ON THE OCCURRENCE AND VERTICAL MOVEMENT OF KINK AT KODAIKANAL *

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ABSTRACT

The occurrence of ionospheric irregularities observed as sharp discontinuities (kinks) on the ionograms and moving upward with time at Kodaikanal have been studied for a period covering high, medium and low solar activity conditions. These kinks are most common during the summer season and during the morning (0900 LT) and evening (1500 LT). The vertical velocities of these irregularities obtained by true height analysis of the ionograms lie in tbe range 10-40 m/sec. The velocity shows a minimum around noon with no significant solar cycle dependence. One of the possible causes for the generation of these irregularities is suggested to be the accumulation of metallic ions over the equator by equatorward neutral winds or gravity waves and their uplift to be due to the E × B drift.

INTRODUCTION

The equatorial ionosphere is known to have properties very different from those of the ionosphere at middle latitudes. The first abnormality, detected by *Seaton* and *Berkner* (1939), was that the daily variation of f_0F_2 at Huancayo, close to the magnetic equator, shows two maxima, one in the morning and the other in the evening with a bite-out during midday. *Appleton* (1946) noted that the latitudinal variation of f_0F_2 at noon shows a trough over the magnetic equator and two maxima at magnetic latitudes around 20°N and 20°S. The height of peak ionisation at an equatorial station shows a very large increase around midday hours in low sunspot years, this rise continues till the sunset hours during high sunspot years (*Rastogi*, 1971a). These abnormal features of the low-latitude ionosphere have been explained by the so-called Fountain Effect, namely that the ionosphere over the magnetic equator is lifted upwards by the E×B force with simultaneous movements away from the equator roughly along the lines of force (*Martyn*, 1947, *Rastogi*, 1959, *Duncan*, 1960, *Bramley*, and *Peart*, 1965, *Moffett* and *Hanson*, 1965). The expected vertical drift of ionisation over the magnetic equator has been confirmed by the backscatter observations at Jicamarca by *Woodman* and *Hagfors* (1969).

Some distortions noted in ionogram recordings known as travelling ionospheric disturbances have been detected at a number of middle and high latitude stations. These disturbances start at the F_2 critical frequencies, move along the trace down to the F_1 layer and disappear between E and F-regions. These disturbances have been suggested to be due to horizontal displacement of wave front with a forward tilt or due to the downward propagation of disturbances originating outside the atmosphere (*Munro*, 1948, *Beynon*, 1948, *Bibl*, 1952, 1953, *Bibl et al.*, 1955, *Munro* and *Heisler*, 1956a, b, *Bibl* and *Rawer*, 1959).

Shortly after the commencement of ionospheric recordings at Thumba (dip. lat. 0.3° S), which is very

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close to the magnetic equator in Indian zone, a new type of upward moving ionospheric irregularities was noted by *Rastogi,* 1970), These disturbances, called by him 'kinks', appear as an intermediate layer between E and F-region and move upward through the whole F–region with the progress of time. Subsequently these kinks have been observed at other equatorial stations, namely Kodaikanal (dip. lat. 1.7°N) by *Rastogi* (1971b), Fort Archambault (dip. lat. 1.5°S), Ouagadougou (dip. lat. 4.5°N) by *Faynot et al* (1971), Huancayo (dip. lat. 1°N) by *Rastogi* (1972), Chimbote (dip. lat. 3°N), Natal (dip. lat. 0°), Djibouti (dip. lat. 3°N), Jicamarca (dip. lat. 1°N) by *Rastogi* (1973).

The present article describes the characteristics of kinks observed in the ionograms of Kodaikanal and the upward drift velocity computed from the temporal variation of the height of the kink for years of low, medium and high solar activity.

CHARACTERISTICS OF IRREGULARITIES SEEN ON THE IONOGRAMS

Lunar stratifications have been noted at some equatorial stations, Huancayo, Kodaikanal and Talara (*Gautier et al.,* 1951; *Bhargava* and *Saha,* 1967; *Shapley,* 1970). The equatorial F_2 layer is lifted up very rapidly for a few hours after sunrise. This rapid rise sometimes causes an additional layer which is often referred to as the G layer (*Rivault,* 1950).

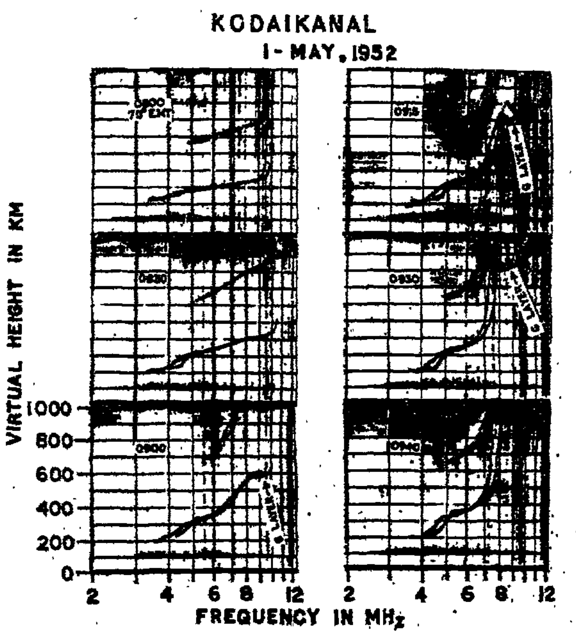

Fig. 1

A sequence of ionograms on 1 May, 1952 showing the occurrence of G layer at Kodaikanal. The cusp corresponding to G layer is marked with an arrow.

A sequence of ionograms showing the G layer at Kodaikanal on 1 May 1952 is reproduced in Fig. 1. The ionogram at 0800 LT is quite normal, $h'F_2 = 280$ kms, while $h_pF_2 = 330$ kms. At 0830 LT, although f_0F_2 has not changed much, $h'F_2$ increases to 300 km. and h_pF_2 has increased much more, to about 400 km. A small discontinuous change in h'(f) trace is also seen. At 0900 LT a clear cusp is seen close to f_0F_2, h_pF_2 now being more than 550 km. This layer is generally referred to as the G layer. The G layer is seen on ionograms till about 0930 LT, when it goes above the peak of F_2, and a thick F_2 region with decreased f_0F_2 is left behind at 0940 LT.

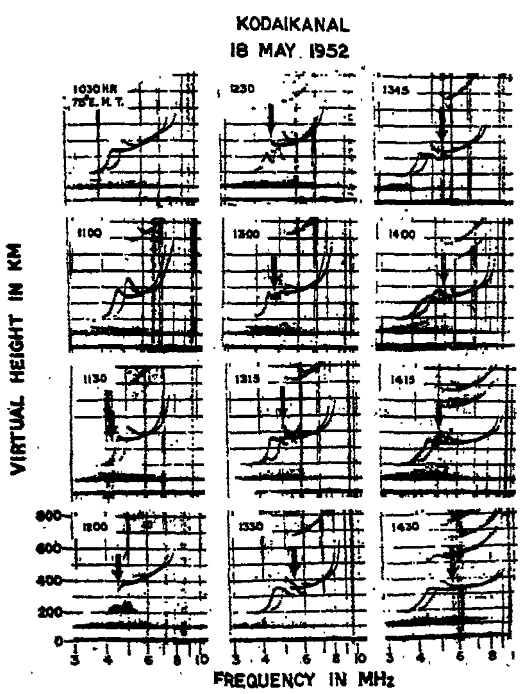

Fig. 2

A sequence of ionograms on 18 May, 1952 showing the occurrence of kink at Kodaikanal indicated by an arrow in the diagram. Note the frequency and the height of the kink increases progressively with time.

The irregularity referred to as a kink is a completely different phenomenon. This is evident from Fig. 2 in which an example of the occurrence of kink at Kadaikanal as seen from ionograms is reproduced, for 18 May 1952. At 1030 LT one can see the normal q type of sporadic E and the F_2 layer is distorted due to the uplifting of ionisation. At 1100 LT and 1130 LT one can see very intense ionisation at about 120 km which is transparent to the upper reflections. At 1200 LT this intense E_2 ionisation disappears and a discontinuity or a ledge is formed on the F_1 trace. At subsequent ionograms this discontinuity continues to steadily rise in both the virtual height and the frequency.

It is to be noted that these kinks indicate a definite extra ionisation and are distinguishable from the E_s irregularities, which blanket the reflections from upper layers. On each of the ionograms the irregularity can be clearly seen on both the ordinary and extra-ordinary traces. Further, whenever second order traces are visible within the height range of the ionogram, the height of the irregularity in the second order trace is exactly double that on the first order trace, indicating that it is not due to any off–vertical reflection, in which case the height of the kink in the second order trace will be less than twice the height of the first order trace.

On many occasions kinks are seen simultaneously with the G layer. This is evident from Fig. 3 in which a sequence of ionograms at Kodaikanal for 1 May 1964 and 13 Feb. 1964 are reproduced. At 0930 and 0945 LT the upper portion of the trace is distorted due to the uplifting of the layer. At 1000 LT and 1015 LT one can see the additional G layer cusp. At 1030 LT a small distortion of the trace is seen at a virtual height of about 420 km, which is marked in the figure as a kink. On 13 Feb. 1964 the kink starts at about 1530 LT. At 1600 LT and 1630 LT the kink and the G layer are simultaneously present. The G layer has disappeared at 1700 LT but the kink still persists till 1700 LT.

METHOD OF ANALYSIS

Ionograms at Kodaikanal are recorded on a regular basis every 15 minutes. On all the events when kinks

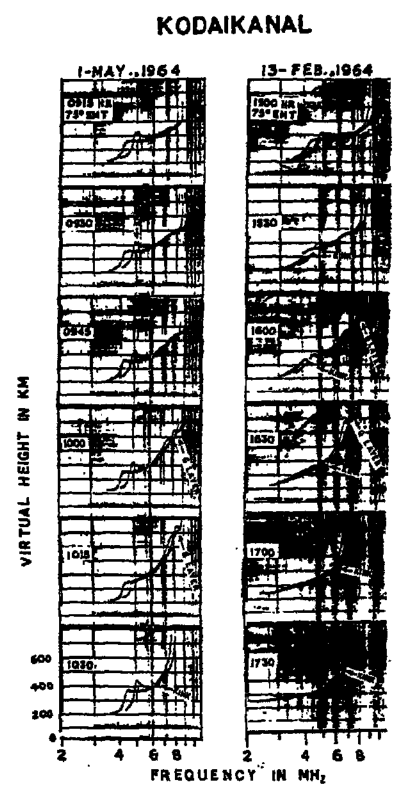

Fig. 3

A sequence of ionograms at Kodaikanal for 1 May, 1964 on the left-side and 13 Feb. 1964 on the right-side of the diagram. Note that the kink and G layer can occur simultaneously.

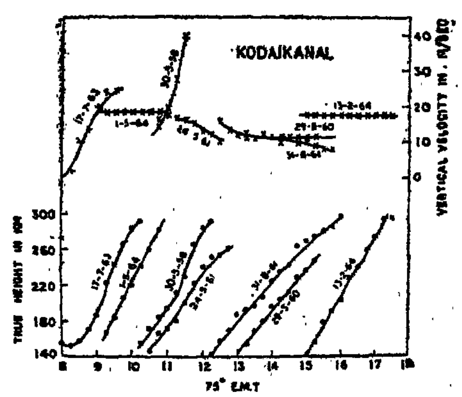

Fig. 4

Typical plots of the variation with time of true eight and velocity of kink at Kodaikanal occurring at different times of the day. Figure shows kinks with constant velocity (13 Feb. 1964), kinks with increasing velocity (30 May 1958) and with decreasing velocity (24 May 1961) with height.

are observed on the ionograms, the true height of these kinks was computed using the method of *Doupnik* and *Schmerling* (1965). From the variation of the true height with time one gets the velocity of upward drift. In Fig. 4 are reproduced the true height variation of some of the events, and the vertical velocity component derived from it is shown in the upper part of the diagram. In the original paper of *Rastogi* (1970) he has shown that the true height of the kink increases linearly with time and thereby concluded that the upward drift velocity in the F region is independent of height. Later analysis had indicated that at height below 180 km the magnitude of velocity is significantly reduced. Further the velocities during sunset time are much smaller than during the pre-noon hours. This diagram shows that although in many cases the velocities are constant there are instances when the velocity does increase with height. From a general examination of the data it is found that the kink occurs mostly between 180 and 240 km. On some cases the kink is seen to move right from the E layer to the top of the F_2 peak.

DIURNAL VARIATION OF THE OCCURRENCE OF KINKS

In Fig. 5 are shown the number of days on which kinks are observed in the Kodaikanal ionograms as

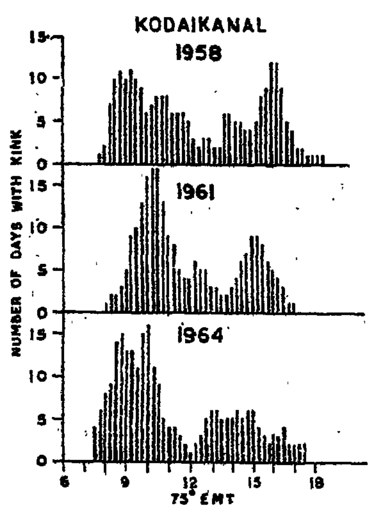

Fig. 5

Histograms showing the occurrence pattern of kink at Kodaikanal with time for the years 1958, 1961 and 1964. Figure shows two peaks one in the morning and the other in the evening with a dip around midday.

function of the time of the day at intervals of 15 minutes. A particular event may be seen in a number of successive ionograms. The diagram shows that kinks are most frequent during the forenoon hours arround 0900 LT and in the evening hours around 1500 LT with a dip around noon. The evening peak seems to be much stronger in the high sunspot years and occurs at slightly later time.

SEASONAL VARIATION OF OCCURRENCE OF KINKS

Fig. 6 shows the percentage occurrence of kinks for different months of the year 1964, 1961 and 1958. One

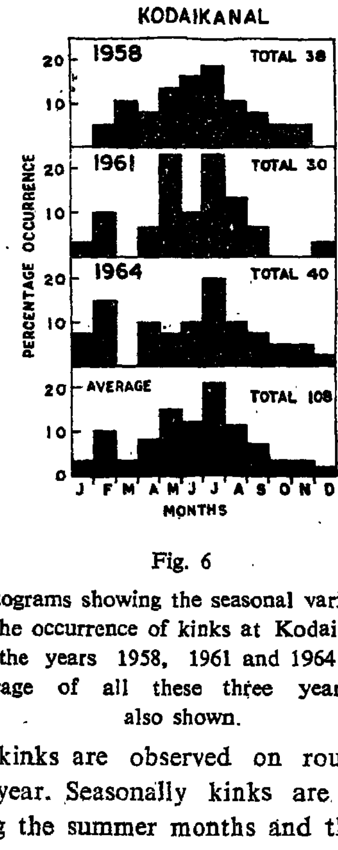

Fig. 6

Histograms showing the seasonal variation of the occurrence of kinks at Kodaikanal for the years 1958, 1961 and 1964 and average of all these three years is also shown.

can see that kinks are observed on roughly 30 to 40 days in any year. Seasonally kinks are seen to occur mostly during the summer months and their occurrence is least during winter months for any of the years.

DISTRIBUTION OF VERTICAL VELOCITY IN THE F-REGION

In Fig. 7 are shown the histograms of the magnitude of the vertical drift velocity for different years. The velocity for any solar activity condition ranges from 10–40 m/sec. The average velocity for any of the years lies between 17 and 19 m/sec, the mean velocity being

6.5 m/sec. in low sunspot years and 18.8 m/sec in high

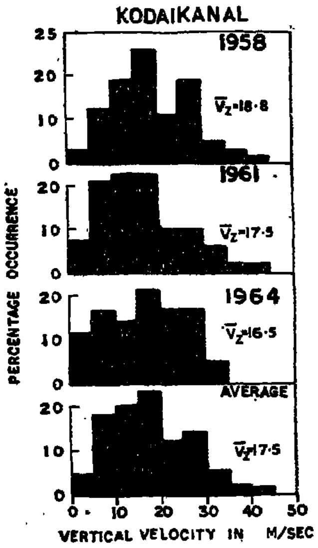

Fig. 7
Velocity distribution of kinks at Kodaikanal for the years 1958. 1961 and 1964 and averaged forthese three years. The mean velocities ($\bar{V}_Z$) are also indicated in the figure.

nspot years. The diurnal variation of the drift velocity shown in Fig. 8. There appears to be a minimum in

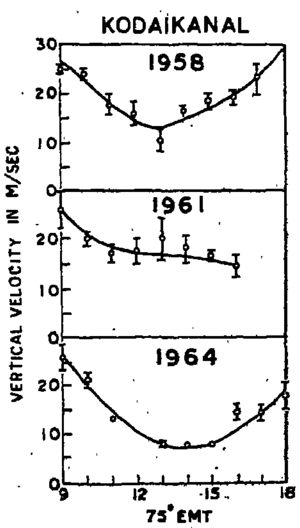

Fig. 8
Variation of vertical velocity of kinks at Kodaikanal with time of the day for the years 1958, 1961 and 1964. Increases of velocity towards the morning and evening hours with a dip around midday is seen.

the velocity around 1300 LT, the magnitude being around 8 m/sec during low sunspot years and 12 m/sec during high sunspot years. There is a tendency for the velocity to increase towards the early hours as well as later hours from midday. Whether there is a maximum of velocity cannot be determined from the present observations because kinks are rarely seen before 0800 LT and after 1800 LT. Velocities are computed for different groups of heights and the average drift velocities for different height groups of the kinks are shown in Fig. 9. Taken as a whole, the average velocity slightly increases with height between the height range of 120 to 260 km.

DISCUSSION

The analysis reveals some of the features of these upward travelling disturbances. *Rastogi* (1971b) had found that the morning peak of occurrence of kinks coincided fairly well in time with the peak in F-region horizontal drift at Thumba, the maximum in height of

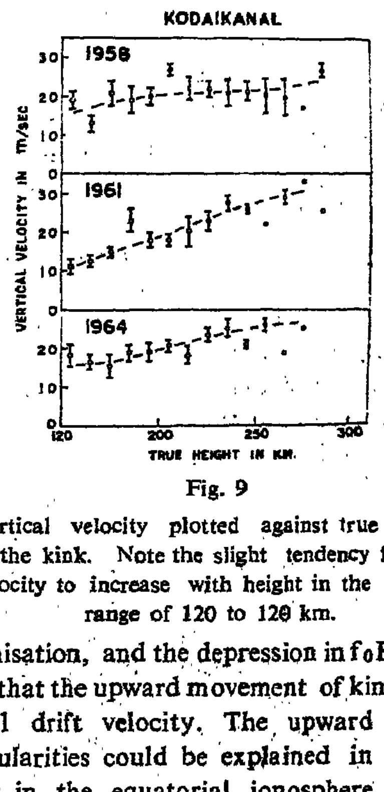

Fig. 9
Vertical velocity plotted against true height of the kink. Note the slight tendency for the velocity to increase with height in the height range of 120 to 120 km.

peak F_2 ionisation, and the depression in f_0F_2. He had also suggested that the upward movement of kinks represented the vertical drift velocity. The upward movement of these irregularities could be explained in terms of the $E \times B$ drift in the equatorial ionosphere. The electric fields in the E-region at low latitudes are mapped into the F-region via the highly conducting field lines. During the daytime, the eastward electric field interacting with the northward magnetic field would move the F_2 layer ionisation in the vertical direction. *Balsley* and *Woodman* (1969) and *Woodman* (1970) have reported the results of vertical drift measurements at Jicamarca using the backscatter technique. They have found that the velocities are upward by day and downward by night. The velocities they obtain are widely variable over a range (10–40 m/sec) as large as the velocity itself. The order of magnitude of the velocity they measured and obtained from our present study are in good agreement. The upward moving kinks are also seen only in daylight hours. *Balsley* and *Woodman* (1969) have found that the velocity does not vary much with height in the altitude range of 200–700 km. But our results seem to favour a slight increase of velocity with height in the altitude range of 120–260 km. The observed velocities are such that it rules out the possibility of magnetohydrodynamic wave motion being responsible for the movement of these irregularities, as suggested by *Akasofu* (1956).

These irregularities are seen for a long period of about 3–4 hours. This suggests that they must be extra-ionisation possibly due to metallic ions having low loss rates. *Hanson et al.*, (1972) have shown the existence of metallic ions in the equatorial F-region from the Ogo observations. Fe^+ ions of mass number 56 fit best their experimental data. They have calcutated the distribution, layer shape and vertical velocity of these ions. The velocity they derived is of the same order as ours. They have argued that if there exists a geographically uniform source of Fe^+ ions below 100 km, these ions will be raised to 160 km height, which is the boundary for the collisional domain, by the strong polarisation fields in the equatorial electrojet. Since the equatorial electrojet itself is a narrow belt, the mechanism could be operative only in a narrow belt around the equator. In fact, *Rastogi* (1973) has shown the kinks are observed only in a latitude belt of $\pm 6°$ centred around dip equator. Once the ions are raised above the collisional domain they will be lifted up by the electromagnetic drift. *Untiedt* (1967) has shown that the usual method of calculating the dynamo current system with no vertical currents fails at the equator. The vertical polarisaton field at the equator also gives rise to vertical currents. It is the ion velocity associated with these currents that help the metallic ions to escape from the source region below 100 km. On several occasions mass spectrometers have detected the presence of Fe^+ ions in the E_s layer at about 95 km (*Narcisi*, 1968). Equatorward neutral winds or a varying chemical source induced by gravity waves could be possible candidates responsible for the accumulation of metallic ions over the equator.

SUMMARY AND CONCLUSIONS

The occurrence pattern and vertical velocity of ionospheric irregularities seen as kinks on the ionograms are studied for the station Kodaikanal for the years 1958, 1961 and 1964 covering a period of high, medium and low solar activity. The main conclusions may be enumerated as follows:

1. Kinks are different from the additional cusp of ionization in F_2 region which is generally known as G layer. Kinks are seen only at equatorial regions and only during the daytime hours.
2. Kinks are the manifestation of a sharp thin layer of ionisation created in the ambient electron density distribution of the E and F-regions.
3. The daily variation of occurrence of F–region kinks shows two maxima, in the morning and evening hours.
4. The variation of average velocity with time of day also shows a dip around noon with increasing values towards morning and evening hours.
5. Kinks are more frequent in summer than in winter months.
6. The upward velocity of the kinks is considered to represent the vertical drift velocity of the F–region and its magnitude ranges from 10 to 40 m/sec.
7. There is no significant solar cycle effect in the vertical drift velocity in the F–region.
8. These kinks are suggested to be due to the accumulation of long-lasting metallic ions, probably Fe^+ over the magnetic equator by the equatorward neutral winds or gravity waves, with subsequent upward motion because of the $E \times B$ drift.

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