km or more on the top-side. These features, which are confined to the equatorial ionosphere, show seasonal, latitudinal and diurnal variations and have been found to vary strongly with solar and geomagnetic activity [*Aarons and Basu*, 1985]. It is therefore not surprising that the detection, characterization and prediction of these irregularities is of interest from both a pedagogical and a practical perspective.

The disruption of signal power level and phase coherence is referred to as scintillation. A commonly used measure of scintillation is the S_4 index which is defined as follows.

$$S_4^2 = \frac{\langle I\rangle^2 - \langle I^2\rangle}{\langle I\rangle^2} \tag{1}$$

with *I* the power of the signal. Scintillation can occur in both amplitude and phase of the signal, but we will be concerned here with amplitude scintillation only. Also, the occurrence of scintillation varies greatly and in a complicated way with frequency of the receiver [*Basu, et al.* 1988]. The results presented here are limited to the 250 MHz region, primarily because there is virtually no scintillation at frequencies above 1 GHz at the equator during solar minimum.

Extensive statistical characterization of this scintillation has been achieved at two locations near the geomagnetic equator, Huancayo (O° dip latitude; 75.3°W) and Ascension Island (17°S dip latitude; 14.4°W) throughout one-half of a solar cycle [*Basu, et al.*, 1988]. These data, along with much more limited data sets from Ancón, Peru (2°S dip latitude; 77.4°W) and Kwajalein Island (4°S dip latitude; 165°E) were used to develop a statistical predictive model of scintillation called the Wide Band Model or WBMOD [*Secan, et al.*, 1995]. This model predicts the probability of scintillation at a given location, sun spot number, local time and magnetic activity. The model is presently used extensively for the forecast of potential communications outages.

Most of what we know of the details of ESF instabilities has come from campaigns [*e.g. Basu et al.* 1996] which combine multiple instruments, locations and viewing geometries in an attempt to discern the short-term dynamics of the structures giving rise to the phenomenon of scintillation. Although these data are of great value in working toward an understanding of the mechanisms of ESF, they are of necessity available over a limited time period, perhaps a month at best.

There are, therefore, two ways to study scintillation: one from a climatological perspective attempting to define the average occurrence over a long period of time and another probing the details of the event over the course of a night. The scintillation detection system currently in place along the western coast of South America can, we believe, make some headway toward bridging the gap between campaign study and statistical climatology. The system takes data continuously from two stations listening to the east and west in the UHF (250 MHz) and overhead in the S-band (1.5 GHz). A diagram of the system is shown in Figure 1.

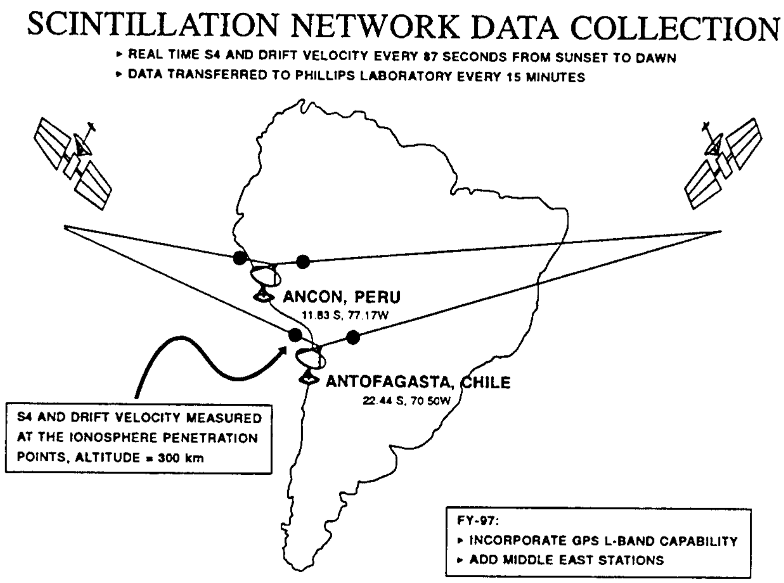

Figure 1. Schematic diagram of the UHF portion of the South American data collection system.

The stations are located in Ancón, Peru (2°S dip latitude; 77.2°W) and Antofagasta, Chile (11°S dip latitude; 70.5°W). The circles in Figure 1 represent the 300 km penetration point of the station-to-satellite link. In addition to measuring S_4 the system measures the zonal ionospheric drift velocity by the use of spaced antennae both to the east and west of Ancón and to the west of Antofagasta. The system also records power spectra of the instabilities, which we have yet to utilize. The location of the receivers allows for several unique measurements to be made. From the western link at Ancón to the eastern link at Antofagasta, the system covers about 12° in longitude. The eastern link at Ancón and the western link at Antofagasta lie on approximately the same field line, allowing for measurements of the same scintillation structure at two different latitudes. Finally, the measurements from the east and west link of each station allow us to compare scintillation in two relatively close regions at nearly the same latitude.

In this preliminary report of results from these stations, we will focus on two aspects. The first of these is a comparison of the measured climatology with the predictions of the scintillation model WBMOD. Following this, we will present some of the more obvious things that one can do with the data, including comparisons of scintillation to the east and to the west of each station and comparisons of simultaneous scintillation along the common field line link. Since it is the intent of this program in general to extend the predictive capability of scintillation models, which presently are purely statistical, we discuss some preliminary findings pertaining to next-day prediction based on data from previous nights. We will finish with a discussion of the future aspirations for this network and the application to SCINDA, the scintillation warning system currently in place.

2. THE DATA

Collection of data began in July 1994 with the first data consisting of an S_4 index and a drift velocity for Ancón West only. In November 1995, the easterly and westerly links at Antofagasta were added and in late August 1996, the easterly link at Ancón was added. We have included data in this study up to February 1997 and have experienced no significant gaps except for January and February 1996 at Antofagasta due to structural problems at the site. Table 1 gives the number of days available for each of the links.

TABLE 1. Available Data

Station	Start Date	Gaps	Total Days
Ancón West	10 May 1994	None	1002
Antofagasta East	28 Nov 1995	Jan-Feb 1996	434
Antofagasta West	28 Nov 1995	Jan-Feb 1996	434
Ancón East	23 Aug 1996	None	168

From the table, one can see that we do not yet have a large amount of simultaneous data from all four links. The period allowing comparisons between the four is limited to the period September 1996 to February 1997. The most extensive data set is from Ancón West, comprising close to three years. We can compare data from the common field line only during the overlap of Antofagasta West and Ancón East, roughly a five month period. Finally, we can compare easterly and westerly links from Antofagasta over approximately a one year period. The Antofagasta data set is available to the present, which allows us to examine a full yearly cycle, in spite of an unfortunate gap at the beginning of 1996.

The data are obtained as raw S_4 values taken at approximately 90-second intervals which are edited for spike removal and averaged into even 5-minute intervals. The editing process is very successful in removing contamination. A sample night of data from the four links is shown in Figure 2.

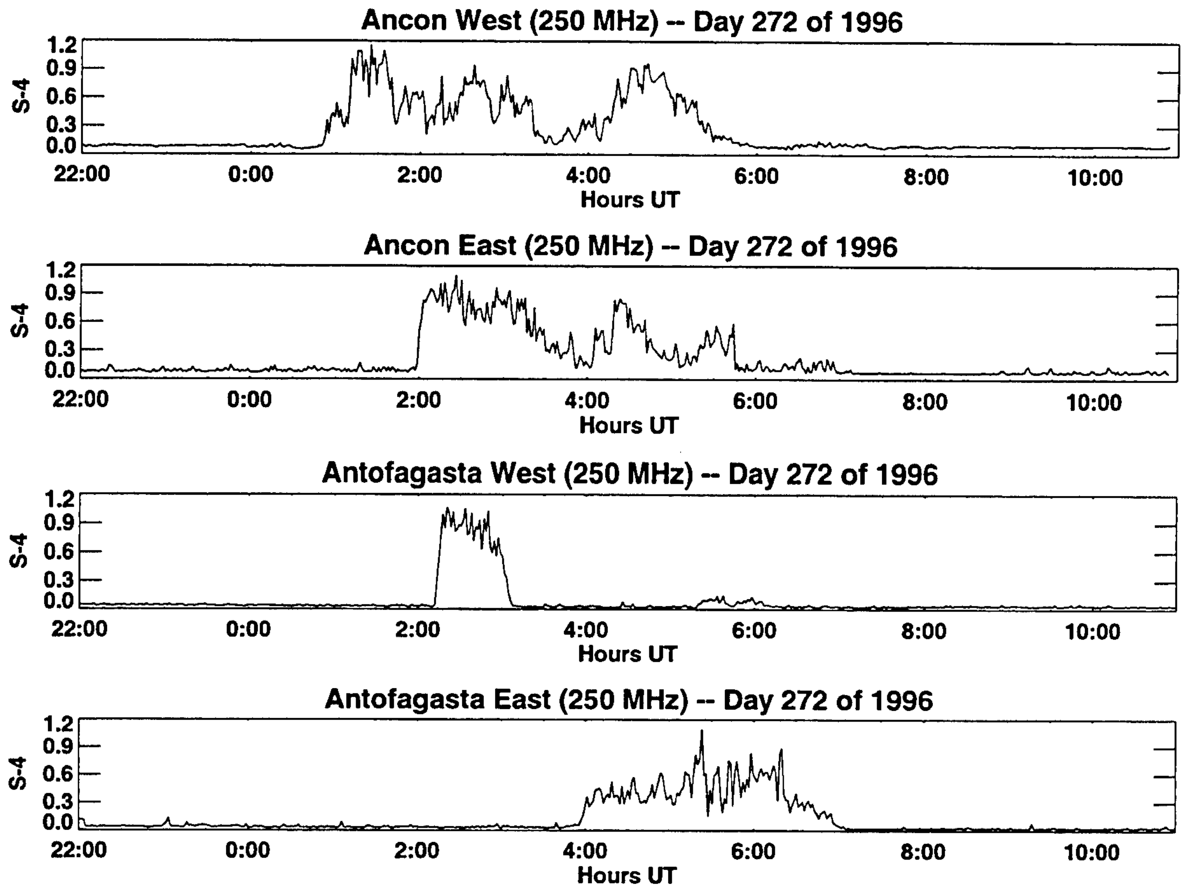

Figure 2. Sample of scintillation data taken from the two stations. The 300 km penetration point from Ancón East intersects the same field line as the penetration point of Antofagasta West.

One remarkable feature in Figure 2 is the relative duration of the scintillation between the equatorial station (Ancón) and the station down-field (Antofagasta). Comparing the common field line links, we see that the initial scintillation bubble at 02:00 UT appears to extend all the way down the field line. However, scintillation at Antofagasta ceases at about 03:00 UT while it continues at Ancón until 06:00 UT. We suggest the following scenario based on the data from the four links as follows: A fully developed bubble formed at the westernmost link and was recorded by the central two links simultaneously. After that, though, no full plumes developed west of the central links, as evidenced by the lack of scintillation at Antofagasta West throughout the remainder of the night. Scintillation at Antofagasta East indicates that there were fully developed plumes to the east, however.

There is an alternative explanation for some of the scintillation present at the equator, but not down field, in Figure 2. Often fully formed plumes coexist in the ionosphere with other irregularities which cause scintillation but do not extend to altitudes as high as true spread-

F irregularities. A prime example, one which is quite likely the cause of some of the equatorial scintillation in Figure 2 is the so-called "Bottom Side Sinusoidal" (BSS) instabilities [*Valladares, et al.,* 1983]. These are made up of sinusoidal variations in the plasma density which are limited to a narrow altitude range around 300 km and occur most frequently in regions near the equator. On occasion they may occur as far spread from the magnetic equator as 20 degrees magnetic latitude, however this is rare. These instabilities cause scintillation of comparable severity to true spread-F plumes, however, they may be more localized geographically, propagating differently as well.

A good indication of a true spread-F plume may be the abrupt change of scintillation intensity at the onset and conclusion of the event, and the constant nature of the value of S_4 during the event. The scintillation in the Antofagasta West link of Figure 2 is an example. On the other hand, the scintillation at the Ancón East link begins quite abruptly, but the die off of the scintillation is quite slow. Recalling that Antofagasta West and Ancón East share the same field line, we can imagine that a true plume formed shortly after 02:00 UT and left the area shortly after 03:00 UT. After the departure of the plume, BSS instabilities remained, causing disruption of the equatorial link. Since the BSS did not extend all the way down the field line to Antofagasta, communications at this link were not disrupted.

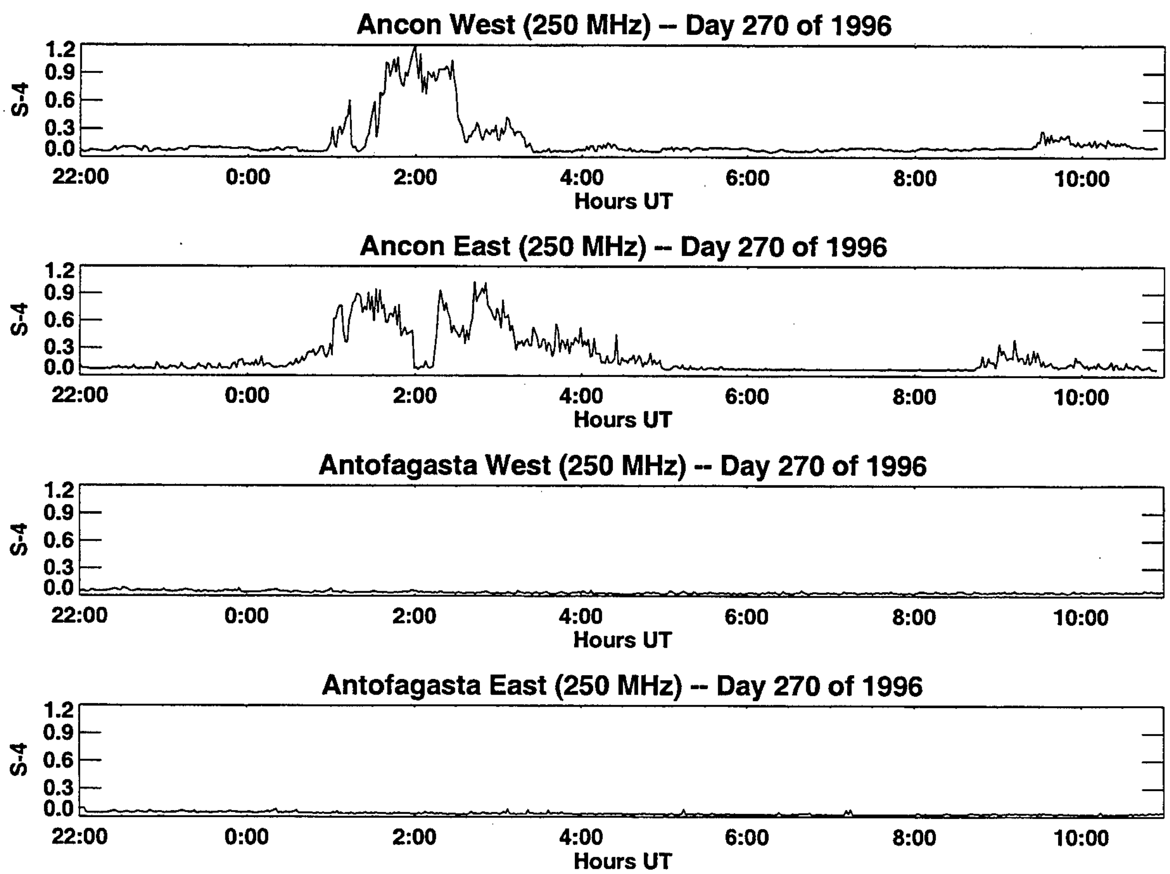

Figure 3. Scintillation from two nights prior to that in Figure 2 showing no scintillation at the southern station.

The presence of BSS is even more evident in Figure 3. On that night we see heavy scintillation at the equator but no disruption whatsoever to the south. This is a relatively common occurrence which is of particular importance in the forecasting of outages. We have hopes in the future to be able to differentiate between true plumes and BSS from examination of the spectra. If BSS is prevalent, this is also quite relevant to climatological models especially when the data used for modeling is taken at the magnetic equator. In WBMOD, scintillation over the South America is based on data from equatorial stations. The scintillation level is then extrapolated down-field by a model for the latitudinal variation in electron density. Thus, BSS would be incorrectly extrapolated down-field.

Turning to the effects of the variation in the ionosphere with latitude, we see the phenomenon in these scintillation measurements as well. One example is shown in Figure 4.

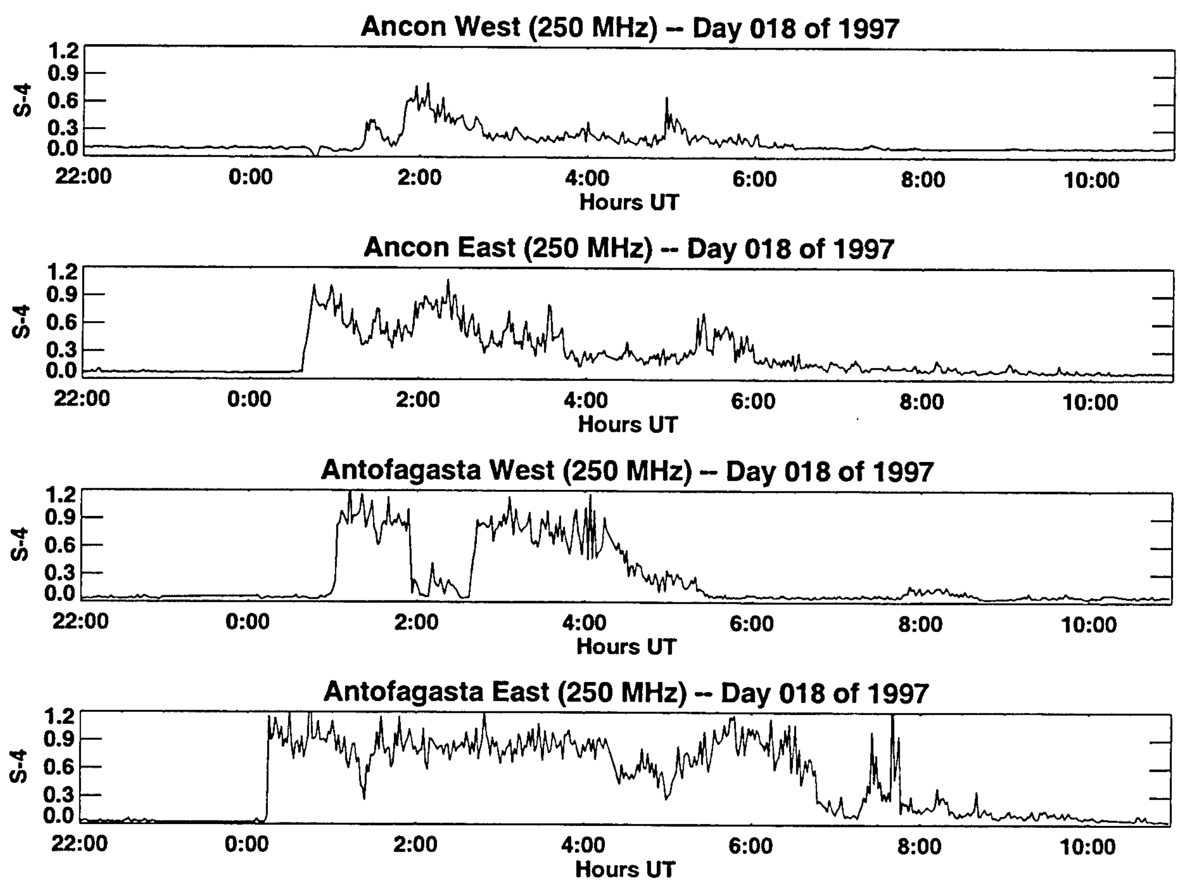

Figure 4. A night showing strong latitude dependence in scintillation

The latitudinal dependence measured at the stations arises because the level of scintillation depends on the total electron density along the path [*Basu, et al.* 1988]. the strength of the scintillation varies because the background electron density (N) varies with latitude, while the amplitude of the irregularity ($\Delta N/N$) may be the same all along the field line. We see, then, that the station configuration can be used to analyze the features of the density anomaly through the common field line link.

Another feature which shows up quite clearly in Figure 4 is the persistence of scintillation at Antofagasta East compared to the westerly link. In this case, if we sum the time period during which scintillation is taking place, we find that the easterly link scintillates for about twice as long as does the westerly link. This is a feature we have seen consistently in the year of operation at Antofagasta.

Although the preceding discussion has little to do with climatology, we have attempted through it to point out some of the benefits offered by the multi-station, multi-link data set. In what follows, we will present results from some of the more obvious studies that one can do with the data. We should keep in mind that these are preliminary studies and that much more can be done. Our purpose here is to summarize what we have learned in the first year or so of operation. We begin with direct comparisons of the statistical results with the predictions of WBMOD.

3. CLIMATOLOGY

We begin by presenting what we call "climatology" which is to say the seasonal and diurnal variations in the scintillation. Before looking at the data, it is instructive to discuss the climatological model WBMOD with which our data will be compared. WBMOD is designed to predict instantaneous values of two quantities;

(A) The n-th percentile value of S_4 which is the scintillation index below which n percent of the data fall. Said another way, the 90-th percentile S_4 is the value that is exceeded 10% of the time.

(B) The fraction of time that a particular value of S_4 is exceeded, on average.

Both these quantities are specified for a particular ground station to satellite link, a particular frequency, a particular time of the night, a particular day of the year, and values for the smoothed sunspot number (SSN) and K_p index. WBMOD overall predicts higher scintillation levels for higher SSN and lower scintillation values for higher K_p index.

In the first presentation of the data from South America, we will calculate these two parameters directly in a statistical sense. These we will then compare to WBMOD evaluated at an average SSN for the period, which we take to be 12. The maximum Zurich SSN for the period was 24, however this applies only to the first few months of data from Ancón West. By the start of the Antofagasta data, the SSN was down to 11 and remained below 12 until January of 1997. We have examined these results for the first year of data from Ancón and find no significant variability. We have therefore adopted the value of 12 as an upper limit for WBMOD in light of the fact that WBMOD tends to under-estimate the data we have seen so far. Likewise for the K_p index we have chosen to evaluate WBMOD at its maximum scintillation level by setting the value to zero. Scintillation has an inverse relationship to magnetic activity because high activity tends to create turbulence in the ionosphere which disallows the formation of the structures that comprise the scintillation plumes.

Because scintillation is not an every night event, we have chosen to average the data over a sliding 31-day interval. This does tend to smear out the values somewhat, but using this window produces reasonably good looking plots from this limited data set. Such smoothing must have been done in producing WBMOD as well, judging from the maximum data set being one solar cycle at best [*Secan, et al.* 1995]. Averages are generated at half-hour time intervals in a sliding one-hour bin as a function of time past sunset at the penetration point. We compute the average 90-th percentile value of S_4 by saving all the values that fall into a particular bin then sorting them by magnitude. We compute the fraction of the time S_4 exceeds a chosen threshold by simply summing all the values that fall into a bin above the threshold and dividing by the total number. These are compared to the WBMOD results for Ancón West in Figures 5 and 6.

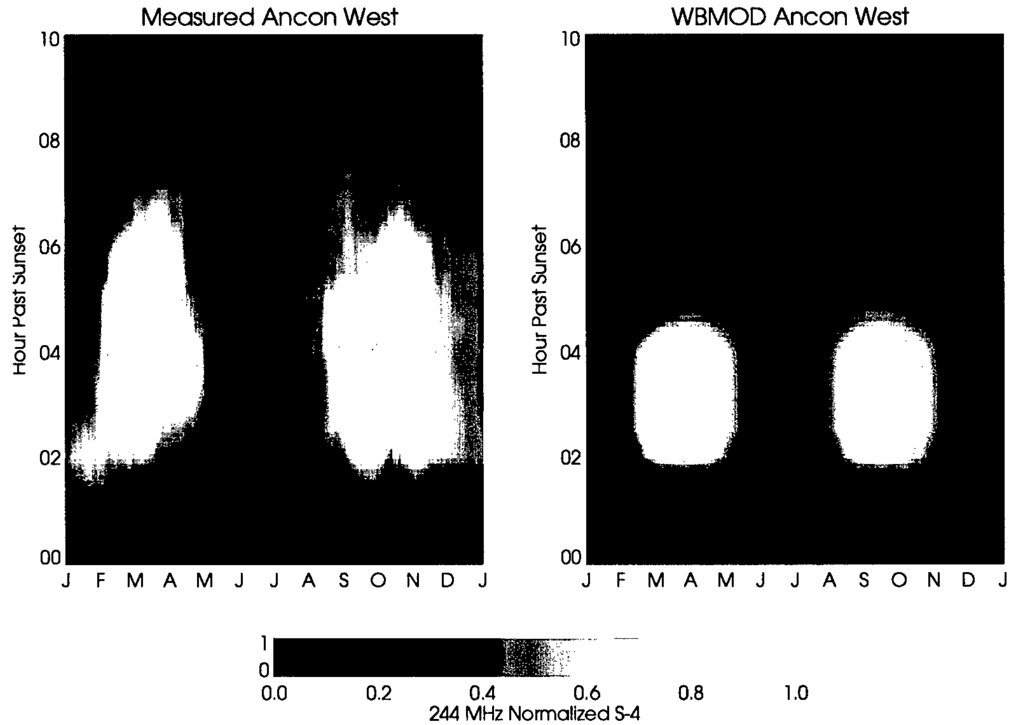

Figure 5. 90-th percentile S_4 over Antofagasta listening to the west.

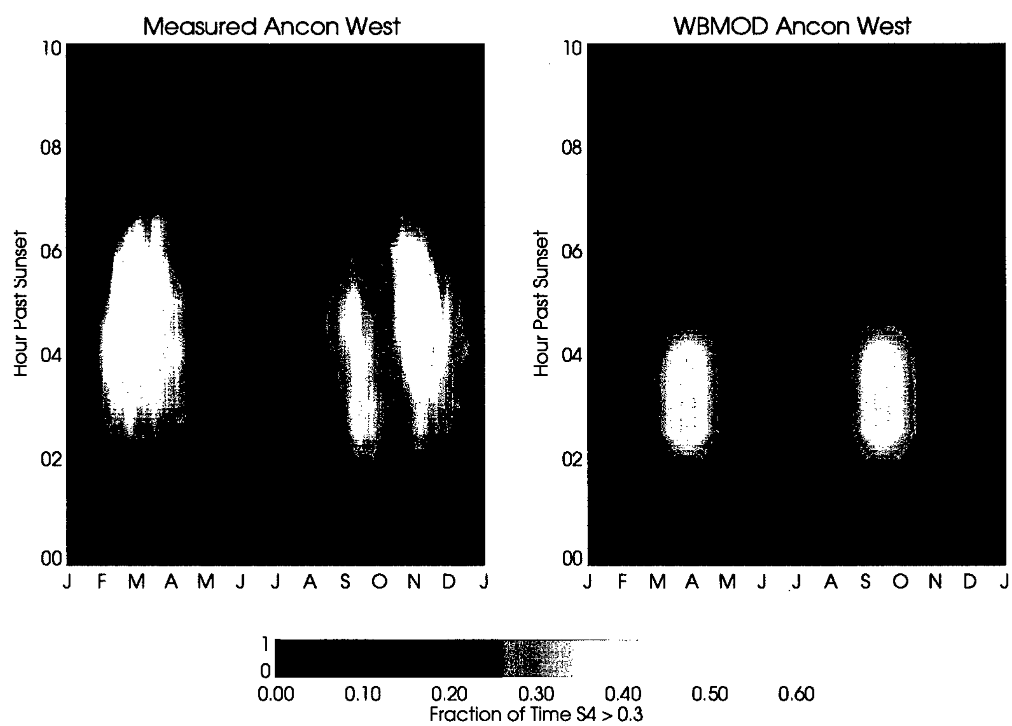

Figure 6. Fraction of the time S_4 exceeds 0.3 for Ancón listening to the west.

In these figures, the measured results are shown on the left and the WBMOD results on the right. What is perhaps most remarkable about the comparison is that the scintillation we have measured in the past three years at Ancón persists far later into the night than would be predicted by WBMOD. The model predicts significant scintillation only between about two and four hours after sunset. The data, on the other hand, shows significant scintillation until at least six hours after sunset. This is especially true at vernal equinox and shows up most clearly in the 90-th percentile S_4. However, it can be clearly seen at autumnal equinox as well. The onset, about two hours after sunset, is predicted well by the model as are the intensities of the scintillation. The absolute value of the 90-th percentile S_4 is not an especially good method of comparison, but is meaningful to note that the maximum percent of the time that S_4 exceeds 0.3 is about 50%, both as predicted and measured. Also, we see that the seasonal variation in the scintillation is reflected quite well by the model, with strong scintillation occurring in the February to April and the September to November intervals. However, the data shows that scintillation takes place quite frequently even in December and January, which is not predicted by WBMOD.

We turn to the corresponding data from Antofagasta East in Figures 7 and 8. Here, we see that there is the same sort of disagreement with the duration of scintillation in both the 90-th percentile S_4 and in the probability of scintillation. The WBMOD results do show high scintillation throughout the months of December and January, which is also evidenced in the data. We see, however, that the data show substantial activity from about two to nearly seven hours after local sunset. Another interesting feature is seen in the probability data in Figure 8. This is what appears to be a peak in the frequency of scintillation in the month of December. It would seem that December scintillation was more probable than at any other time of the year. This is not at all reflected in the WBMOD results, which show rather that there ought to be something like a 20% chance of scintillation at any given time early in the evening.

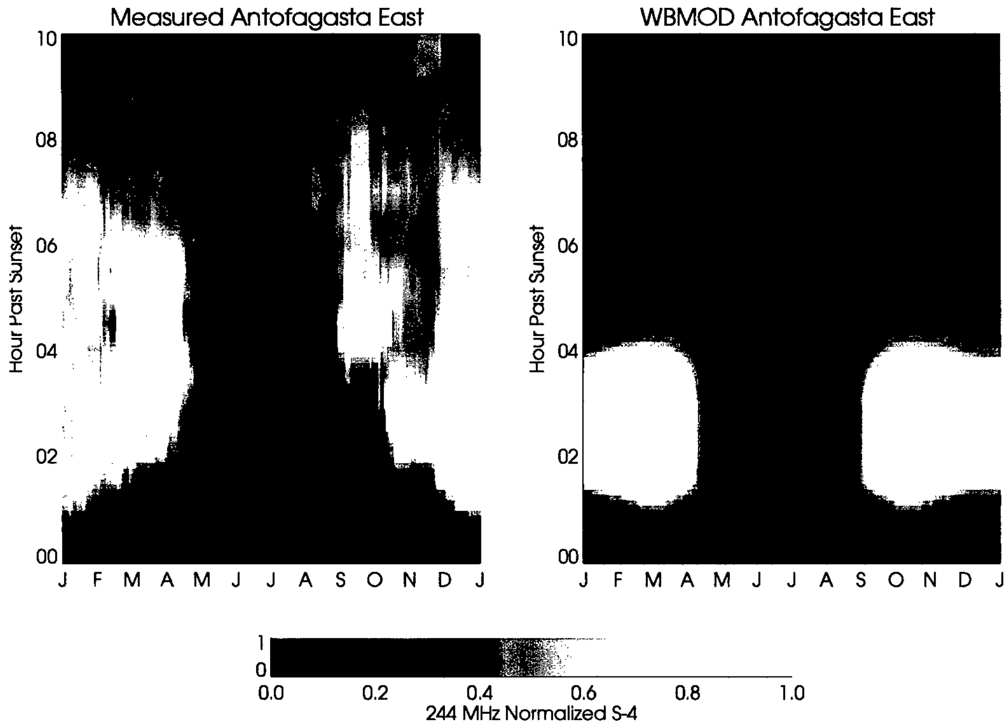

Figure 7. 90-th percentile S_4 over Antofagasta listening to the east.

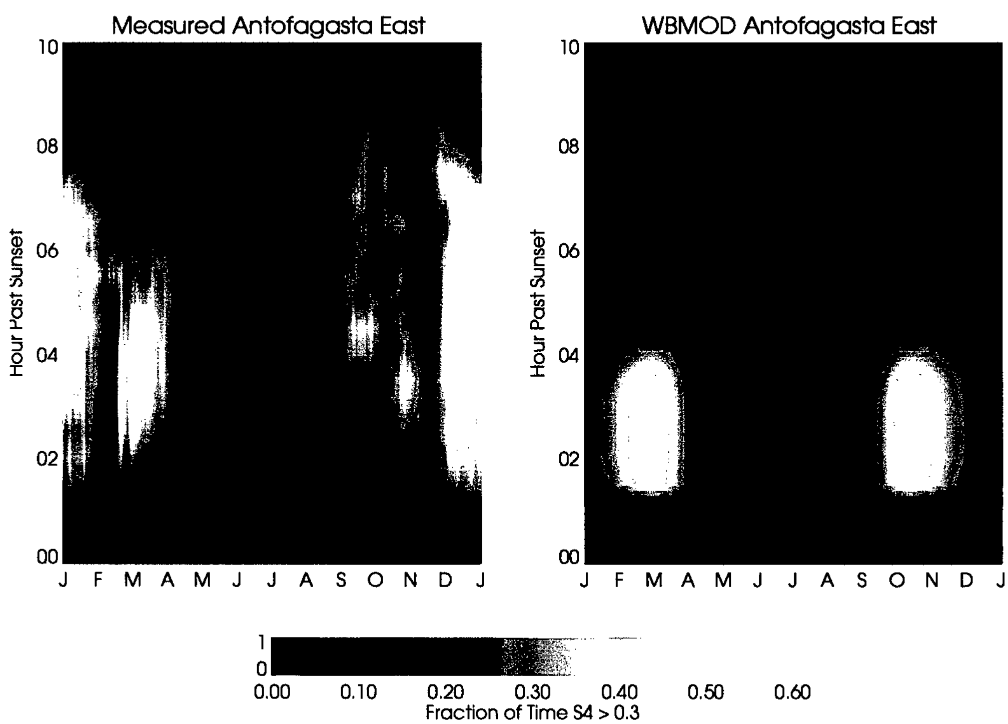

Figure 8. Fraction of the time S_4 exceeds 0.3 for Antofagasta listening east.

Interestingly, we can see from Figure 8 that WBMOD actually over estimates the probability of scintillation during the two equinoctial peaks. Again, this might be due to contamination of the equatorial data set used for WBMOD with BSS, adding to the total scintillation predicted down field, where BSS should not be seen.

On the other hand, it could just as easily be inaccuracies in the model for the anomaly. It is easy to imagine that WBMOD could be less accurate away from the geomagnetic equator, since the data included is limited to equatorial stations as noted before. This emphasizes the need for off-equator collection of scintillation data and the comparison of the common field line data links is a central goal of this effort.

As for the disagreement in the diurnal persistence, there could be several forces at work. The bulk of the data in WBMOD over South America is taken from Huancayo. The data taken at Ancón is limited to the years 1976-1979. Although the geographic separation of Ancón and Huancayo is not great, it is conceivable that the mountain range has some profound effect on the scintillation and that the scintillation inland is significantly different in its diurnal persistence. It is also possible, we suppose, that the present solar minimum is substantially different for some reason from that included in WBMOD, as least as far as scintillation is concerned. However, comparison of the sunspot numbers from the three periods involved, 1976 and 1986 for WBMOD and 1996 for our data set, show only minimal differences.

It is more likely that WBMOD simply does not contain much data at solar minimum. If the whole of 1964 had been available there should have been a full year with sunspot numbers below about 20. However, the Huancayo data from 1986 would give only about four months with sunspot number less than 20. Finally, it is unknown to us how the extrapolation of the diurnal variation with sunspot number is carried out in WBMOD. It may be that the combination of lack of data at solar minimum and the extrapolation technique leads to decreased accuracy at solar minimum. In any case, it will be interesting to see how the climatology changes and how it compares to WBMOD as we begin to the ascent toward solar maximum.

A most interesting feature seen at Antofagasta is the maximum in the probability in mid-December. Since there are data from two Decembers in the data set, we can examine the apparent glut of scintillation in December at Antofagasta in more detail to see if the behavior persists from year to year. We do so by calculating the average number of hours of significant scintillation ($S_4 > 0.3$) month by month throughout the data set. Since WBMOD gives us the probability $\mathcal{P}$ that there is scintillation above the threshold at any time during the night, we can also compute the WBMOD prediction for the number of hours $\mathcal{H}$ of scintillation on a daily basis.

$$\mathcal{H} = \int \mathcal{P}(t)\, dt \qquad (2)$$

These results are shown in Figure 9 for all months with sufficient data from Antofagasta to arrive at reasonable averages. In that figure, the WBMOD predictions are calculated using the actual K_p for the day, taken at midnight universal time. This gives an indication of the sensitivity of WBMOD to variations in K_p. The sunspot number of 10 is used, which is within ±3 of the value throughout the period. This small variation would make no significant difference in the predictions of WBMOD. Figure 9 shows the comparison between WBMOD and 15-day averages of the number of hours per night with S_4 greater than 0.3.

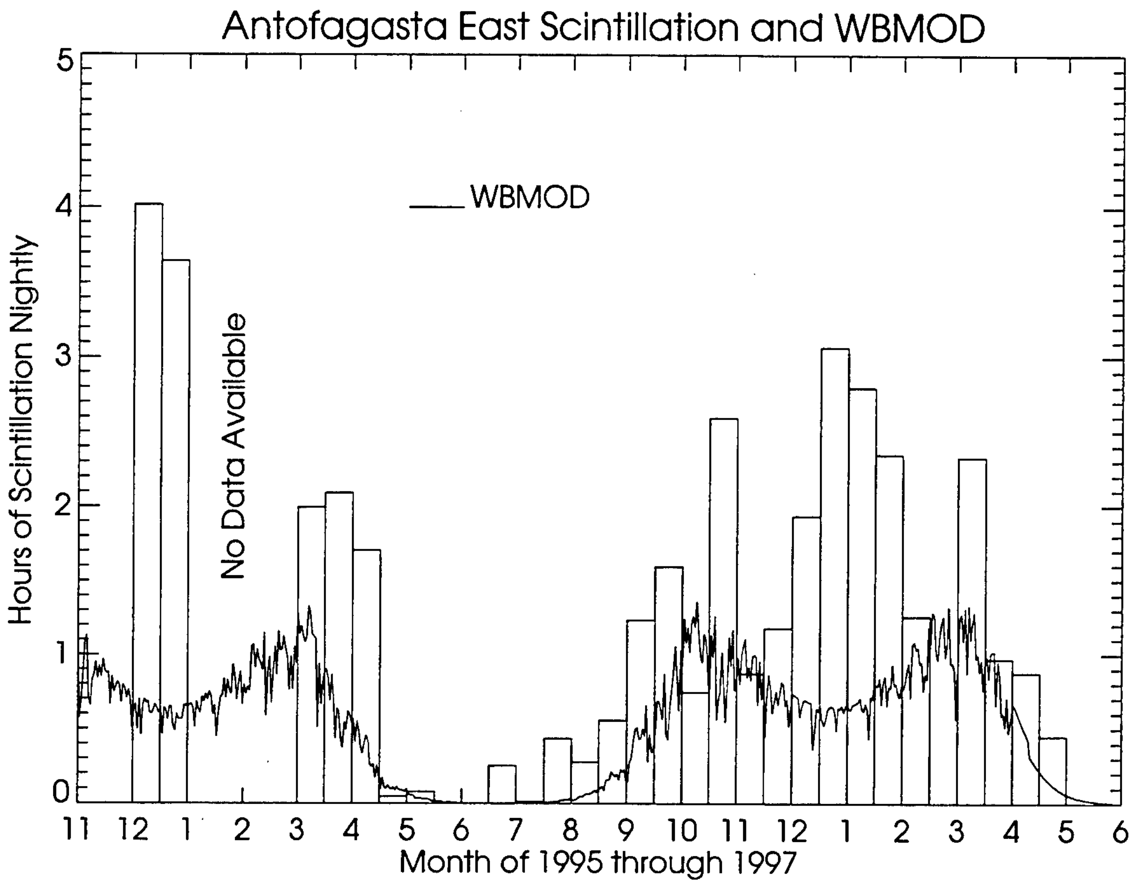

Figure 9. A comparison of 15-day average duration of scintillation from Antofagasta East (bars) with WBMOD predictions using daily K_p and SSN 10 (line).

It is clear from the comparison that, although the month of December 1995 was extremely active, December 1996 was also significantly more active than would have been predicted, even proportionally, by WBMOD. It is also quite clear that WBMOD underestimates the duration of scintillation by something like a factor of two. As mentioned, the midnight value of K_p was used in this plot to evaluate WBMOD and we can see that the variation with this parameter is not terribly strong. It is generally assumed that there are two scintillation seasons, peaking when the terminator is perpendicular to the magnetic equator. These data would indicate, though, that at Antofagasta there is really only one with the duration of scintillation peaking in December. Referring back to Figure 7, it would seem that as far as the magnitude of the scintillation is concerned, there is a slight decrease in December.

4. ASYMMETRY

Since data collection at Antofagasta began, we have noted that there is often substantially more scintillation to the east than to the west. In fact, there are often nights when the western link does not scintillate at all but the eastern link shows strong scintillation. We show this in Figure 10 by plotting the total number of hours of scintillation on a day-to-day basis.

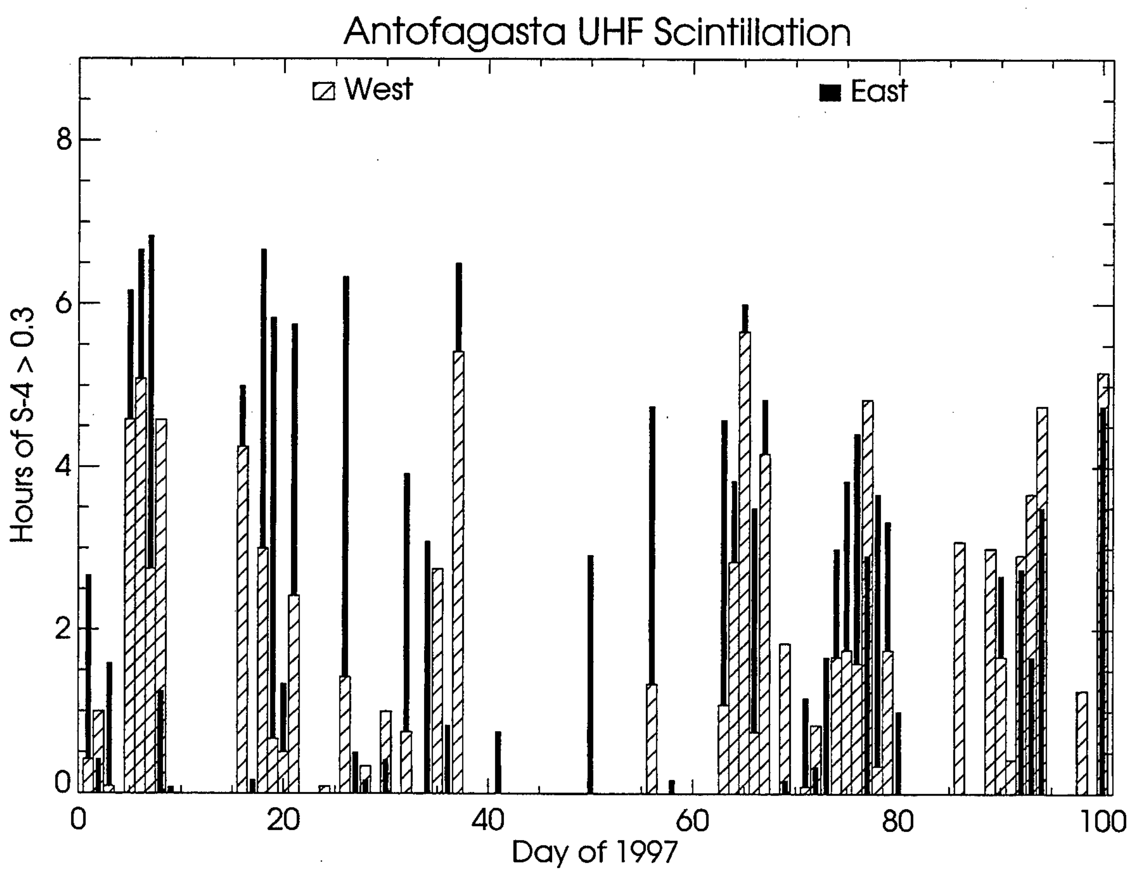

Figure 10. Nightly total hours of scintillation measured at the Antofagasta.

Study of the figure shows that the duration of scintillation at the eastern link is significantly longer most of the time. The data is taken from the first part of this year and there are a few minor gaps, especially between Days 40 and 60. However, it appears that in January and February, the eastward scintillation lasts about twice as long most nights. Later on in March, it seems that the western link catches up a bit and there are even days where the western scintillation exceeds that in the east. This hints of a seasonal variation in the effect. In the period, there are 36 days when east exceeds west and only 16 in which the converse is true.

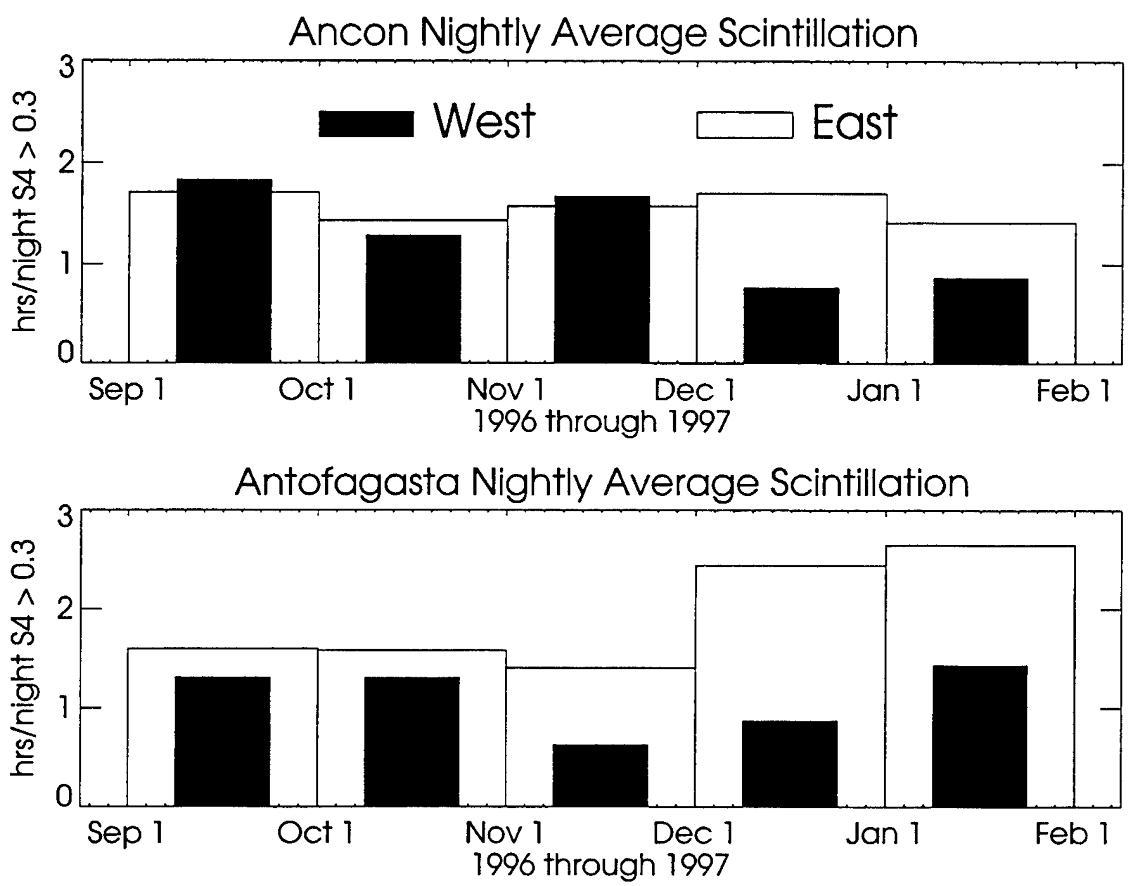

Figure 11. Comparison of the average duration of scintillation for all four UHF links using all currently available data.

In the search for asymmetry at Ancón as well, we have taken monthly averages of the hours of nightly scintillation at all four links. The data at hand limits us to only five months to study. These results are shown in Figure 11. Ancón shows no asymmetry in September through November, at least when analyzed in this fashion. Antofagasta shows a slight asymmetry in September and October which becomes stronger in November and peaks in December and January, when there is almost twice as much scintillation to the east as to the west. Interestingly, when Antofagasta shows very strong asymmetry, Ancón shows some asymmetry as well.

Based on the limited data set available, it is difficult to draw any firm conclusions from Figure 11. The presence of asymmetry at Antofagasta, however, is quite clear. Recently, *Meriwether, et al.* [1996] have reported measurements of thermospheric winds. These measurements were made by Fabry-Perot interferometry at Arequipa, Peru. This station is about half-way between Ancón and Antofagasta and is also in the foot-hills of the Andes. Interestingly, measurements of temperature and wind speed made to the west, over the ocean, differ substantially from those made to the east, over the mountains. The viscous dissipation of waves propagating into the thermosphere is implicated by these authors as the cause of the asymmetry. Gravity waves have also been implicated in the initiation of ESF [*Huang et al.* 1993]. It seems possible that the same forces driving the asymmetry in the thermospheric winds is making the initialization of scintillation more probable over the mountain range.

5. COMMON FIELD LINE

We are just beginning to evaluate methods to analyze the data from the common field line link. We have performed a short study of the distribution of scintillation along the common link by binning the data from Ancón East whenever the link at Antofagasta West was scintillating above the 0.3 level. Table 2 gives the results. Data from this study was taken from the last three months of 1996.

TABLE 2. Distribution of Scintillation along the Common Link

Ancón S_4 ➡➡	0.0 to 0.3	0.3 to 0.5	0.5 to 0.7	0.7 to 1.0
Antofagasta S_4 ➡ 0.3 to 0.5	58%	21%	12%	7%
Antofagasta S_4 ➡ 0.5 to 0.7	43%	26%	17%	13%
Antofagasta S_4 ➡ 0.7 to 1.0	19%	23%	28%	31%

We note that, when down-field scintillation is low (first row) there is a strong tendency for equatorial scintillation to be low, or even negligible. At the highest down-field scintillation level (third row), equatorial scintillation is predominantly above the 0.5 level. The goal of this effort is to be able to specify the characteristics of the latitudinal variation in electron density, but much still needs to be done in order to characterize the structures on an individual basis and to account for the slight separation in longitude of the penetration points.

6. PREDICTION

An aspect of considerable importance in the application of these data to communications is the ability to forecast outages well in advance. In the best of all possible worlds, one would like to be able to predict a day in advance whether scintillation was likely to take place the following evening. The current forecast capability of WBMOD is limited to a prediction of the probable hours for scintillation *if* scintillation should occur and an estimate of the probability of scintillation during this period. We have noticed in the data that there seems to be some degree of day-to-day persistence in scintillation, indicating that the factors that give rise to scintillation persist on a time scale longer than a day. We have also noted that days without scintillation tend to occur as two or more "quiet" days in sequence. To demonstrate this, we show in Figure 12 a plot for the first 120 days of 1996 taken from the Ancón West link. This data set was selected because it is nearly complete, with only one missing day, and for no other reason in particular. The data from other periods and stations gives similar results during active seasons.

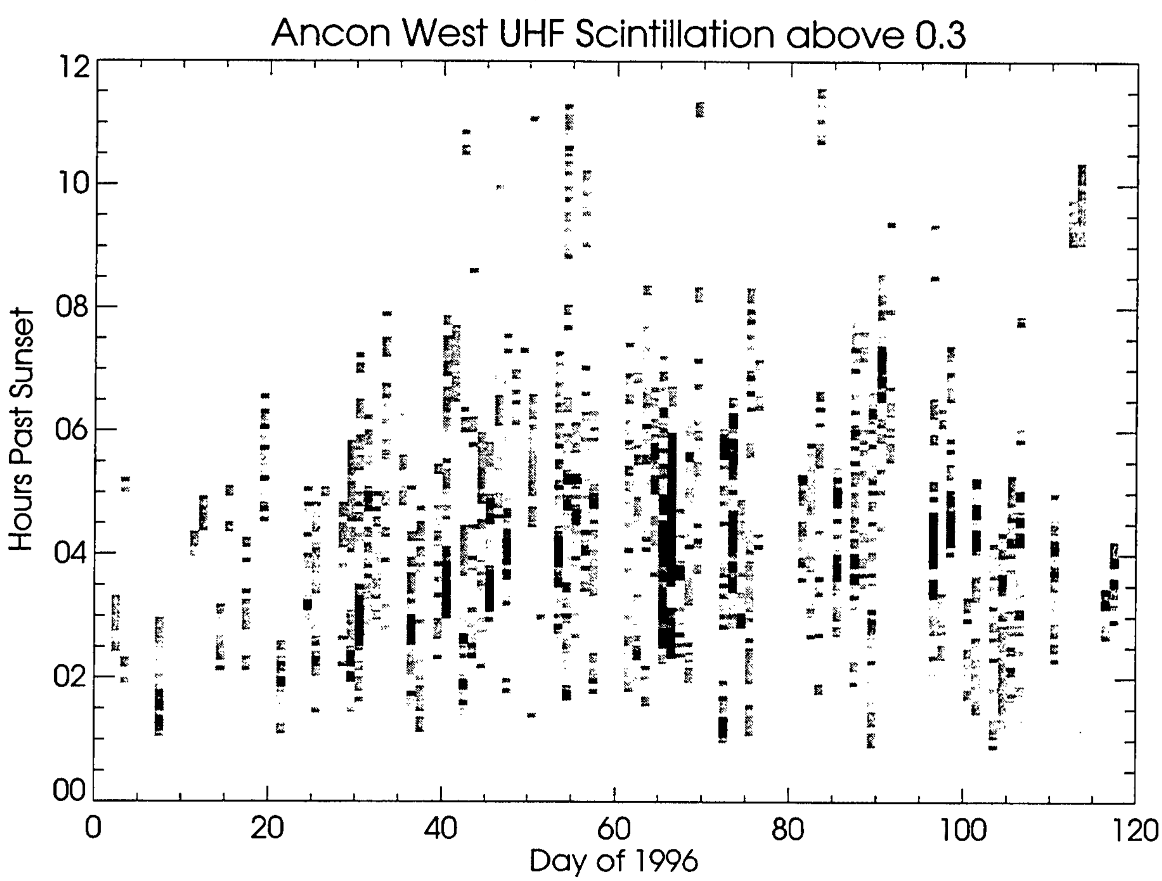

Figure 12. Scintillation above 0.3 at Ancón West.

In Figure 12, we have plotted all scintillation with S_4 above the 0.3 level. Interestingly, we see a few days with scintillation in the early morning. However, most is congregated between two and eight hours after local 300 km sunset. We have therefore limited our attempt to quantify the persistence to the eight hours after sunset. Groups of "quiet" days can be seen in several places throughout the four month scintillation season. There are two especially long quite periods around days 75 through 80 and days 90 through 95. We have analyzed the active days by calculating the probability throughout the period of one, two and three or more hours of scintillation followed by one, two or three or more hours on the following night. These results are compared to the uncorrelated probability, that is, the probability that there is one, two or three hours of scintillation on any given night throughout the 120 days, in Table 3.

TABLE 3. Correlation of Scintillation at Ancón West

Last Night's Scintillation	Tonight > 1 Hrs	Tonight > 2 Hrs	Tonight > 3 Hrs	No. of Cases
> 1 Hrs	69%	61%	44%	61
> 2 Hrs	72%	62%	43%	47
> 3 Hrs	78%	62%	38%	32
Uncorrelated	53%	41%	27%	118

We believe that the results in Table 3 show some promise for next-day prediction of scintillation, at least in a probabilistic sense. Beginning with the uncorrelated probability, we see that there is about a 50% chance of an hour or more of scintillation on any night during the period in question. On the other hand, if we were to see an hour of scintillation on any given night, the chance for one hour or more of scintillation the following night rises to 69% and, if we see more than three hours on any given night, the chance for an hour the following night rises to 78%. Looking at the very active nights, we see that there is a 44% chance of a three-hour night following any night with significant scintillation.

One can argue the first month of the year at Ancón is not really part of "scintillation season" and that including, perhaps, days 1 through 20 brings down the uncorrelated probability. If we exclude days 1 through 20 we find that the uncorrelated probability of an hour of scintillation rises to 60% while the correlated probability of a an hour of scintillation based on observation of at least one hour on the previous night actually rises from 69% to 74%. The other values in the table also rise slightly.

We have also investigated the issue of the correlation of quiet nights in much the same manner. It would be very useful in planning to be able to predict, based on observation of scintillation on the previous night, the probability that the next night would be clear. If, as we contend, quiet nights tend to come in pairs, this probability will be significantly greater than chance. Table 4 presents the results from the correlated and uncorrelated probability of a quiet night, that is, one with less than one hour of scintillation.

TABLE 4 Correlation of Nights without Scintillation

Tonight's Scintillation ➡➡	< 1 Hrs	< 2 Hrs	< 3 Hrs	> 3 Hrs	Cases
Last Night Was < 1 Hrs	63%	81%	91%	9%	57
Uncorrelated Probability	47%	59%	73%	27%	118

The first row of the table tells us the likelihood of scintillation less than one, two and three hours following a night in which no scintillation was observed. The second row tells us the uncorrelated probability, that is, the likelihood that less than one, two or three hours of scintillation, on average, was observed on any night in the period. Although it is not straightforward to evaluate a climatological model like WBMOD for numbers to compare with those in Tables 3 and 4, it is the uncorrelated probability that most represents the climatological result for the prediction. In fact, one might even say that the uncorrelated probability is a best-case scenario for climatological models in that the numbers are derived from the same data set.

The values in Table 4 are, we believe, even more encouraging than those for what we might call "positive prediction". We see that we can predict a quiet night based on a quiet night before with a certainty about 15% greater than chance. What is more interesting is that there is a very small probability that a night with more than three hours of scintillation will follow a night with none at all, only one chance in ten as compared to one in four as would be predicted by chance. This indicates that there is a "ramp-up" period for scintillation of at least a day.

We have also made some progress in short-term predictions through the development of a model driven by real-time data input from the stations. The model creates geometric forms for the plumes, mapping them along the field lines. It makes predictions by using the measured drift velocities to move these structures to the east. Predictions from this model are valid for approximately the lifetime of the structures, perhaps three hours. The model is described by Groves *et al.* [1997].

7. SUMMARY

We have presented preliminary results from the collection and analysis of UHF scintillation data taken at two stations along the western coast of South America during the 1994-1996 solar minimum. We have found substantial disagreement between the diurnal scintillation measured and that predicted by WBMOD, with our data showing persistence of strong scintillation well past local midnight. We suggest that the WBMOD data set may have been insufficient at solar minimum, leading to the disagreement. We have also noted a strong asymmetry in the scintillation to the east and west, especially at Antofagasta. We suggest that thermospheric winds over the Andes mountains may be the driving force for this asymmetry. We have also presented some very crude analyses of the scintillation along the common field line and of the persistence of scintillation from day-to-day. It appears to us from this preliminary work that next-day prediction may be possible.

It is obvious that much more needs to be done to fully utilize the information contained in this data. The possibilities increase exponentially as we begin the ascent to solar maximum and extend the effort to L-band climatology. We have GPS units currently operating at both stations as well as the link to a geostationary L-band satellite. We also plan to deploy both GPS receivers and UHF systems at other locations throughout the world. The data garnered should provide the opportunity to characterize transionospheric disturbances with a mix of long-term data collection and detailed structural analysis in a way quite unique amongst data sets taken to date. As we understand more about the behavior, we can hope to become more facile at predicting the impact of scintillation on communications systems.

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