Critical assessment of the temporal forecast of L-band scintillation and moving towards the spatial temporal forecast of the scintillation over the Indian region

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Abstract

Bagiya et al. (2014) [1] critically evaluated the L-band scintillation forecast method proposed by Sridharan et al. (2012) [2] using the special campaign mode observations from Trivandrum (8.5°N, 76.91°E, dip latitude 0.5°N). To minimize the uncertainties due to moving satellite platform (TEC & S4 observations from GPS satellites), they used fluctuating component of the foF2 from the ground based ionosonde(76.9°E) to represent the electron density perturbations and ionospheric scintillation at L1 from the geostationary satellite GSAT-8(75.46°E). To correlate the scintillation over the GSAT IPP (ionospheric piercing point) to the forecast perturbations over the ionosonde, the required zonal velocity of the perturbations was estimated using GSAT and GPS scintillation data during one of the close-by GPS passes and taken to represent the particular solar epoch and season. By adopting the above changes, it has been noted that the forecasting capability of L-band scintillation has remarkably improved vindicating the role of perturbations in the evolution of the scintillation. The non-occurrence of scintillations on some occasions is understood in terms of background ionospheric/thermospheric conditions. A threshold upward velocity for the evening F-region as early as 1730-1830 h, has been worked out to be 5 ms^{-1} for the ESF to get triggered. Since it is known that the electron density perturbations travel eastward and when the integrity of wave train of the perturbations is retained, any particular feature that passes over Trivandrum would have crossed over another location west of Trivandrum at an earlier time dictated only by the zonal velocity. With this, it is fairly reasonable to generate the probable spatial pattern and guess the temporal evolution of L-band scintillation. The prediction on the total duration has been derived on the prevailing good correlation between the total duration of scintillation and the base height of the F-region (h'F) at 1930 LT and this has been explained in terms of the favourable background neutral atmospheric conditions. Following Bagiya et al. (2013)[3], the relation between h'F at 1930 LT and the probable maximum latitudinal extent of the scintillation has enabled specification of the upper limit for the latitude region that is likely to be affected by the scintillation. It is believed that the presented results hold enough potential to generate reliable temporal- spatial L-band scintillation forecast maps and provide the necessary alerts to the satellite based air navigation users.

1. Introduction

During post sunset hours, under favourable background ionospheric/thermospheric conditions, the presence of suitable perturbations are believed to trigger the plasma instabilities, well known as equatorial spread-F (ESF), culminating in the generation of a wide range of irregularity scale sizes that affect the complete range of VHF, UHF and L-band communications. In view of the increasing demand for continuous and precise satellite based communication and navigation, 'forecasting' of ionospheric scintillation in the L-band that is used for the navigation links becomes extremely important. A novel method was evolved by Sridharan et al. (2012) [2] by making use of GPS-TEC to forecast ionospheric L-band scintillation with reasonable accuracy. Bagiya et al. (2014) [1] had evaluated this method systematically using the observation from equatorial stations Trivandrum, India. With the help of observations from ground based ionosonde (DPS-40) and Indian geostationary satellite GSAT-8 they could minimize the uncertainties due to the movement of the satellite platform. The present work discusses the salient features of this recent effort.

Along with the temporal variability, it is well known that ESF shows large spatial variability also. To be useful to any potential user, in an ideal sense, a snap shot picture of irregularities that cause the scintillations in latitude-longitude plane along with its temporal variations should be forecast. Since it is known that the electron density perturbations which causes the irregularities travel eastward with certain zonal velocity, having knowledge of this velocity values the approximate arrival time of the perturbations at the adjacent longitudes can be calculated and a spatial map of irregularity occurrence pattern can be generated. The present work also proposes the forecast of likelihood spatial (longitudinal) occurrence pattern of scintillations in the longitude zone of our interest viz., 65 E-95 E covering the entire Indian zone along with the likelihood total duration well before 1930 LT.

2. Approach

Before embarking on forecasting the characteristics of the scintillation patches, it should first be ascertained beforehand whether the scintillations are likely to occur or not. The upward velocity of the base height of F-region (h'F) during the time window of 1730 - 1830 LT had been used as an index that would give clues on the occurrence probability of scintillation during the course of the night. It is conjectured that under normal conditions, signatures of the impending vertical motion of F-region have to be present in the vertical velocity even before sunset and thus the rate of change of h'F (dh'F/dt) during sunset hours itself could be taken as a measure of the impending electrodynamical drift in the equatorial ionosphere. While attempting to get a feel of the PRE of the F-region that has a direct control on the triggering of the R-T instability at a later time (~1900 LT), in advance, it was found that the dh'F/dt at 1730 – 1830 LT did show a prior indication. It could be seen whenever the vertical velocity exceeded 5 ms^{-1}, ESF / L-band scintillation had occurred during that night. This threshold could be taken to be a representative value for the corresponding solar epoch and season. The measured dh'F/dt revealed day to day variation which has to be necessarily due to the electrodynamics that is known to have such variability as the apparent velocity due to chemical recombination would not have significant day to day variability during the same season and solar activity level.

After identifying the highly probable ESF days by as early as 1830 LT, the synthesized electron density perturbations were derived in terms of $(df_oF_2)^2$ values following the method suggested by Sridharan et al. (2012) [2] to forecast the occurrence time and duration of scintillation patches. To generalise the forecast, only periodicities ranging from 30 min to 4 hours, falling under the classification of gravity waves were considered. These forecast perturbations would now have both positive and negative swings with respect to the mean value. It is well known that the negative phase of the perturbation grows due to the R-T instability and supports the generation of irregularities [2]. The plasma within the negative phase region would get depleted nonlinearly with time. In order to correlate the forecast perturbations over the ionosonde(76.9°E) and scintillation over the GSAT(75.46°E) IPP, the approximate zonal velocity with which the irregularity patch/perturbations move eastward was estimated by using the simultaneous scintillation observations of GSAT-8 and close-by GPS passes. The time lag between the evolution of a scintillation patch at these two IPPs and the longitude separation between them was used to calculate the approximate velocity values and were taken to represent the particular solar epoch and season.

The derived forecast perturbations are in the 'temporal domain' for a given location. Since it is accepted that these perturbations retain their characteristics for an extended duration, it becomes feasible to transpose the temporal variation as evinced over any location to a spatial pattern, with a basic knowledge on the zonal velocity. In other words, the train of perturbations over any location, say in this case Trivandrum (76.9 °E) had traversed with a zonal velocity v. This would imply that, when the integrity of the train of perturbations is retained, any particular feature that passes over Trivandrum would have crossed over the location west of Trivandrum at an earlier time dictated by the zonal velocity v. With the available approximate zonal velocity, calculated using nearby GPS passes and the GSAT data and assumed to remain constant all through the night, the wave train representing the perturbations had transposed to ~12 deg west of Trivandrum i.e. to ~65 E longitude, an earlier time and up to ~18 deg east of Trivandrum i.e. to go up to ~95 E longitude, future time. The next section briefly discusses the outcome of this unique attempt.

3. Results and Discussion

Since usually ESF manifestations occur only after 1930 LT, the forecast was attempted only beyond this time and the occurrence pattern is controlled by the negative phase of the perturbation. Figure 1(a-d) shows the event of 20th April and 28th April 2012. It could be seen that on 20th April, fig 1 (a), a total of twelve favourable time windows shaded in light grey were identified for scintillation to occur. However, only two distinct scintillation patches were observed between 2200 and 0030 LT which exactly coincided the forecast windows. The scintillation observations were adjusted for the time shift calculated using the velocity derived from GPS and GSAT geometry discussed earlier. Out of twelve forecast time windows, one encounters total absence of scintillation in ten windows. Since the requirement from the perturbation point of view is satisfied, the absence of the irregularities would then be due to certain changes brought about in the background conditions. Going by the R-T instability growth rate expression, [$\gamma = (1/L)(g/\nu_{in})$], the parameters of importance would be the ion- neutral collision frequency (ν_{in}) and the plasma scale length (L). Since the ν_{in} decreases exponentially with increase in altitude, the h'F could be taken as representative of this background condition. To have an understanding on the temporal variability of L, once again the ionospheric data has been made use of taking 5 MH_Z as the reference, centered around it, the gradient (dn_0/dz) has been obtained from which the L values were determined ($L = [1/n_0(dn_0/dz)]^{-1}$). Fig 1(b) depicts the variation of h'F (dashed line) and L (solid line) for 20th April. Going by the scintillation free time zone in the night and noting the h'F and L values at that times , it is hypothesised that one of the pre-requisites for ESF to occur in this epoch and season could be that h'F should be above 225 km and the other L should be below 20 km. On 28th April 2012, (fig 1c) scintillation was present all through the night. The perturbation variations had shown seven favourable phases. Out of which only two windows were free of irregularities. Both h'F and L indicate favourable conditions from 1930-2030 LT beyond which the L value increased above the threshold and remained so up to 2145 LT (fig 1d). Though scintillations were absent in the forecast window during 1930-2030 LT its presence is conspicuous. The present study highlights the role of perturbations in the initiation and sustenance of the primary R-T instability. Not simply stopping at providing a trigger to the instability and allowing it to grow as a free running system and to decay over a time period dictated by the background conditions, the perturbations have been shown to be closely linked to the instability all through, when the background conditions are favourable.

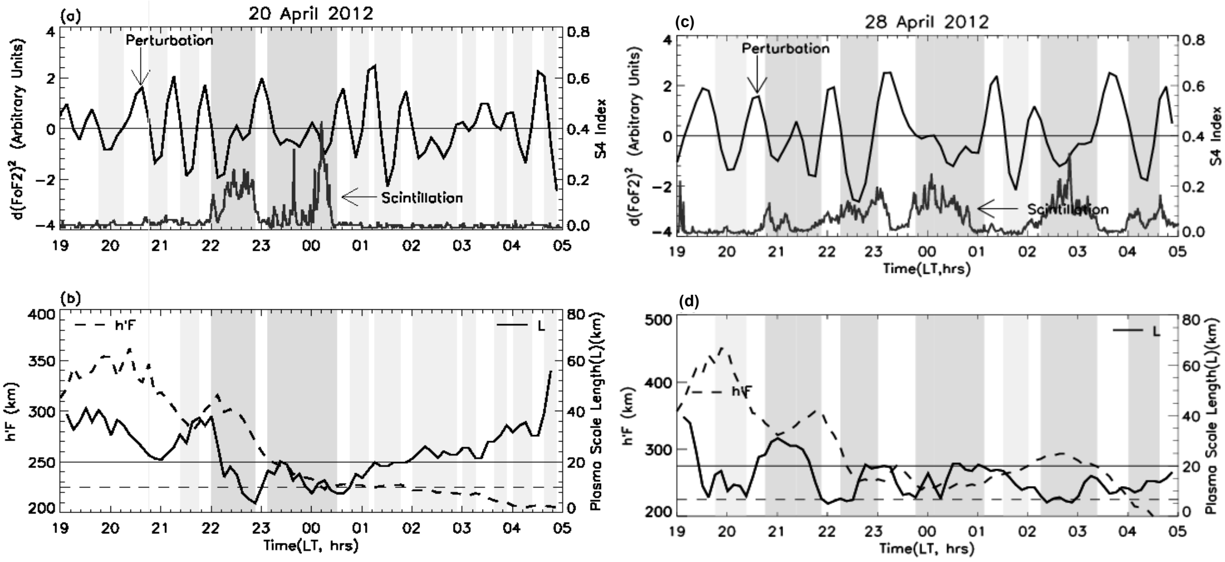

Figure 1: (a & c) Forecast density perturbations [$d(f_oF_2)^2$] along with the actual S_4 index from GSAT observations, (b & d) h'F (base height) of F-region and plasma scale length L variations during 1900 to 0500 LT on 20th and 28th April 2012 respectively. The dark shaded regions show the time windows where scintillation forecast has been successful. The light shaded regions show the windows where scintillation was forecast but did not occur.

It is all the more welcome if the forecasting system should be able to indicate the total duration of scintillation well in advance, at least by 1930 LT, when the F-region is still stable. A nonlinear relation between h'F and the total duration of scintillation, or in other words, the upper time limit beyond which the scintillation would cease, has been worked out and the same is depicted in figure 2a. The lower time bound is kept at 1930 LT for all the days and the figure depicts the time duration with respect to the reference time of 1930 LT. Both ways, when h'F is < 300 km or >300 km, the duration of the scintillations tends to increase.

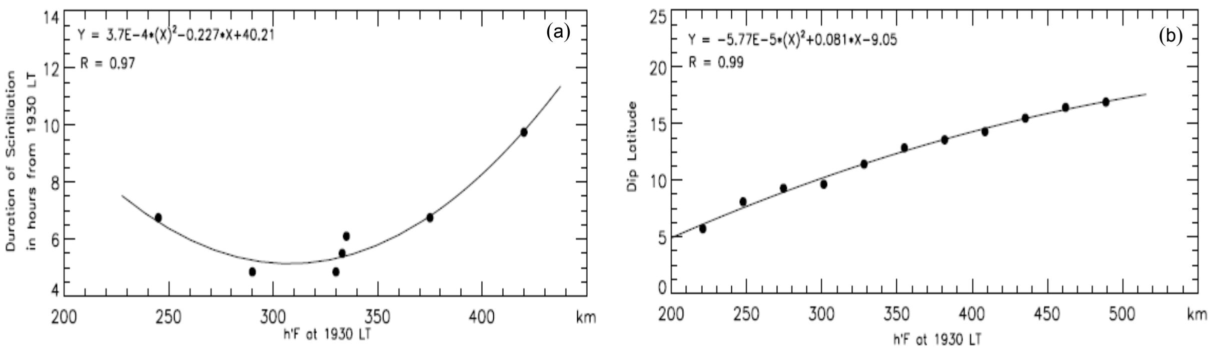

Figure 2 : (a) The plausible relation between h'F at 1930 LT over an equatorial station and the duration of the scintillations during the course of the night represented a best fit second order polynomial. The near symmetric behaviour is explained on the basis of the competing effects of the ion–neutral collision frequency and the plasma scale length (b) A relationship between h'F and the maximum latitudinal extent likely to be affected by scintillations based on the results linking the h'F at 1930 LT and the altitudinal extent of the irregularities over the equator [3]

For the nonlinear relationship between h'F at 1930 LT and duration two competing processes are suggested. The h'F is treated to represent the ion-neutral collision frequency in the growth rate expression of the primary R-T instability. As h'F decreases, the recombination of F-region ionization becomes more effective due to the increased abundance of molecular species. Due to the differences in the scale heights of the atomic and molecular species, the recombination effects dominated by molecular species results in to the steeper gradients in the F-region, this would over compensate the quenching effect due to the increased ion neutral collision frequency controlled by atomic species at lower heights. Thus the irregularity would still be effective even if the h'F becomes lower and could persist for a longer duration. The maximum latitude extent which is likely to be affected has been worked out in figure 2b using the relation between the h'F at 1930 LT and the maximum altitudinal extent of the density irregularities over the magnetic equator and its further mapping along the geomagnetic field line [3].

Finally, figures 3(a-b) depict the spatial temporal forecast maps of scintillation, generated as per the procedure mentioned in the previous section, along with the actual scintillation occurrences (elevation > 45, S_4 > 0.2) detected while monitoring the GPS satellites over various stations Agatti (AGT) (10.83 N, 72.2 E), Trivandrum (TRV) (8.5 N, 76.9 E), Visakhapatnam (VSG) (17 N, 83 E) and Port Blair (PBR) (11.61 N, 72.41 E) for 21st and 28th April 2012. The amplitude of the perturbation not being of any consequence here, the favourable (-ve phase) and unfavourable (+ve phase) phases of the perturbation are depicted by dotted lines and blank portions respectively. Since time is shown in the Y-axis and the longitudes in the X-axis, at every instant of time one could notice the spatial zones likely to experience the scintillations. Therefore, each one of the plots in the figure 3 could be said to depict the temporal evolution of the spatial occurrence pattern. The total duration of the likelihood scintillation is shown as the cessation time of scintillation forecast on each day in figure 3, estimated from the analytical expression given in figure 2a. Along with this, the actual cessation time of scintillation has also been depicted. On 21st April, the forecast scintillation pattern showed large variation and the expected total duration turned out to be for ~7 h corresponding to the h'F of ~245 km. Many satellites had been monitored by the ground stations like AGT, TRV and VSG. Based on the analytical expression relating the h'F and latitudinal extent (figure 2b) the latitudinal region likely to be affected has been estimated to be ±7.43^o magnetic latitude. Figure 3b shows results pertaining to 28th April. The expected duration along with the actual duration had been shown in the plot. The projected latitudinal extent had also been mentioned in the plot. It could be seen that most of the patches fell in the expected time/longitude zones, with a couple of exceptions cutting across the zone where no scintillations were expected.

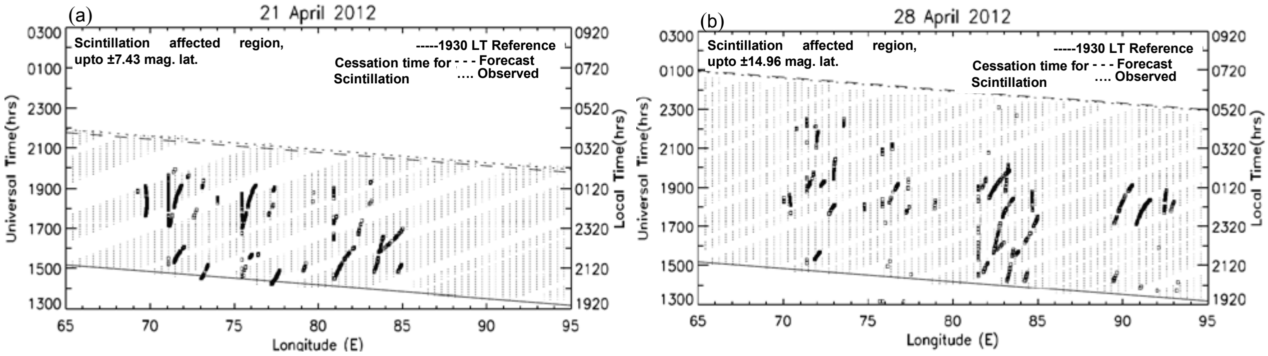

Figure 3 : The spatial maps of the occurrence pattern of L-band scintillations for the longitude range of 65^o E - 95^o E for the whole duration of 1930 LT to the forecast time limit estimated from figure 2 for 21th and 28th April 2012 along with the actual observations of the scintillations (elevation >45 deg and S4 >0.2) from all stations viz., AGT, TRV, VSG and PBR. The occasional slippages/ mismatch between the predicted time window and the occurrence have been explained based on the background diurnal wind and variable perturbation/irregularity velocity

The observed slippages may due to the background diurnal wind or variable perturbation/irregularity velocity. The diurnal background winds directly deal with the perturbations, which are assumed to retain their characteristics through out the day and extend all through the night, thus the scintillation pattern. Another major aspect is day to day variability of the perturbation/irregularity velocity which is taken as constant all through the night for present season and solar epoch. Any deviations would get reflected in the identification of the temporal and spatial zones prone for scintillations. With the known fact that irregularity velocity varies during the night, once the actual velocity values are known many of the slippages in the occurrence pattern would get resolved.

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5. References

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