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III

The concept of isolated substorms having two temporal phases was developed through analyses of worldwide surface magnetic field observations. These phases have been called DP-2 and DP-1 (Nagata and Kokobun, 1962; Nishida, Iwasaki and Nagata, 1966; Obayashi, 1967; Nishida, 1971) or the growth and expansion phases,(McPherron, 1970). Recently the concept has been questioned experimentally through independent analyses of ground magnetometer data similar or identical to that which led to the formulation of the hypothesis (Akasofu and Snyder, 1972; Kawasaki and Akasofu, 1972; Matsushita and Balsley, 1972; Meng, et al, 1972). Thus, from the point of view of ground magnetometer data, the growth and expansion phases of isolated substorms are not accepted concepts.

However such concepts possess considerable theoretical interest becau of the physical appeal of the model in which substorms occur in the followin two steps;

1. Magnetospheric convection becomes enhanced. This enchanced flow leads to conditions of instability after a time delay during which the predominant feature is the increased flow of field lines and plasma. This time epoch might be called the growth phase of the substorm.
2. The instability that follows a period of enhanced convection triggers the expansion phase of the substorm, during which the most spectacular features of the substorm are observed.

Because this model has been fruitful in the development of substorm theories (Coroniti and Kennel, 1972 a, b, c), it is important to consider the definition of the growth and expansion phases of substorms in terms of the above processes rather than from ground magnetometer signatures. It is thus relevant to review experimental evidence for such temporal sequences in magnetospheric convection during isolated substorms.

Balloon electric field measurements during nineteen isolated substorms have been averaged to produce such signatures of the growth and expansion phases of substorms (Mozer, 1971). The electric field data of Figure 1 summarizes this analysis through presentation of the average electric field measured near local midnight in a non-rotating frame of reference on a time scale whose zero is defined by the onset of the negative bay at the ground magnetometer below the balloon.

The pertinent temporal variations in Figure 1 are;

1. The existence of a westward electric field component for about an hour before the expansion phase of the substorm. Since this westward field causes sunward convection in the nightside auroral zone, it is the expected signature of enhanced magnetospheric convection during the growth phase.
2. The development of a southward electric field component at the time of the substorm expansion. While there is no generally accepted explanation of the origin of this component, it is clearly associated with plasma instabilities existing during the expansion phase.

Since there is experimental evidence from electric field measurements for the existence of growth and expansion phases of substorms, the validity of these concepts as defined in terms of magnetospheric convection becomes established if the electric field data are accepted. This data may be questioned from several points of view that are discussed below.

It may be possible that the westward electric field data of Figure 1 represents a spatial rather than temporal variation. For example, the westward electric field might be constant in time and exist over a confined spatial region that is fixed in a non-rotating frame of reference. The balloon might then rotate into this region to produce a westward field variation with time that is due to a spatial structure. This explanation is unlikely in view of the relatively few simultaneous balloon electric field measurements at separated longitudes in the auroral zone (Mozer and Manka, 1971; Mozer, 1971), which indicate that the westward field enhancement is a temporal effect. It is virtually ruled out by consideration of substorm related energetic particle flux variations in and near the nighttime synchronous satellite orbit (Lezniak and Winckler, 1970; Bogott and Mozer 1972). An example of such data is given in Figure 2, in which the particle fluxes from the Berkeley energetic particle detector on ATS-5 showed increases associated with the expansion phase of a substorm at about 0705 UT (0005 LT). For about thirty minutes prior to this event, the particle fluxes decreased slowly to levels below the detector thresolds, which are represented by the horizontal groups of data points at times such as near 0700 UT. This relatively slow decrease of flux precedes many substorms and is interpreted as the inward movement of the radiation belt in the enhanced westward electric field existing during the substorm growth phase. Some justification for this interpretation is provided by simultaneous measurements of equatorial particle fluxes and ionospheric electric fields (Mozer, Bogott, and Tsurutani, 1972). Since the particles of Figure 2 gradient-B drifted in longitude through hundreds of degrees during the flux decrease, it is impossible to attribute this decrease to a spatial structure of temporally constant electric fields, but instead it must be associated with a temporal increase in the convection.

As is well known (Cummings, et al, 1968; Fairfield and Ness 1970; Coleman and McPherron, 1970; Camidge and Rostoker, 1970; Russell et at, 1971) and as is illustrated in Figure 2, the magnetic field in the equatorial plane at $\sim 6R_e$ often becomes tail-like during an ~ 1 hour period before the expansion phase and becomes dipole-like during the expansion phase. These facts may be interpreted as evidence of enhanced convection during the growth phase since such convection brings the tail-like magnetic field geometry closer to the earth. Because the magnetic field structure has a large spatial scale, the inward motion of the magnetic field geometry must be due to a temporal rather than spatial variation in the westward magnetospheric electric field. It should also be mentioned that considerable further particle evidence for the growth phase of substorms exists (Hones, et al, 1967; Vasyliunas, 1968; Hones, et al, 1970, Schield and Frank, 1970), much of which also requires that the enhanced convection occurring before substorms is a temporal and not spatial effect.

In summary, it is suggested that the definition of the growth and expansion phases of substorms should rest on magnetospheric convection theories and data because of the ambiguities in interpretation of ground magnetometer records from which these concepts arose originally. Data such as that discussed above offers strong evidence for the validity and usefulness of the concepts of the growth and expansion phases.

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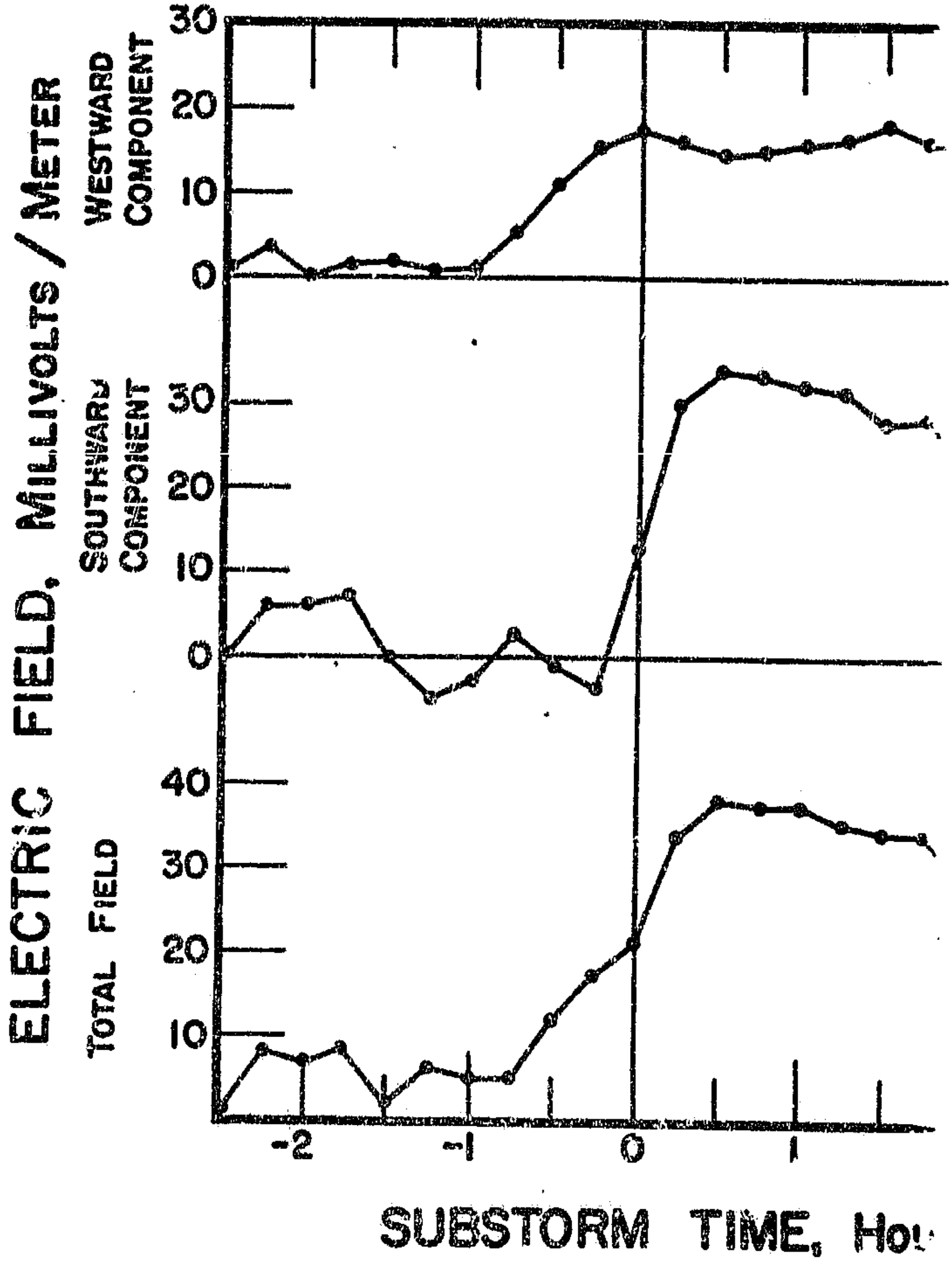
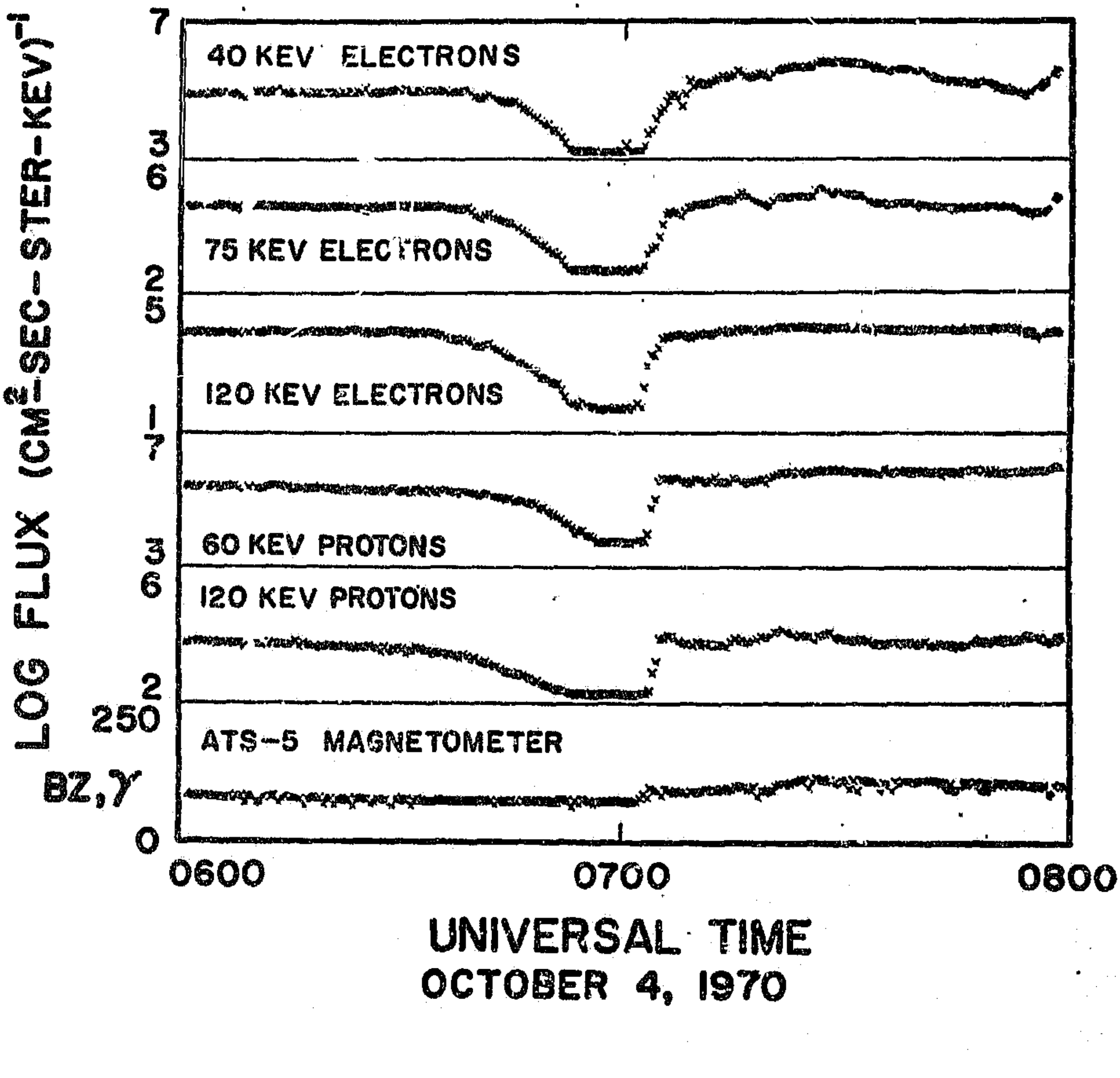
FIGURE CAPTIONS

Figure 1. Fifteen minute averages of the electric field data obtained during 19 balloon flights, presented in a nonrotating coordinate system.

Figure 2. Energetic particles and magnetic field observations made on ATS-5 in synchronous orbit during an isolated substorm.


ELECTRIC FIELD, MILLIVOLTS / METER
WESTWARD COMPONENT
SOUTHWARD COMPONENT
TOTAL FIELD
30
20
10
0
30
20
10
0
40
30
20
10
-2
-1
0
1
SUBSTORM TIME, HO

11


LOG FLUX (CM²-SEC-STER-KEV)⁻¹
7
3
6
2
5
1
7
3
6
2
250
BZ,γ
0
40 KEV ELECTRONS
75 KEV ELECTRONS
120 KEV ELECTRONS
60 KEV PROTONS
120 KEV PROTONS
ATS-5 MAGNETOMETER
0600
0700
0800
UNIVERSAL TIME
OCTOBER 4, 1970