CHAPTER – 6

**OI 630 nm Night Airglow Emissions During Spread-F Events.**

6.1 **Introduction**

Plasma depletions are large-scale structures of plasma density associated with the phenomenon of the equatorial spread-F. The ionospheric plasma depletions, first observed by Hanson and Santani (1973) using satellite borne experiments, have been observed subsequently by number of in situ [1-4] and ground based [5-24] techniques. With ionosonde, short pulses of high frequency (HF) radio waves are transmitted upward, and these are reflected from ionosphere. These reflected waves are recorded as traces in the ionograms depicting the virtual height (h’F) of reflecting at varying frequencies (1-20 MHz range). On certain nights, recorded traces of reflected waves show defused traces; this event is called as spread-F (ESF). The F-layer near the magnetic equator becomes unstable around local sunset time on the days of ESF occurrence and as a result irregularity develops in the electric field and plasma densities with a wide range of scale size. These irregularities are aligned with the Earth’s magnetic field lines forming sometimes huge density depletions called “bubbles” or “holes”. It is observed that plasma irregularity first develops in the bottom side of F-layer and believed to be caused by the collisional Raleigh-Taylor instability. Under prevalence of quite magnetic conditions, bubbles generally form early in the evening, due to post sunset increase in
height of equatorial-F layer and perturbed bottom side of F-layer by gravitational Rayleigh–Taylor instability [26].

The optical imaging techniques [6, 12, 13, & 21] from 10° to 15° dip latitude regions can very well provide information about structure of these plasma depletions above the magnetic equator as well as their temporal movement. The OI 630nm emission provides a convenient tool for remote sensing of the upper atmosphere. The dynamics of ionospheric plasma irregularities can be monitored through ground based remote observations of night airglow emissions. The OI 630nm emission provides a convenient tool for remote sensing of the upper atmosphere. The large scale F-layer plasma depletions which contain equatorial bubbles and associated ionospheric irregularities typically manifest themselves as region of low OI 630 nm emission [12]. Mukherjee [12, 13], through his work, studied the characteristics of equatorial plasma depletions using all-sky camera and filter tilting photometer at OI 630nm. They found that the north-south extent of these depleted plasma regions are more than 1000 km in length with east-west dimensions of 50-250 km. Also, the depletions were normally confined to the time between 21:30 and 01:00 Hrs. The occurrences of plasma bubbles are much more frequent (55%) during higher solar activity (HSA) than during lower solar activity LSA (33%) [21]. The perturbations at the bottomside of the F-region can occur at any time, but the equatorial F-region
irregularities or plasma bubbles are observed only during night-time (starting just after sunset) and not during daytime. After sunset, the E-region conductivity drops considerably and the electric fields generated at the bottomside of the F-region can develop plasma instabilities. The rapid uplifting of the F-region just after sunset is one of the important conditions for the onset of ionospheric plasma irregularities and fluctuations in the ion drift velocity or plasma density, caused by gravity waves or other large-scale wave structures, can act as the seed for the generation of the initial perturbation [25].

6.2 Data and Methodology

6.2.1 Optical Data (Airglow)

Airglow observations were made from the terrace of Physics Department, Shivaji University, Kolhapur, a low latitude station (16.8° N; 74.2° E; 10.6° N dip lat). Three tilting filter photometers are installed at terrace of Physics Department, Shivaji University, by Indian Institute of Geomagnetism (IIG), Mumbai. Details of tilting filter photometer have been explained in chapter-5.

6.2.2 Ionosonde Data

The ionospheric parameters (critical frequency) of the F2-layer (foF2) and the virtual F-layer height (h’F) of the ionosphere were measured from a nearby station, Ahmadabad (geog. lat., 23.02° N, long. 72.6° E) to know ionospheric conditions during the time of airglow observation. The square of parameter (foF2) is
proportional to electron density at the peak of F2-layer [27] and is given by, \( N_e(\text{max}) \, \text{cm}^{-3} = 1.24 \times 10^{-24} [\text{foF2 (MHz)}^2] \).

**6.2.3 Scintillation Data:**

Scintillation studies, using geostationary satellite with radio beacon, provide a simple way of monitoring the temporal behavior of irregularities with scale size between few tens of meters to about 1 km. The scintillation instrument was installed with the help of Indian Institute of Geomagnetism, Panvel, Navi-Mumbai at the department of Physics, Shivaji University, Kolhapur. It is shown that the nighttime scintillations are associated with equatorial spread-F [28].

**6.3 Result and Discussion:**

Fig 6.1 shows night-time variation of the OI 630 nm intensities observed at Kolhapur by the zenith photometer on the night of (a) 18 February 1996, and (b) 4 Dec 1996. The vertical lined bar shows scintillation observed at Kolhapur. All nights were magnetically quiet nights; however, on the night of 4 Dec 1996 for the period of 2030-2330 IST, the Kp index was 4^+ . On 18 February 1996 the depletion in OI 630 nm intensity was observed on midnight and scintillation was also recorded at the same time. On 19 February 1996 depletion in OI 630 nm intensity recorded around 2230 IST and scintillation was also present. On the night of 4 Dec 1996 the depletions were recorded throughout the night. The decrease in OI 630 nm intensity is associated with regions where the electron density is depleted. The inter depletion distance (IDD)
Fig. 6.1. Variation of OI 630 nm intensity along Zenith direction on the night of (a) 18 February 1996, (b) 19 February 1996, and (c) 4 Dec 1996, at Kolhapur showing propagating wavy disturbances on the spread-F night. The vertical lined bar shows scintillation observed at Kolhapur.
on this night is found to vary between 333 km to about 465 km. On 19 February 1996 three (Zenith, 30°East, and 30°North) photometer were operative and all recorded depletion in OI 630 nm intensity around 2230 IST. The north looking photometer observed the peak earlier than that of zenith before midnight with time delay of 22 minutes. This means there is velocity propagation from North to Zenith (equatoward) direction. The velocity of meridional wind was 110 m s\(^{-1}\).

Figure 6.2 shows the variation of OI 630 nm intensity along zenith direction on the night of 26 February 1998. The panel-a shows typical recording of the propagating airglow depletions in 630 nm intensity recorded on tilting filter photometer and panel-b shows ionosonde data of low latitude station Ahmedabad to study the movement of the F-layer and condition of the ionosphere during the period of observations. The square of the parameter (foF2) is proportional to the electron density at the peak of the F2 layer [29] and is given by \(N_e(max) \text{ cm}^{-3} = 1.24 \times 10^{-24} \text{ [}foF2 \text{ (MHz)}]^2\). Five bubbles were observed, the width of bubble ranged from 225 – 414 km and percentage depth between 4 – 34 %. The VHF scintillation shows good correspondence with the 630.0 nm airglow intensity variations. During the post-sunset hours the zonal electric field leads to \(E\times B\) drifts, thereby lifting the f-layer to altitudes where recombination effect is negligible and collisions are rare, resulting in a condition conducive to the development of plasma irregularities.
Fig 6.2. (a) Depletions observed in OI 630.0 by Photometer on the night of 26 February 1998 at Kolhapur. The vertical lined bar shows scintillation observed at Kolhapur. (b) Ionospheric parameters $h'F$ & $f_{o}F_2$ observed at Ahmedabad.

Fig 6.3. (a) Depletions observed in OI 630.0 by Photometer on the night of 23 March 1998 at Kolhapur. The vertical lined bar shows scintillation observed at Kolhapur and cross bar ESF observed at Trivandrum. (b) Ionospheric parameter $h'F$ & $f_{o}F_2$ observed at Ahmedabad.
Through the generalized Rayleigh-Taylor instability (GRT) mechanism, the bubbles with depleted plasma density are lifted up. During this time small-scale irregularity grow on large scale gradients in plasma bubbles through secondary instabilities. As the plasma-depleted bubbles rises from the bottomside of the F-layer, they are elongated along the field lines to off-equatorial latitudes and extend up to a north-south dimensions of the order of 2000 km [30]. High ambient ionization density (N) in the post-sunset anomaly ionosphere causes intense scintillations at off-equatorial stations like Kolhapur (17° N) which are closer to anomaly crest region, because the magnitude of scintillation is proportional to the product \((\Delta N/N) \times N\) integrated through the ionosphere [31, 32]. The Fig. 6.2 confirms the significant enhancement in the anomaly gradient is accompanied by the intense scintillation activity over Kolhapur.

On the night of 23-24 March 1998 (see fig. 6.3) two photometers were operative. Top panel shows depletion in OI 630.0 nm at Kolhapur, the vertical lined bar represents scintillation observed at Kolhapur, and cross lined bar ESF observed at Trivandrum (8.3° N). The arrow shows depletion in intensity of 630 nm nightglow observed with photometer at Kolhapur. The magnetic activity index \(A_p\) and solar flux \(F_{10.7}\) cm are also shown. The IDD range of bubble is 210-325 km and there were 4 patches recorded.
during the time interval of passage of bubble at Kolhapur. The movement of bubble (depletion in 630.0 nm) was from west to east as the zenith photometer records peak in 630.0 nm earlier than that of 30° east, this shows that there is velocity propagation from west to east (zonal). The airglow structures were moving with velocity in the range of 97 - 115 m/s. At a given longitude, the requirements for Rayleigh-Taylor instability growth within the ESF seasons are: (i) post sunset rise of the F-layer, (ii) the availability of a seed perturbation to launch the Rayleigh-Taylor mechanism and (iii) the absence of strong trans-equatorial thermospheric wind [33]. It is generally understood that the third factor plays a key role in suppressing or causing ESF activity at a given longitude.

Figure 6.4 portrays nocturnal variation of OI 630 nm intensity on the nights of 25–26 March 1998 at Kolhapur. Both the nights were quiet to unsettled (Ap = 06 and 05 respectively). The arrows show depletion in airglow intensity. The solar flux (F10:7 cm) for the day was 114 units. This was a night of moderately disturbed condition with a moderate solar activity. The panel-a shows variation in OI 630.0 nm intensity, panel-b shows ionosonde data from Ahmedabad, and panel-c shows all-sky images taken with 630.0 nm filter. A series of north–south aligned depletions were observed from 20:15 to 01:45 IST and the depletions were very prominent. It was a typical spread-F night. The depth of bubbles (depletions) was estimated to be varying between 27% and 60% and the width of the bubbles was ranging between 195 and 646 km.
Fig 6.4. a) Depletions observed in OI 630 nm by photometer at Kolhapur, b) Ionogram data at Ahmedabad, and c) Depletions observed in OI 630.0 nm by all-sky imager at Kolhapur. [All sky image after Mukherjee, 2003].
Fig 6.5. a) Depletions observed in OI 630.0 by photometer, b) h'F, & c) Depletions observed in OI 630.0 by all-sky imager (All sky Image after Mukherjee, 2002). The vertical lined bar in panel-a shows scintillation observed at Kolhapur.
In Fig. 6.5 we depict the OI 630.0 nm intensity profile on 18 January 1999. Simultaneous depletions were seen in tilting filter photometer and all sky images. It was typically quiet night with moderate solar activity. It shows example of the movement of Appleton Anomaly during the night from north to south with speed of 39-49m/s. In the panel-c, north-south aligned plasma depleted region is shown. These images confirm that during the period of observation of bubble at low latitudes, the anomaly was well developed. Martyn [34] proposed that the anomaly was due to the combined effect of vertical drifts of ionization near dip equator and its subsequent diffusion to higher latitudes, which is well known as fountain effect. Usually in the nighttime, the zonal electric field changes direction and becomes westward. As a result the plasma moves equator ward as seen at the off-equator latitudes, which is known as reverse ionization anomaly. Our results (39-49 m/s) confirm the earlier results from this longitude. The rapid downward motion of F-layer in the evening hours, the weakening of the unstable layer takes place due to usually large downward drift velocities driven by westward electric field. Generally, a large downward drift followed by a positive drift which remains steady for more than an hour gives rise to spread-F irregularities. The motion of these bottom type irregularities is dominated by E-region dynamo electric fields. The perturbation in electric field in the base of the F-region is required to trigger the growth in the equatorial spread-F
[13]. The depth of bubbles (depletions) was estimated to be varying between 19% and 55% and the width of the bubbles was ranging between 268 and 608 km.

In fig. 6.6 we show (a) Depletions observed in OI 630 nm by Photometer on the night of 5 March 2000, at Kolhapur and (d) the processed images of OI 630.0 nm by all sky imager for the night of 1 March 2000 at 22:06, 22:12, 22:16, 22:21, 22:35, 22:45 IST. It was a disturbed night with Ap=21 and Kp index 3 Hourly Kp Index during period of observations is 3+, 3+, 3, 4+. The photometer data shows the variation of OI 630.0 nm intensity variation along zenith and 30° East directions at Kolhapur showing propagating wavy disturbances on a spread-F night. There is wave propagation in both directions. The all sky images on the same night from Kolhapur has recorded similar observations. Dark regions represent low airglow-intensity and were thus associated regions where electron density was depleted relative to the background. The quasi north-south magnetic field-aligned depletions (dark structures) seen in the images were optical signatures of the plasma bubbles [35]. The degree of depletion observed for the period of observation varied between 19 and 35% with corresponding width of the bubble ranging from 235 to 586 km.

Table 6.1 indicates that large scale ionospheric plasma depletions were observed at different times during the course of a night and under both geomagnetic disturbed and quiet conditions. The results are in agreement with Mukherjee et al. [11-13].
Figure 6.6. (a) Depletions observed in OI 630 nm by Photometer on the night of 5 March 2000, at Kolhapur. The vertical lined bar shows scintillation observed at Kolhapur. (b) Ionosperic parameter h’F & foF2 observed at Ahmedabad, (c) Dst Index, and (d) All-sky images of OI 630.0 nm emission on the night of 1 March 2000 at Kolhapur showing several depletion regions moving towards east (All sky image after Hari Kishore et al, 2007).
Table 6.1 The range of inter-depletion distance (IDD), 3 hourly Kp index, number of bubbles observed during the plasma depletions observed in 630.0 nm at Kolhapur.

<table>
<thead>
<tr>
<th>Date</th>
<th>Period of obs. (LT)</th>
<th>No of bubbles observed</th>
<th>IDD Range in km</th>
<th>3 Hourly Kp Index During period of observations</th>
</tr>
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<tr>
<td>18-19 Feb 1996</td>
<td>20:00 – 05:00</td>
<td>2</td>
<td>333 - 484</td>
<td>2, 3+,3-,4</td>
</tr>
<tr>
<td>19-20 Feb 1996</td>
<td>20:00 – 05:00</td>
<td>1</td>
<td>414</td>
<td>1, 0+,2, 2+</td>
</tr>
<tr>
<td>4-5 Dec 1996 (D)</td>
<td>20:00 – 05:00</td>
<td>5</td>
<td>125 - 333</td>
<td>3-, 4-, 3, 3</td>
</tr>
<tr>
<td>4-5 Jan 1997 (Q)</td>
<td>20:00 – 05:00</td>
<td>8</td>
<td>127 - 433</td>
<td>0+, 0+, 0+, 1</td>
</tr>
<tr>
<td>5-6 Jan 1997</td>
<td>20:00 – 05:00</td>
<td>8</td>
<td>100 - 516</td>
<td>1-, 1+, 1-, 0+</td>
</tr>
<tr>
<td>6-7 Jan 1997 (Q)</td>
<td>20:00 – 05:00</td>
<td>3</td>
<td>300 - 360</td>
<td>1+, 1-, 0+, 0+</td>
</tr>
<tr>
<td>7-8 Jan 1997</td>
<td>20:00 – 05:00</td>
<td>3</td>
<td>250 - 446</td>
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</tr>
<tr>
<td>8-9 Apr 1997</td>
<td>20:00 – 05:00</td>
<td>4</td>
<td>190 - 500</td>
<td>1, 1-, 2-, 1+</td>
</tr>
<tr>
<td>23-24 Feb 1998</td>
<td>20:00 – 05:00</td>
<td>4</td>
<td>210 - 325</td>
<td>2+, 2+, 3, 3</td>
</tr>
<tr>
<td>25-26 Feb 1998</td>
<td>20:00 – 05:00</td>
<td>5</td>
<td>210 - 360</td>
<td>0+, 1, 2-, 1-</td>
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<tr>
<td>26-27 Feb 1998 (Q)</td>
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<td>5</td>
<td>225 - 414</td>
<td>0+, 0+, 1, 1-</td>
</tr>
<tr>
<td>20-21 Mar 1998</td>
<td>20:00 – 05:00</td>
<td>3</td>
<td>300 - 475</td>
<td>2, 3, 2+, 2+</td>
</tr>
<tr>
<td>23-24 Mar 1998</td>
<td>20:00 – 05:00</td>
<td>4</td>
<td>268 – 370</td>
<td>1-, 1-, 1-, 2-</td>
</tr>
<tr>
<td>25-26 Mar 1998</td>
<td>20:00 – 05:00</td>
<td>6</td>
<td>200 - 645</td>
<td>4+, 5-, 3-, 2-</td>
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<tr>
<td>18-19 Jan 1999</td>
<td>20:00 – 05:00</td>
<td>5</td>
<td>260 - 610</td>
<td>1-, 2, 3, 2+</td>
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<tr>
<td>12-13 Mar 1999</td>
<td>20:00 – 05:00</td>
<td>3</td>
<td>225 - 478</td>
<td>3-, 2+, 3+, 3-</td>
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<td>6</td>
<td>198 - 322</td>
<td>4, 3, 3, 4-</td>
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<td>165 - 565</td>
<td>1-, 1, 0+, 1</td>
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<tr>
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<td>6</td>
<td>133 - 403</td>
<td>2-, 2+, 2, 0+</td>
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<tr>
<td>19-20 Mar 1999</td>
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<td>268 - 360</td>
<td>2, 2, 3, 1</td>
</tr>
<tr>
<td>7-8 Apr 1999</td>
<td>20:00 – 05:00</td>
<td>2</td>
<td>376 - 403</td>
<td>2-, 2-, 3, 2+</td>
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</table>
6.4 Conclusion:

We have presented the results of the characteristics OI 630.0 nm observations using tilting filter photometer and all-sky-imager carried out at a low-latitude station, Kolhapur, in India. Corresponding ionosonde data were also used to study the formation and evolution of large-scale ionospheric plasma depletions. The main results can be summarized as follows:

a) The depletions were normally confined to the time between 20:30 and 01:00 IST. The photometer and all sky imager, both observed depletions in oxygen emission line OI 630.0 nm on the night of 25 March 1998, 18 January 1998, 1 March 2000, and 2 March 2000.

b) The widths of the structures were varying between 100 and 720 km. The degree of depletion observed for the period of observation varied between 4 and 55%
c) The meridional plasma drifts speeds ranging from 39 to 115 m s\(^{-1}\). It was also found that, at night the meridional winds were equatorward and abated at midnight.

d) The plasma bubbles were generally aligned north-south direction with eastward movement. In the night-time equatorial F-region, the eastward neutral wind develops a vertically downward polarization electric field, which drives the plasma eastward.

e) The occurrence of plasma bubbles is very frequent phenomena at low latitude stations over Indian sector. Number of bubbles, width and percentage depth of bubbles under identical ionospheric conditions, are not same. It makes the problem complicated and needs further investigation.

The recent studies of F-region depletions were made from Kolhapur, India using an all-sky camera and tilting filter photometer for OI 630.0 nm oxygen airglow [12, 13, and 35]. They found that the widths of airglow structures were varying between 50 to 350 km. The average eastward plasma drift velocity was found to be varying between 0 to 289 m s\(^{-1}\). The depletions have varying degree of depth and degree of depletion ranged between 10 to 25\%.
References:


11. Mukherjee, G. K., Carlo, L., and Patil, P. T., First all sky imaging observations from India, South Pacific STEP Workshop, University of Newcastle, Newcastle, Australia, 5–9 July 1993.


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OI 630 nm Night Airglow Emissions During Spread-F Events.


36. Mukherjee, G.K., Mapping of the simultaneous movement of the equatorial ionization anomaly (EIA) and ionospheric plasma bubbles through all-sky imaging of OI 630 nm emission. TAO, 13, 1, 53-64, 2002.