Low-latitude HF Doppler short-period oscillations associated with storm sudden commencements

P. Anjaneyulu[1,*], N. Lakshmana Das[1], B. M. Rao[3] and Ch. Ramakrishna[2]

[1]Department of Electronics, and [2]Ionosphere Research Laboratory, Department of Physics, Andhra University, Visakhapatnam 530 003, India
[3]Department of Environmental Studies, College of Science, Gandhi Institute of Technology and Management, Visakhapatnam 530 045, India

HF Doppler measurements of F-region vertical plasma drifts (*Vz*) at a low-latitude station, Visakhapatnam (dip–17°N) in association with two storm sudden commencements (SC*/SC) on 21 February 1994 (during daytime 0902 h UT) and 28 May 1994 (during night time 1357 h UT) are analysed. Measurements of *Vz* at SCs are compared with the *H*-field variations of high latitudes down to dip equatorial latitudes. It is found that there is an abrupt enhancement in *Vz* (or in Doppler velocity V_D) in coincidence with the main impulse of SC*/SC in both the events. In the case of the first event, upward enhancement in *Vz* is unusual and is nearly 2 to 3 times that of the usual velocities. Also, in the same event there is a downward trend in *Vz* prior to this enhancement, after which short-period oscillations (60–90 s) in *Vz* which are coherent with the magnetic fluctuations at several high latitudes down to equatorial latitudes are observed. The observed changes in *Vz* (V_D) at SCs are discussed in the light of the effects of magentosphere-generated electric fields promptly penetrated to these low latitudes by means of transmission of electromagnetic waves through earth–ionosphere waveguide and direct transmission of compressional hydromagnetic waves.

Keywords: Doppler velocity, HF Doppler measurements, oscillations, plasma drift, storm sudden commencement.

MAGNETOSPHERIC disturbances such as storm sudden commencements (SSCs) or simply sudden commencements (SCs) are attributed to the interaction of sudden changes in the solar wind dynamic pressure with the earth's magnetosphere. Hence these disturbances provide an opportunity to study the response of the magnetosphere to solar wind variations.

Among a variety of SCs, a class called as SC* is characterized by a negative impulse in the *H*-field component called preliminary impulse (PI) preceding the main impulse (MI)[1]. The PI is observable at high and dip equatorial latitudes but may not appear significantly at low latitudes. The ionospheric current system for the PI was first identified by Araki *et al.*[2]. It was recognized that the PI and MI correspond to two different driving mechanisms. After a thorough study of SSCs, Araki[3] proposed a model to interpret the observed features. According to this model, the components of SC disturbance field are given by $D_{SC} = DP_{PRI} + DP_{MI} + DL_{MI}$, where PRI part of SC and a part of MI are due to polar electric fields and the remaining part of MI is due to compressional hydromagnetic waves. Thus the disturbance of SC may manifest in the *H*-field in the atmosphere as superposition of DP part over DL part.

In addition to the above features of PI and MI, sometimes magnetic disturbances may manifest as short-period fluctuations at the onset of SCs. These fluctuations are called micropulsations and are of two types: pulsations continuous (Pc) and pulsations irregular (Pi). Recently, electric-field fluctuations in coherence with magnetic fluctuations (Pc5, Pi-2) have been observed during magnetospheric disturbances such as DP-2 events and substorms[4,5]. Doppler oscillations associated with short period (Pc3-4) pulsations at the times of SCs are rarely reported. Low-latitude response during these disturbances may provide additional information in studies of interaction of the magnetosphere with the solar wind dynamical changes. In the present study it has been observed that in one of the SC events, quasi-periodic oscillations are found at the onset of SC. This event provided an opportunity to study the response of low-latitude ionosphere to these magnetic fluctuations, in addition to the general SC features.

HF Doppler technique is a sensitive tool in detecting ionosheric electric field oscillations of several scale sizes during mangnetospheric disturbances such as SC, SI, DP-2 events, etc.[6–11]. In the present investigation HF Doppler measurements of vertical plasma drifts (*Vz*) are used to study the response of the low-latitude ionosphere during two SC events.

We have recorded phase path of *F*-region reflections at 5.5 MHz during 1993–95 using a coherent HF Doppler radar at the low-latitude station, Visakhapatnam (dip 20°N). Scrutiny of data showed the availability of phase-path measurements during two SC events on 21 February and on 28 May 1994.

The HF Doppler system consists of pulsed HF transmitter, phase-coherent receiver, frequency synthesizer, multi-channel strip-chart recorder, and transmitting and receiving antennas. The transmitter pulsed RF, and the receiver local oscillator frequencies as well as the timing and gate pulses were all derived from a 10 MHz crystal oscillator whose stability is better than one part in 10^7. The system was operated at a frequency of 5.5 MHz with a pulse width of 100 μs and a pulse repetition frequency (PRF) of 50 Hz, to probe the bottom side *F*-region. The receiver detects the received signal and provides sampled outputs of in phase ($I = A\cos\varphi$) and quadrature ($Q = A\sin\varphi$) signals, where *A* and φ are the instantaneous amplitude and phase of the received signal. The *I* and *Q* signals were recorded on a strip-chart. From these, the time variations of *A* and

*For correspondence. (e-mail: apattem2k2@yahoo.com)

φ were scaled. The rate of change of φ gives the Doppler frequency (Δf) of the receiver signal and the line-of-sight plasma drift velocity Vz. The chart recorder was run at a speed of 10 cm/min, which provides measurements of Doppler shifts in the range of 0–2.5 Hz, corresponding to vertical plasma drift velocities in the range of 0–70 m/s. In the present study, the rate of φ was scaled at 12 s intervals and from these values, Doppler velocities (V_D) and vertical plasma drifts ($Vz = V_D/2$) were calculated. (From the group height measurements noted in the log book, it is found that in both the SC events the height of the reflecting layer is well above 300 km and hence chemical losses may be neglected). These Vz (or V_D) values are compared with the H-field variations in the magnetograms of a nearby station, Hyderabad (geomag. lat. 7.6°N) and from World Geomangnetic Data Centers (courtesy of WDC-C2, and 210 Magnetic Meridian Chain).

Scrutiny of solar geophysical data revealed that the SC on 21 February 1994 is reported as SC* and remarkable by 16 observatories, whereas the SC on 28 May 1994 was reported as simple SC by ten observatories. Vz and H-field variations during these two events are presented.

For the SC event on 21 February 1994, a chain of magnetic observatories lying nearly around the same longitude (210 MM network stations) is shown in Figure 1. Stations covering high latitudes down to equatorial on both the hemispheres (±60° geographic latitudes are also shown). H-field variations recorded at a nearby low-latitude station, Hyderabad (M. lat. 7.6°N, M. long 148.9°E) are shown in Figure 2 *a*. An abrupt increase in the H-component, nearly 45 nT at SC (indicated by arrow) around 0900 h UT is also shown and then the field is found to suddenly decrease. The exact duration of rise and fall is not identifiable, as the magnetograms are normal-run magnetograms. The magnetogram also indicates quasi long period (30–40 min) oscillations in the H-component after SC, which continued up to 12 h UT (1730 h IST).

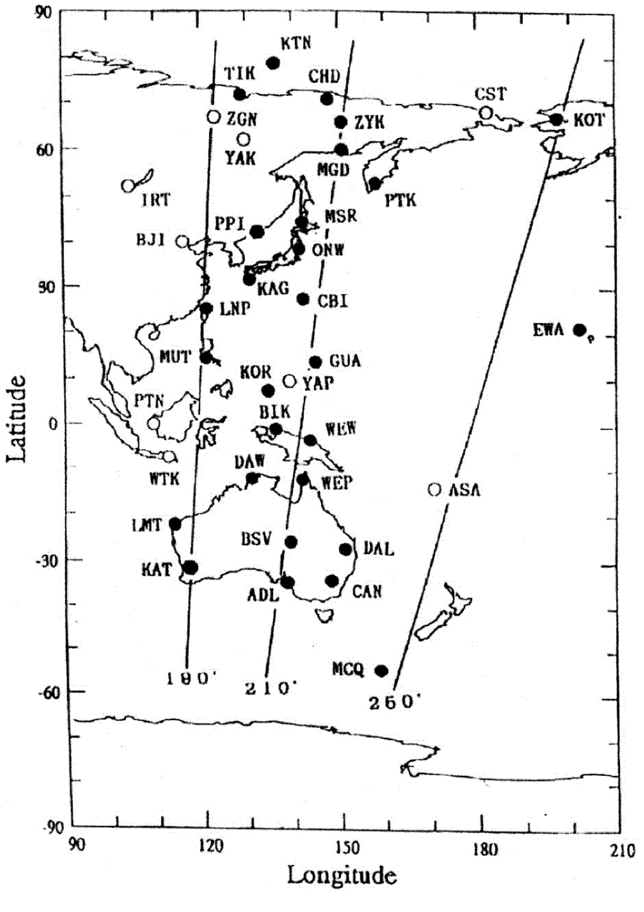

Figure 1. Map showing locations of a chain of stations covering ± 60° geographic latitudes around the dip equator and around 190, 210 and 250° geographic longitudes.

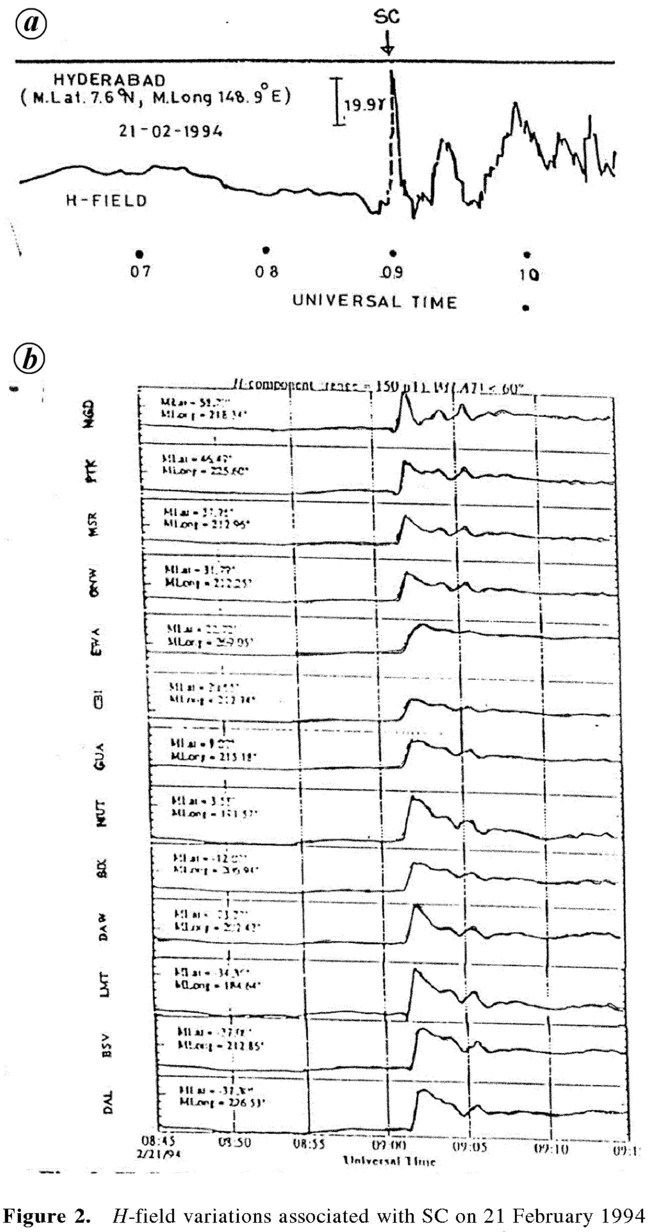

Figure 2. H-field variations associated with SC on 21 February 1994 showing SC onset at 0901 h UT (***a***) at Hyderabad and (***b***) at several stations covering ± 60° geographic latitudes around the dip equator.

Table 1. Geographic and geomagnetic coordinates of observation sites of magnetograms shown in Figure 2 *b*

Station	Abbreviation	Geographic coordinates		Geomagnetic coordinates	
		Latitude	Longitude	Latitude	Longitude
Magadan	MGD	59.97	150.86	53.56	218.66
St. Paratunka	PTK	52.94	158.25	46.34	225.91
Moshiri	MSR	44.37	142.27	37.61	213.23
Onagawa	ONW	38.43	141.47	31.65	212.51
Ewa Beach	EWA	21.32	202.00	22.67	269.36
Chichijima	CBI	27.15	142.30	20.59	213.00
Guam	GUA	13.58	144.87	4.57	214.76
Muntinlupa	MUT	14.37	121.02	3.58	191.57
Biak	BIK	–1.08	136.05	–12.18	207.30
Darwin	DAW	–12.40	130.90	–23.13	202.68
Learmonth	LMT	–22.22	114.10	–34.15	185.02
Birdsville	BSV	–25.54	139.21	–36.58	212.96
Dalby	DAL	–27.18	151.20	–37.09	226.80

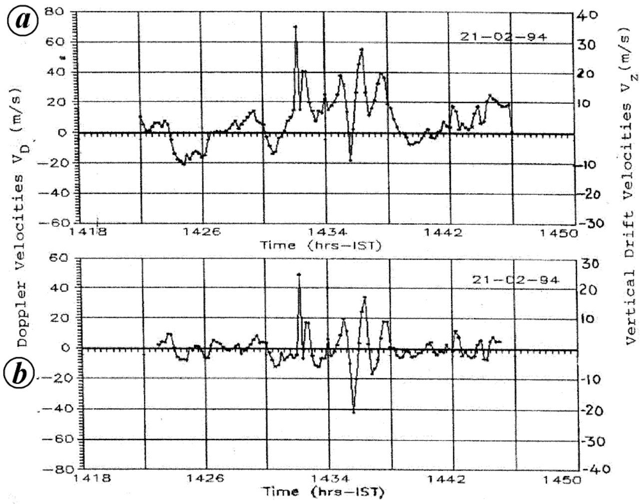

Figure 3. Variations of Doppler velocities of *F*-region reflections on 5.5 MHz associated with SC onset on 21 February 1994 at Visakhapatnam observed in (*a*) vertical drifts (*Vz*) and (*b*) short-period fluctuations in *Vz*.

Magnetograms of a few stations of the 210 MM network chain (1 s plots of *H*-field) are shown in Figure 2 *b*. Geographic and geomagnetic coordinates of these stations are given in Table 1. In all these magnetograms there is a sudden increase in the *H*-field indicating SC and thereafter, quasi short-period fluctuations continue for a few minutes (5 min). Thereafter, the *H*-component decreases to pre-SC level. Fluctuations in all the magnetograms indicate that these are of global nature. Also, in the magnetograms of high-latitudes stations [MGD, PIK, LMT, BSV, DAL], there is a small negative impulse (PI) before the main impulse (MI). This small-amplitude PI is not visible in low-latitude magnetograms. Solar geophysical data revealed that 16 observatories reported this SC as SC* and are remarkable. This confirms the features of the event on 21 February 1994 as SC*.

Vz and Doppler velocities on this storm day are shown in Figure 3 *a*. The Doppler velocity is abruptly enhanced at 0902 h UT (1432 h IST), coincident with the main impulse of the SC. The upward enhancement is from –18 to 65 m/s. This velocity is unusual and is nearly 2 to 3 times that of usual velocities during daytime. After this enhancement, Doppler velocity is suddenly decreased and again increased in the upward direction. Thus, oscillations in *Vz* (V_D) are continued up to 1438 h IST (0908 h UT). These oscillations are extracted by passing Doppler velocities through a running mean filter (180 s) and the residues are shown in Figure 3 *b*. Periodicities of the oscillations which are in the range of 60 to 90 are also shown. Magnetic fluctuations observed in all the magnetograms of the network station shown in Figure 2 *b* and the short-period Doppler oscillations shown in Figure 3 *b* occurred in coincidence and continued for about 5 min. This indicates that these Doppler oscillations are the effects of global fields generated and/or propagated to these latitudes at the time of SC. But it is found that the Doppler oscillations are not in phase with magnetic fluctuations of any of the stations shown in Figure 2 *b*.

For the SC event on 28 May 1994 also the 210 MM network record is used. The record on the storm day is shown in Figure 4. It can be seen from Figure 4 that in most of the stations there is an abrupt increase the in *H*-field at around 1400 h UT (1930 h IST), but of small amplitude. Later, the field decreased gradually in a few tens of minutes and then further to below normal levels. In the solar geophysical data, it is found that more than ten observatories reported this SC and the onset at 1357 h UT (1927 h IST). Thus the SC in this event is simple SC having the characteristic of MI only.

The *H*-component magnetogram collected from Hyderabad on this storm day is shown in Figure 5 *a*. In this mangnetogram the SC onset is at around 1400 h UT (1930 h IST) and is of small amplitude (nearly 13 nT).

The SC is indicated with an arrow. After this rise, the H-component gradually decreased in a few minutes and crossed its normal value at around 1430 h UT. The Doppler velocities (V_D) on this day during 1352–1400 h UT are shown in Figure 5 *b*. It can be seen from Figure 5 *b* but there is a sudden increase in V_D in coincidence with the onset of SC. Though the magnitude is small, there is a sudden increase in V_D from –2 m/s to +2 m/s at 1927 h IST. This sudden increase is coincident with the MI of the SC.

In the present study it is confirmed that there is sudden enhancement in Vz (or V_D) in coincidence with the main impulse (MI) of the SC (0902 h UT). Also, prior to this sudden increase, there is a downward trend in Vz, which may be at the time of PI. Thus the downward trend in Vz before MI, may be attributed to the effect of PI, though this downward drift is not significant. At these low-latitude stations, vertical plasma drifts are mainly due to effects of electric fields and/or neutral wind fields. It has been confirmed by several authors that changes in the H-field at MI and PRI are due to the effects of magnetospheric-generated electric fields[3,6,7]. As there is no time delay between changes in Vz and changes in magnetic field at global stations, the observed changes in Vz at MI and PRI can be attributed to the effects of magnetospheric-generated electric fields.

Kikuchi[6] provided the evidence for the prompt penetration of dawn-to-dusk eastward electric field to low-latitudes at the time of MI and dusk-to-dawn westward electric field at the time of PRI of SC* event. Sastri *et al.*[7] using HF Doppler measurements at equatorial station, provided evidence for penetration of eastward electric field in response to PI of SC* and westward electric field in response to MI.

In the present study, the observed features of enhancement in the upward drift in Vz coincident with MI and a small downward drift just before this enhancement are in agreement with the results of Kikuchi. As the amplitude of the magnetospheric-generated electric field decreases when it penetrates down to low latitudes, the effect of the electric field responsible for PRI may not be significant at this low-latitude station. Hence the small downward drift before MI may be attributed to the effect of electric fields due to PRI. Thus the upward drift at MI and downward drift at PRI may be due to presence of eastward and westward electric fields. As suggested by Kikuchi[6], the eastward electric fields at MI might be generated in the polar region and are instantaneously propagated to these low latitudes by electromagnetic waves through earth–ionosphere waveguides and the presence of westward electric field at PRI of SC* might be the induced field due to direct transmission of compressional hydromagnetic waves.

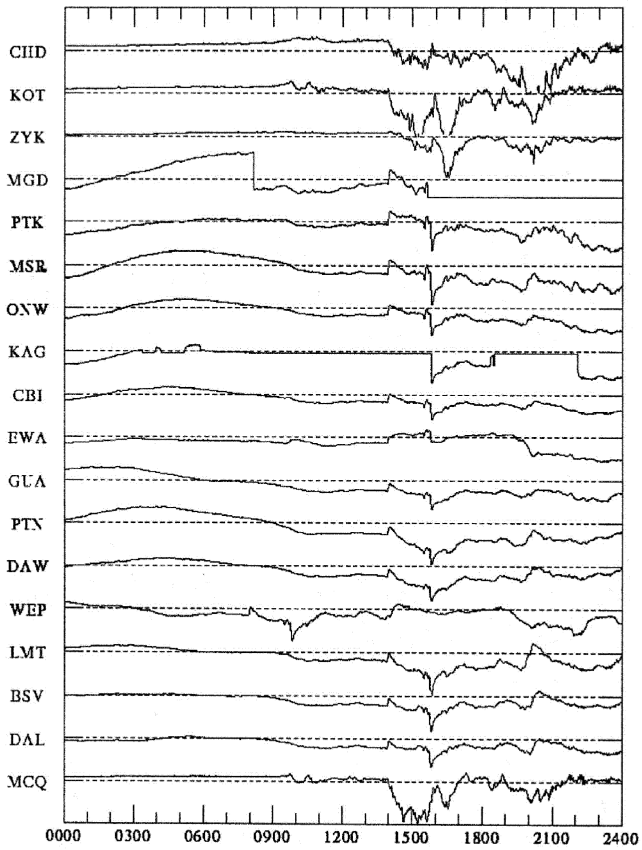

Figure 4. *H*-field variations showing SC on 28 May 1994 at a chain of stations covering ± 60° geographic latitudes around the dip equator.

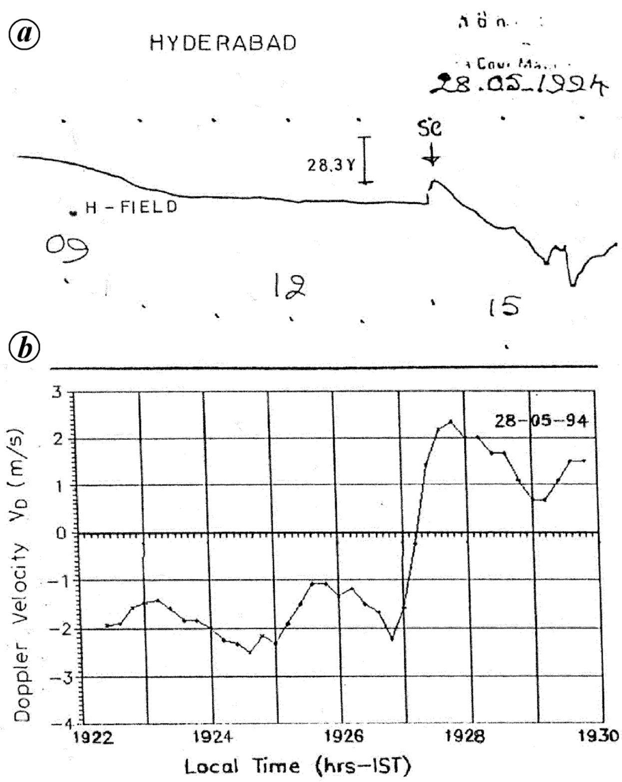

Figure 5. Variations associated with SC onset on 28 May 1994 in (***a***) horizontal component of magnetic field (H) at Hyderabad and (***b***) vertical drift velocities (Vz) at Visakhapatnam.

In the case of the first event, the observed short-period (60–90 s) Doppler oscillations coincident with the magnetic fluctuations at observatories located at several longitudes and latitudes around dip equator, may be due to the effect of fields of disturbance of global origin. These magnetic fluctuations called micropulsations, might have occurred at the SC. Matsushita[1] suggested that the initial shock of SC may produce not only hydromagnetic waves responsible for SCs and SIs, but also smaller amplitude and short-period hydromagnetic waves. These waves may propagate simultaneously and oscillate the ionosphere, causing ionospheric currents. From the theory of micropulsations, when the hydromagentic wave moves through the plasmasphere along a flux tube, the varying magnetic field would compress and rarify the intervening plasma. This mechanism may create magnetic fluctuations as well as plasma motions. In a modelling work of Doppler osciallations due to micropulsations, Poole *et al.*[12] suggested that compressions and rarefractions of the plasma may be the dominant factor for the observed oscillations in the Doppler shifts, when compared to the effects due to refractive index variations. If this were to be considered, as the plasma motions may manifest in EXB drifts, the observed short-period oscillations in Vz (or in V_D) may be because of the effects of plasma motions due to hydromagnetic waves.

1. Matsushita, S., On geomagnetic sudden commencements, sudden impulses, and storm durations. *J. Geophys. Res.*, 1962, **67**, 3753–3777.
2. Araki, T., Iyemori, T., Tsunomura, S., Kamei, T. and Maeda, H., Detection of an ionospheric current for the preliminary impulse of the geomagnetic sudden commencements. *Geophys. Res. Lett.*, 1982, **9**, 341–344.
3. Araki, T., Global structure of geomagnetic sudden commencements. *Planet. Space Sci.*, 1977, **25**, 373–384.
4. Motoba, T., Kikuchi, T., Luhr, H., Tamihara, H., Kitamura, T. I. and Hayashi, K., Global Pc5 caused by a DP2-type ionospheric current system. *J. Geophys. Res.*, 2002, **107**,
5. Kikuchi T., Luhr, H., Kitamura, T., Saka, O. and Schlegel, K., Direct penetration of the polar electric field to the equator during a DP2 event as detected by the auroral and equatorial magnetometer chains and the EISCAT radar. *J. Geophys. Res.*, 2000, **105**, 23,251–23,261.
6. Kikuchi, T., Evidence of transmission of polar electric fields to the low latitude at times of geomagnetic sudden commencements. *J. Geophys. Res.*, 1986, **91**, 3101–3105.
7. Sastri, J. H., Visweswara Rao, J. V. S. and Ramesh, K. B., Penetration of polar electric fields to the nightside dip equator at times of geomagnetic sudden commencements. *J. Geophys. Res.*, 1993, **98**, 17,517.
8. Sastri, J. H., Huang, Y. N., Shibata, T. and Okuzawa, T., Response of equtorial-low latitude ionosphere to sudden expansion of magnetosphere. *Geophys. Res. Lett.*, 1995, **22**, 2649–2652.
9. Sastri, J. H., Luhr, H., Tachihara, H., Kitamura, T. I. and Rao, J. S. V. S., Electric field fluctuations (25–35 min) in the midnight dip equatorial ionosphere. *Ann. Geophys.*, 2000, **18**, 252–256.
10. Sastri, J. H. *et al.*, Preliminary impulse of the geomagnetic storm sudden commencement of 18 November 1993. *J. Geophys. Res.*, 2001, **106**, 3905–3918.
11. Motoba, T., Kikuchi, T., Shibata, T. F. and Yumoto, K., HF Doppler oscillations in the low-latitude ionosphere coherent with equatorial long-period geomagnetic oscillations. *J. Geophys. Res.*, 2004, **109**, A06214.
12. Poole, A., Sutcliffe, P. R. and Walker, A., The relationship between ULF geomagnetic pulsations and ionospheric Doppler oscillations: Derivation of a model. *J. Geophys. Res.*, 1988, **93**.

ACKNOWLEDGEMENTS. We thank Dr V. V. Somayajulu, Ex-Scientist, Vikram Sarabhai Space Centre, Thiruvananthapuram for providing useful research material and valuable suggestions. P.A. and N.L.D. are grateful to the management of Gandhi Institute of Technology and Management, Visakhapatnam, for encouragement. We also thank the 210 MM network and National Geophysical Research Institute, Hyderabad for providing geomagnetic data.

Received 17 February 2006; revised accepted 23 June 2006

Climatic variability and its impact on cereal productivity in Indian Punjab

S. S. Hundal and Prabhjyot-Kaur*

Department of Agronomy and Agrometeorology,
Punjab Agricultural University, Ludhiana 141 004, India

Dynamic crop growth simulation models CERES-Rice and CERES-Wheat for rice and wheat, respectively were used to study the effect of climate change on growth and yield of these crops under non-limiting water and nitrogen availability. Analysis of recent 30 year historical weather data from different locations in the state revealed that the minimum temperatures have decreased or increased (–0.02 to + 0.07°C/year), maximum temperatures decreased (–0.005 to –0.06°C/year) and rainfall increased (2.5–16.8 mm/year). Keeping in view the observed trends in climate variability, growth and yield of crops were simulated under plausible synthetic climatic scenarios of changes in temperature and solar radiation. In general, with an increase in temperature above normal, the phenological development in wheat was advanced, but that of rice was not much affected. With an increase in temperature up to 1.0°C the yield of rice and wheat decreased by 3 and 10%, respectively. On the other hand, crop yields decreased with decrease in radiation and vice-versa. The interaction effects of simultaneous increase/decrease in parameters were also simulated. When the maximum temperature decreased by 0.25 to 1.0°C while minimum temperature increased by 1.0 to 3.0°C from normal, the yield in rice and wheat decreased by 0.8 and 3.0%, respectively from normal.

*For correspondence. (e-mail: prabhksidhu@yahoo.com)