SCINTILLATION RESPONSE OF GLOBAL POSITIONING SYSTEM SIGNALS DURING STORM TIME CONDITIONS.

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ABSTRACT: A principal method of studying low latitude ionospheric irregularities is through the observation of radio wave scintillation. The Global Positioning System (GPS) provides an ideal way of measuring scintillation effects as the signals are continuously available and can be measured along many paths through the atmosphere simultaneously. A single frequency GPS receiver utilizing the L1 (1.57542 GHz) signal was used to measure both amplitude and phase variations during the geomagnetic storm of 22 September 1999. The receiver was based at the southern equatorial anomaly station Vanimo (2.4^0S geographic latitude) in Papua New Guinea. Suppression of scintillation was observed prior to maximum excursion of Dst, while enhanced activity occurred during the recovery phase of the storm.

INTRODUCTION

When a radio signal, be it a satellite or radio star, interacts with the disturbed ionosphere the received signal will show rapid fluctuations in amplitude and phase which are not consistent with the source strength or modulation. This so called scintillation is attributable to electron density irregularities, which in turn manifest themselves as changes in the refractive index [1]. The amplitude and phase diffraction patterns associated with a signal passage through plasma density irregularities are readily observed as scintillation when the spatial diffraction patterns are transformed into temporal ones. For geostationary satellites, ionospheric drift will generally cause the temporal variation while for satellites in low Earth orbit, the satellite motion relative to the receiver and to a much smaller extent the change in structure of the irregularities with time, contributes to ionospheric scintillation [2]. The scintillation observed at low latitudes is primarily controlled by the generation and growth of irregularities over the magnetic equator. The equatorial anomaly consists essentially of two regions of enhanced plasma located at approximately 20^0 dip latitude north and south of the geomagnetic equator and is an area where scintillation activity is most pronounced. A physical picture that emerges for the generation of plasma irregularities that cause scintillations, is that after sunset the E region begins to recombine thereby decreasing its conductivity. The effects of recombination and **ExB** drift on the bottom-side F region provide a steep electron density gradient. When the altitude of the F region is high enough or the bottom-side background electron density gradients large enough to overcome recombination effects, the Rayleigh-Taylor Instability mechanism initiates a growth in plasma fluctuations. An upward moving bubble of depleted plasma is produced which rises and eventually transforms itself into a plethora of smaller irregularities, generally associated with the bubble walls. These irregularities map down the magnetic field lines towards the equatorial anomaly. The occurrence of scintillation is thus essentially an evening phenomenon [3].

SCINTILLATION AND GLOBAL POSITIONING SYSTEM (GPS)

At GPS frequencies, the electron density dependent refractive index introduces range errors and range rate errors. If the depth of the induced signal fading from scintillation exceeds the fade margin of the receiving system, message errors in the form of data loss cycle slips may occur. If the ionosphere produces phase changes faster than the receiver bandwidth can tolerate, loss of receiver phase lock occurs. GPS signals may suffer considerable scintillation during periods of maximum solar activity. [4]. The constellation of GPS satellites provides an excellent means of studying scintillation through the use of a specially designed receiver.

EQUIPMENT

Scintillation activity was monitored at Vanimo, (2.4^0 S, 141.24^0 E geographic coordinates, -21.6^0 dip latitude) in Papua New Guinea using an Ionospheric Scintillation Monitor (ISM) single frequency receiver configured to measure amplitude and phase scintillation at the L1 = 1.57542 GHz. GPS frequency in real time. The unit is on loan from AFRL Hanscom and consists of essentially three components, a GPS antenna, a Novatel GPS receiver and a 10MHz oven controlled crystal oscillator. The receiver is controlled from a standard IBM compatible personal computer running LINUX and can track up to eleven GPS C/A signals at the L1 frequency. Phase and amplitude are measured at a 50Hz rate while code/carrier divergence (C/N_0) is sampled at a 1 Hz rate for each satellite. The ISM calculates the phase standard deviation σ_ϕ (defined as the standard deviation of a linearly detrended phase data segment) every minute from the 50 Hz data. Amplitude scintillation is measured by the S_4 parameter (defined as the normalised standard deviation of the temporal intensity fluctuations at the receiver), with a correction factor included to eliminate the effects of ambient noise [5]. The Vanimo ISM is part of a wider regional GPS receiver network [6].

GEOMAGNETIC STORM CHARACTERISTICS

Geomagnetic storms generally occur around the maximum phase of the sunspot cycle. If there is a southward directed interplanetary magnetic field $B_z < -10$nT for more than three hours, a geomagnetic storm will occur [7]. The classical storm may be considered as having three phases, the initial, main and recovery phases. The initial phase consists of a shock wave preceded by the arrival of enhanced solar activity. The main phase principal characteristic is the decrease in the H (horizontal) component of the earth's magnetic field due to the increase in the trapped magnetospheric particle population. The recovery phase is characterized by the return of the H field back to the pre-storm level [8].

LOW LATITUDE STORM OBSERVATIONS.

Storm data were collected using an ISM from the low latitude station at Vanimo, which has been in operation since August 1999. The effect on scintillation activity from the storm of September 1999 is presented in this paper. An elevation cutoff angle of 25^0 was used to minimise amplitude and phase fluctuations due to multi-path propagation. After processing all satellite passes, four satellites were selected as having experienced enhanced scintillation activity (S_4>0.25). S_4 (corrected) and σ_ϕ were then plotted against universal time (UT). Figure 1 shows the Dst and Kp indices for this event. Kp reached a maximum of 8. Dst is the Disturbance Storm Time index which indicates the effect of the globally symmetrical westward flowing high altitude equatorial ring current that causes the worldwide, main phase depression in H. Kp is the global measure of magnetic disturbance. Figure 1 clearly shows the main phase of a major storm occurring late on September 22 when Kp reached a maximum of 8.

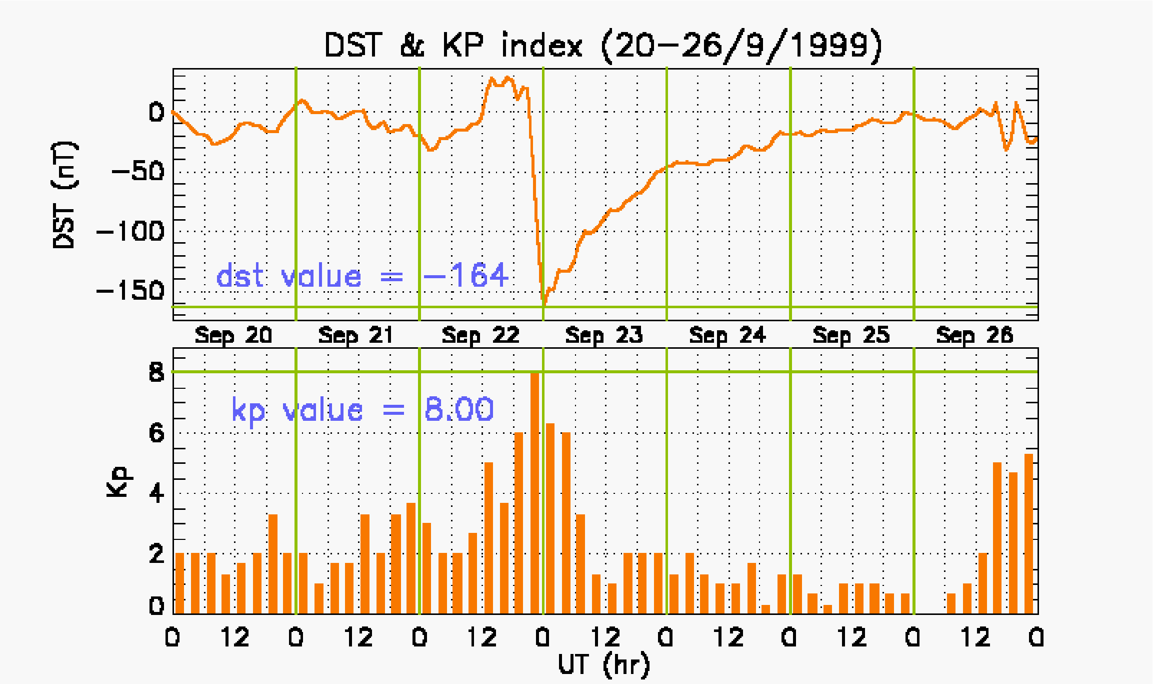

Figure 1. Magnetic Indices Dst and Kp for 20-26 September 1999.

The peak Dst excursion during the September 99 storm was –164nT at 2400 UT 22 September (day 265), while sudden storm commencement (SSC) was at 1222 UT. Figures 2 and 3 show values of S_4 and σ_ϕ recorded at Vanimo for that day. S_4 rarely exceeded 0.25 and σ_ϕ rarely exceeded 0.05, indicating that scintillation activity was essentially dormant

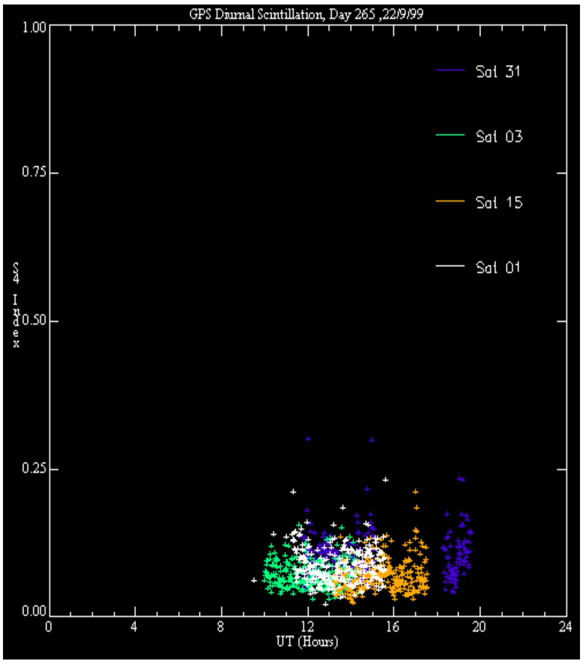

Figure 2. S_4 for satellites PRN #31, #03, #15 and #01 on 22 September 1999 (day 265).

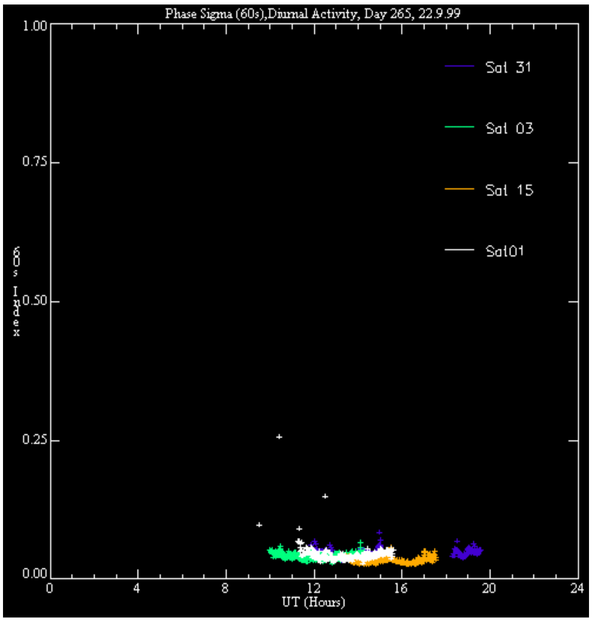

Figure 3. σ_ϕ for satellites PRN # 31, #03, #15 and #01 on 22 September 1999 (day 265).

Figures 4 and 5 show S_4 and σ_ϕ for Vanimo passes on 23 September 1999 (day 266) during the recovery phase of storm. and the increase in scintillation is obvious with both S_4 and σ_ϕ being much enhanced between 1130-1400 UT.

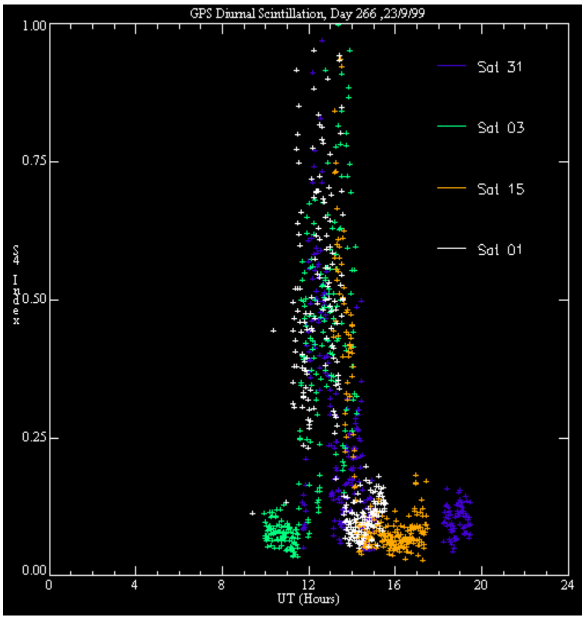

Figure 4. S_4 for satellites PRN #31, #3, #15 and #01 on 23 September 1999 (day 266) during the recovery phase of storm.

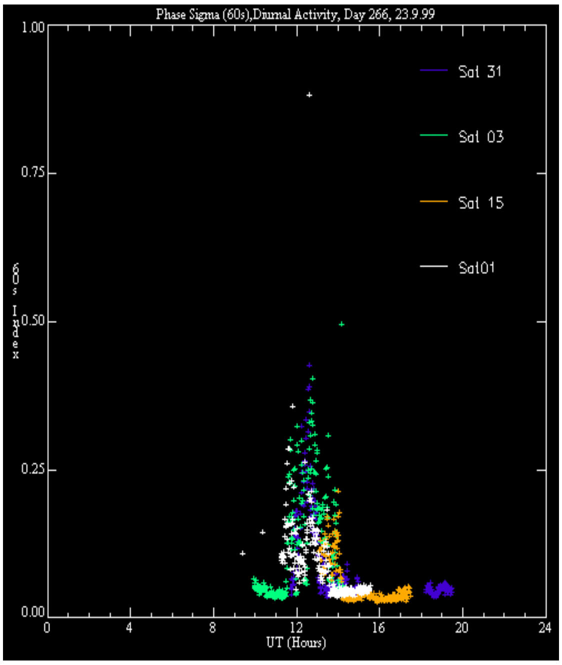

Figure 5. σ_ϕ for satellites PRN # 31, #03, #15 and #01 for 23 September.1999 (day 266) during the recovery phase of storm.

As a comparison with scintillation activity prior to the commencement of the storm, Figures 6 and 7 show S_4 and σ_ϕ on 21 September1999, typical of a normal equinoctial night. Periods of enhanced scintillation activity occur, but they are generally less intense and of a shorter duration than the very disturbed period of 23 September 1999.

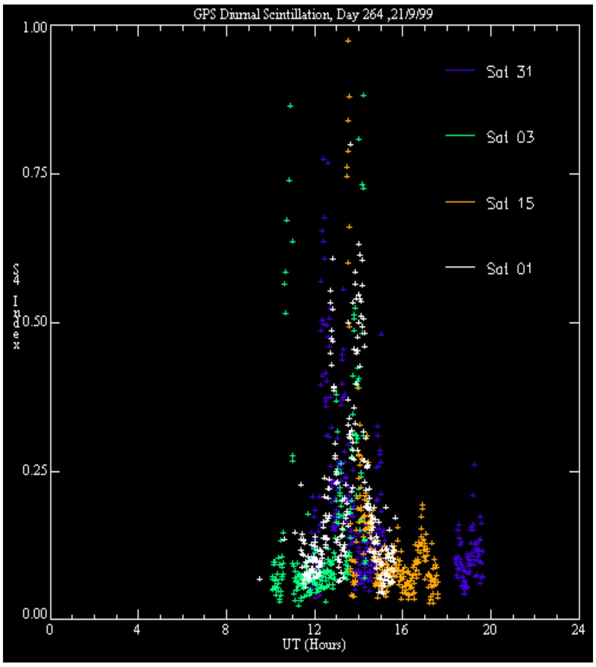

Figure 6. S_4 for satellites PRN #31, #03, #15 and #01 for 21 September1999 (day 264) prior to storm commencement.

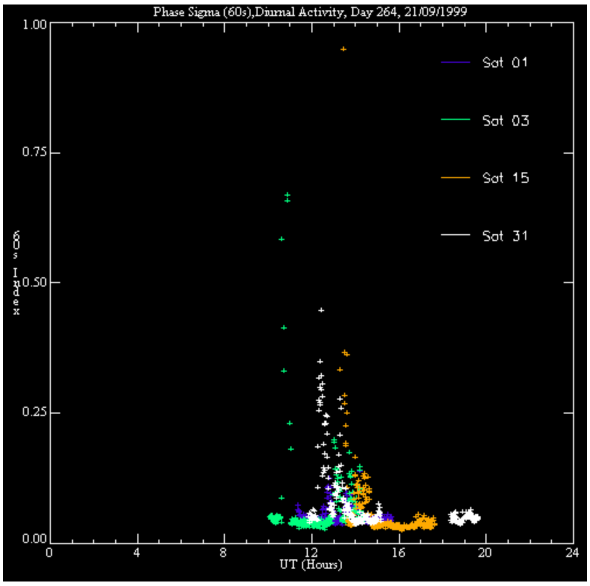

Figure 7.σ_ϕ for satellites PRN #31, #03, #15 and #01 for 21 September.1999 (day 264) prior to storm commencement.

DISCUSSION AND CONCLUSION

Peak scintillation activity in low latitude regions such as Vanimo normally occurs during the equinox months. It has a diurnal dependence and is most likely to occur between sunset and midnight. Occasionally conditions may favor post midnight activity [2]. Figures 6 and 7 show scintillation activity on what could be considered a normal equinoctial night (21 September 1999). Enhanced activity could be seen for several hours commencing at about 10 UT, 20 local time (LT). All satellite passes showed no activity during the morning or post midnight period. With the onset of the storm, Figures 2 and 3 show quiescent scintillation as observed on 22 September. Figures 4 and 5 show scintillation activity returning during the recovery phase of the storm, (23 September1999). An essential property of a magnetic storm is the enhanced ring current through the injection of ions. The Dst index has been used to propose the following three criteria for the effects of the ring current in the generation or inhibition of F-layer irregularities during storm activity [9].

1. If the excursion of Dst takes place during the daytime hours and well before sunset, the normal height rise of the F layer is disturbed and irregularities are inhibited that night.
2. If large excursions occur in the midnight to post-midnight period, the layer height rises and then falls and creates irregularities.
3. If the large excursion of Dst takes place after sunset and before midnight, the layer height rise is not disturbed and irregularities form in the same manner as on an undisturbed night.

Maximum excursion in Dst occurred at 2400 UT on 22 September 1999 (1000 LT). The excursion occurred during the category one period (1000 LT) however suppression was not observed that night, indeed there was enhanced activity (Figure 4). Figure 2 shows suppression of scintillation occurring several hours prior to the maximum excursion. The period corresponds to SSC. In this case, the results were not in agreement with the criteria proposed. However there are a number of studies [9,10,11] that report the observation of pre midnight inhibition and post midnight enhancement of scintillation during increased magnetic activity. Proposed mechanisms to explain such behavior have focused on the height of the F2 layer. Post-midnight scintillation may be attributable to the coupling of high latitude and magnetospheric current systems with the equatorial electric field and cause a reversal from a westward to an eastward direction [10]. Conversely, decreasing the eastward electric field reduces the layer height in the post sunset generation period thereby creating conditions not favorable to the formation of irregularities. Zonal and meridional winds may also be significantly modified during magnetospheric disturbances so as to inhibit the processes required for the growth of plasma irregularities [12]. The relationship between SSC and scintillation warrants further investigation, including a statistical study involving a more extensive data set than the single day of data presented here.

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REFERENCE

1. B.H. Briggs. Ionospheric irregularities and radio scintillation, Contemporary Physics, Vol. 16, No.5, pp. 469-488 1975.
2. S.Basu and S.Basu. Scintillation techniques for probing ionospheric irregularities. Private Communications.
3. S.L. Ossakow. Spread-F theories – a review. Journal of Atmospheric and Terrestrial Physics, Vol. 43, No. 5/6 1981.
4. S.G. Rino, M.D. Cousins, and N.B. Walker. Amplitude and phase scintillation measurement results from GPS satellite observed at Kwajalein and at Ascension Island. AFGL technical memorandum No. 56, 20 Nov. 1981.
5. A.J. Van Dierendonck, Q. Hua, P.Fentonand and J. Klobuchar. Commercial ionospheric scintillation monitoring receiver development and test results, Proc. 52nd annual meeting of the Institute of Navigation, pp. 873-582, 1996.
6. R M Thomas, M A Cervera, K Eftaxiadis, S L Manurung, S Saroso, Effendy, A G Ramli, W Salwa Hassan, H Rahman, M N Dalimin, K Mgroves and Y Wang. A regional GPS receiver network for monitoring equatorial scintillation and total electron content. Radio Science, Vol 36, no 6, pp 1545-1558, 2001.
7. W.D Gonzatez, J.A. Joselyn, Y. Kamide, H.W. Kroehl, G. Rostoker, B.T. Tsurutani and V.M. Vasyliunas. What is a magnetic storm? Journal of Geophysical Research Vol. 99, pp. 5771-5792, 1996.
8. S.C. Dubey and A.P. Mishra. Characteristics of large geomagnetic storms observed during solar cycle 22 Indian Journal of Radio & Space Physics, Vol. 29, pp. 51-60, April 2000.
9. J. Aaron's. The role of the ring current in the generation or inhibition of equatorial F layer irregularities during magnetic storms. Radio Science, Vol. 26, No.4, pp. 1131-1149, July- August 1991.
10. S.Kumar and A.K. Gwal. VHF ionospheric scintillations near the equatorial anomaly crest: solar and magnetic effects. Journal of Atmospheric and Solar-Terrestrial Physics, Vol. 62, pp. 157-167, 2000.
11. S.Banola, B.M. Pathan and D.R.K Rao. Strength of the equatorial electrojet and geomagnetic activity control on VHF scintillations at the Indian longitudinal zone. Indian Journal of Radio & Space Physics, Vol. 30, pp. 163-171, August 2001.
12. M.A. Abdu. Major phenomena of the equatorial ionosphere-thermosphere system under disturbed conditions. Journal of Atmospheric and Solar-Terrestrial Physics, Vol. 59, pp. 1505-1519, 1997.