MAGNETIC FIELD DYNAMICS IN THE ACTIVE REGION IN THE EARLY STAGE OF DEVELOPMENT

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ABSTRACT. Using observations obtained with the vector-magnetograph of the Sayan observatory we have studied the dynamics of the magnetic field in the stage of appearance and formation of the active region SD 135/1984.

Comparison of maps of the longitudinal and transverse components of the magnetic field shows that the field evolution reflects emergence of the main flux tube from the convection zone into the photosphere. In this case the magnetic flux tube is severely branched so that individual smaller flux tubes are subjected to the action of supergranulation motions in the active region.

We confirm the conclusion reached by a number of previous authors that magnetic flux in an evolving active region increases in an impulsive fashion.

A study is made of the evolution of the magnetic field subsystem at the center of the active region. It is concluded that the disappearance of this subsystem at the photospheric level - once the active region reaches its maximum development stage - may be accounted for by the emergence of a twisted (branched rather than dense) main flux tube into higher levels of the solar atmosphere.

ДИНАМИКА МАГНИТНОГО ПОЛЯ В АКТИВНОЙ ОБЛАСТИ НА НАЧАЛЬНОЙ СТАДИИ ЕЕ РАЗВИТИЯ: По результатам наблюдений на вектор-магнитографе Саянской обсерватории прослежена динамика магнитного поля на стадии появления и формирования активной области СД 135/1984.

Сравнение карт распределения продольной и поперечной компонент магнитного поля показывает, что эволюция поля отражает выход основной трубки магнитного потока в фотосферу из конвективной зоны. Причем, трубка магнитного потока сильно разветвлена, так что отдельные малые трубки потока подвержены действию супергрануляционных движений в активной области.

Подтверждается результат, полученный ранее некоторыми исследователями, о импульсном росте магнитного потока в развивающейся активной области.

Прослежена эволюция субсистемы магнитного поля в центре активной области.

Сделано заключение, что исчезновение этой субсистемы на фотосферном уровне при достижении активной областью максимума своего развития можно объяснить подъемом скрученной, но не плотной, а разветвленной основной трубки магнитного потока в верхние слои атмосферы Солнца.

DYNAMIKA MAGNETICKÉHO POĽA V POČIATOČNOM OBDOBÍ VÝVOJA AKTÍVNEJ OBLASTI: Na základe pozorovaní, uskutočnených na vektorovom magnetografe Sayanského observatória, bola analyzovaná dynamika magnetického poľa v prvom období vzniku a formovania aktívnej oblasti SD 135/1984.

Porovnanie máp rozdelenia pozdĺžnej a priečnej zložky magnetického poľa v aktívnej oblasti ukazuje, že vývoj magnetického poľa v oblasti je spôsobený stúpaním základnej trubice magnetického toku z konvektívnej zóny do fotosféry. Pritom, magnetická trubica je silne rozvetvená, takže jednotlivé malé trubice magnetického toku sú ovplyvnené supergranulárnymi pohybmi v aktívnej oblasti.

Výsledok, o impulznom náraste magnetického toku v rozvíjajúcej sa aktívnej oblasti, získaný v predošlých prácach niektorých autorov, bol potvrdený v tejto analýze.

Vývoj (topologického) centra aktívnej oblasti, ako zvláštneho subsystému magnetického poľa, bol podrobený analýze. Vymiznutie tohto subsystému vo fotosférickej hladine, po dosiahnutí maximálneho stupňa rozvoja aktívnej oblasti, je možné vysvetliť stúpaním pokrútenej, nekompaktnej, rozvetvenej hlavnej trubice magnetického toku do horných vrstiev atmosféry Slnka.

1. INTRODUCTION

There are presently a large number of papers devoted to the stage of appearance and to the beginning of development of an active region. However, most of them have been based on longitudinal magnetic field measurements. After the first measurements had been made with a vector-magnetograph during the initial stage of development of an active region (Bappu, Grigoryev and Stepanov, 1968), only a few papers appeared in recent years (see, for ex., Rabin, Moore and Hagyard, 1984), in which the study of the active region evolution was based on data obtained with vector-magnetographs.

There is still no unambiguous answer in the positive as regards some or other particular mechanism responsible for strong local magnetic fields typical of active regions. In the interpretation of observational data, different authors ascribe the role in the formation of the local strong magnetic field to both magnetic flux emergence from the convection zone and concentration of this field by the supergranulation convection. Some authors emphasize the importance of studying precisely the dynamical interaction between mass motions and the magnetic field in the active region. Bumba (1983 a), by studying proper motions of sunspots in evolving regions, drew the conclusion about the importance of precisely the hydrodynamical forces in the formation of the active region magnetic field and about the possible action of the local dynamo mechanism. In his recent review Zwaan (1985) drew the conclusion about emergence of a magnetic flux consisting of a multitude of individual flux tubes with a magnetic field strength corresponding to equipartition of the magnetic and kinetic energy of the gas for the upper part of the convection zone ($\simeq$ 500 G) and about its subsequent enhancement due to convective collapse and merging of the pores and minor sunspots.

It has been our intention in this paper to study the dynamics of the vector magnetic field during the formation of an active region in conjunction with supergranulation motions in this region (SD 135/1984) which were treated in a paper by Grigoryev and Selivanov (1986).

2. THE INSTRUMENT AND OBSERVATIONAL DATA

The observations were done with the vector magnetograph of the Sayan observatory. All components of the magnetic field strength vector and line-of-sight velocities were measured in the 5250.2 Å line of Fe I at a spatial resolution 2"x4". Analyses were made of the observations concerning the active region SD 135/1984 covering a time interval 21-26 June 1984.

The qualitative analysis also utilized magnetograms from the Kitt Peak observatory which were kindly put at our disposal by Dr. Livingston, as well as H_{α}-filtergrams taken at the Hida observatory and kindly supplied by Dr. Kurokawa.

3. OBSERVATIONAL RESULTS

3.1. The appearance and development of the active region magnetic field

The active region (AR) emerged in an already existing background magnetic field of positive polarity. Fig. 1 presents a map (21 June, 10:55 UT) of

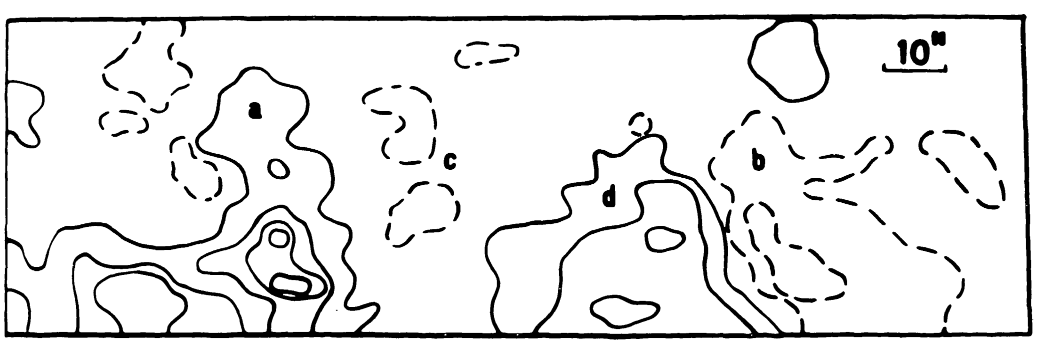

Fig. 1: **Map of distribution of** the longitudinal component of the magnetic field for 21 June (10:55 UT). Isogauss lines (——— N-polarity, ----- - S-polarity) are for 5, 15, 25 and 35 G.

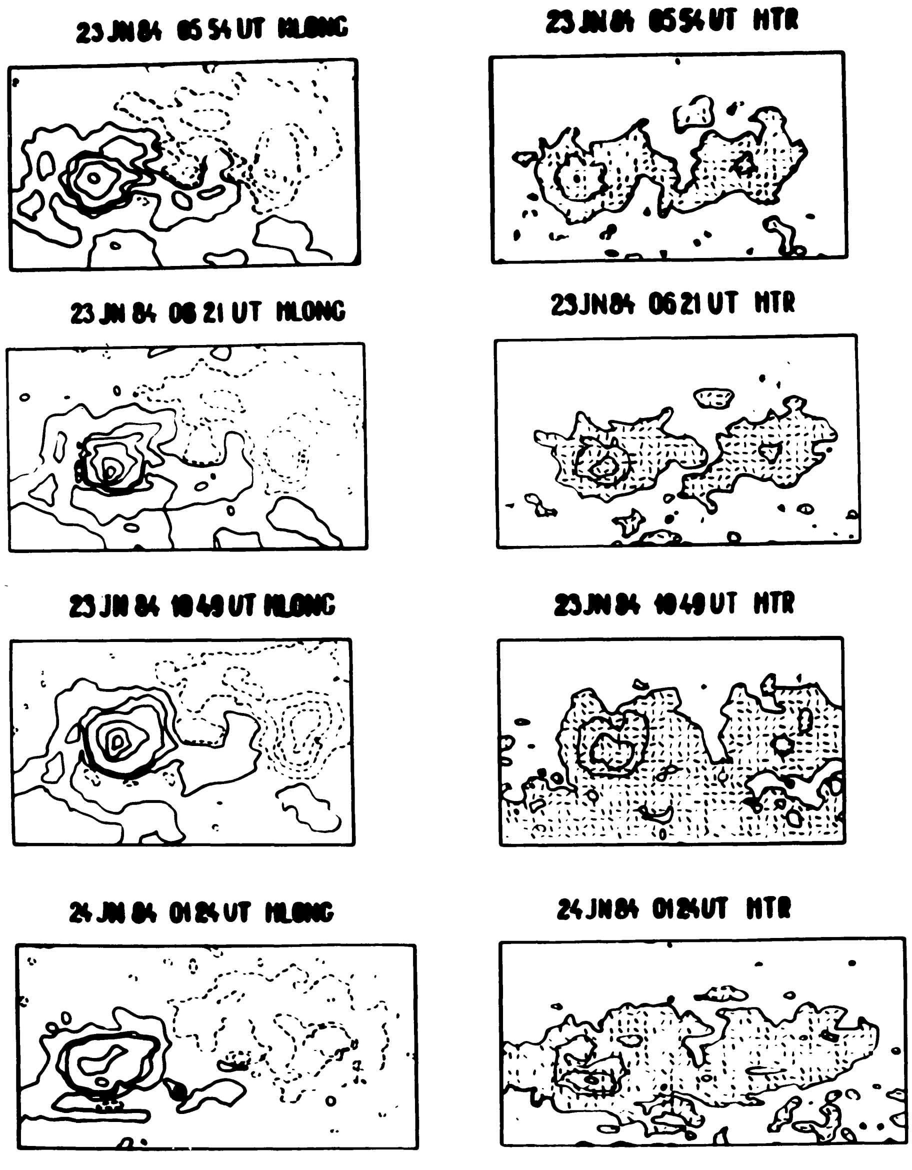

Fig. 2a: The evolution of the distribution of longitudinal and transverse components of magnetic field of the evolving AR for the period 23 and 24 June 1984. The orientation of the maps is E - left and N - top.

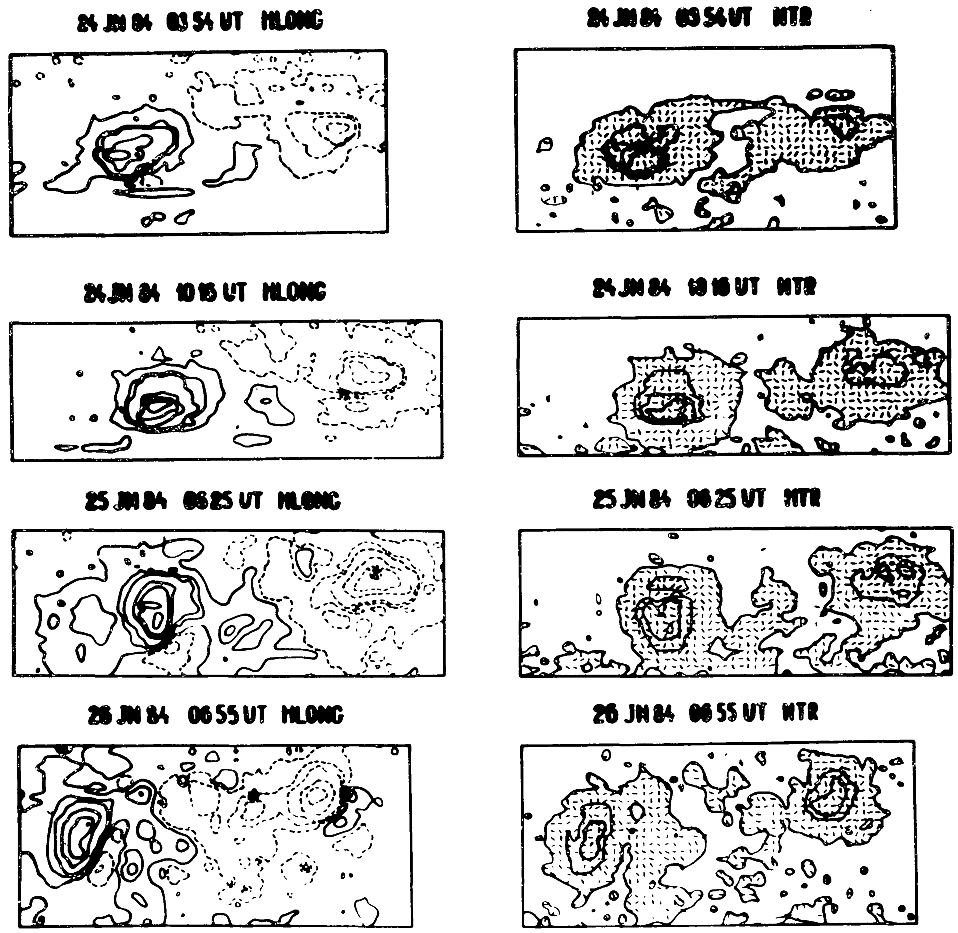

Fig. 2b: The continuation Fig. 2a from June 24 to June 26, 1984.

the longitudinal component of the magnetic field of the AR that appeared. On the map, solid lines (N-polarity) and dashed lines (S-polarity) indicate isogausses 5, 15, 25, and 35 G. At this moment of time, there is an already well-developed general structure of the magnetic field of the would-be AR. This structure represents two main magnetic field hills (a) and (b) of opposite polarity in places in which the formation of the main sunspots proceeds later. In between the main hills of magnetic field we observe hills (c) and (d) which form a bipolsr pair of a polarity opposite to that of the main polarity of the AR.

On 22 June, in the following part develops a sunspot. On 23 June, there occurs the main emergence of AR magnetic flux and this period is associated with the formation onset of the leading sunspot which ends on 24 June. On 25 June, a well-developed sunspot group is observed.

The development of the general structure of the AR magnetic field may be examined using the maps of distribution of the longitudinal and transverse components for the period 23-26 June which are selectively presented in Fig. 2. Isolines of the longitudinal field are shown by solid (N-polarity) and dashed (S-polarity) lines for the values of 10, 50, 100, 500, 1000 and 2000 G and for the transverse field: 100, 500, 1000 and 2000 G. Azimuths of the transverse component of the magnetic field in the picture plane are indicated by short bars in places where $H \geqslant 100$ G.

Comparison of the maps of the longitudinal and transverse field components shows that in the early stage of AR development there is a continuous region of transverse field covering the bipolar region of the would-be sunspot group. By the time of completion of the main sunspot formation in the group, the transverse field region breaks at the inversion polarity line of the longitudinal field so that transverse field regions come to surround the main sunspots of the group. Such a field evolution reflects emergence of the main magnetic flux tube into the photosphere from the convection zone.

However, the observed picture of the magnetic field distribution does not describe quite clearly the unified homogeneous flux tube but show a strong fragmentation. The picture is aspecially distorted at the AR center where there is a magnetic field subsystem (hills c and d). Such a subsystem is, generally, characteristic of the initial stage of development of the AR, and in view of its exceptional activity and influence upon the development of the entire AR it was called by Bumba (1983b) "the center of magnetic activity". It is in the AR center where there occurred most of the pores and minor sunspots which later on were moving towards the main sunspots of relevant polarity.

The fact that the longitudinal magnetic field hills are localized and are moving toward the supergranule boundaries, was, seemingly first, noted in a paper by Bappu, Grigoryev and Stepanov (1968). The comparison between our magnetograms and the maps of supergranulation motions in the AR under study, which were given in a paper by Grigoryev and Selivanov (1986), also indicates a localization of the longitudinal magnetic field hills on the boundaries and, especially, in places where supergranules make contact.

3.2 Magnetic flux variation in the evolving AR

Fig. 3 shows the plots of AR magnetic flux variation for the observational period 21-26 June separately for each polarity, F_N and F_S. The magnetic flux was calculated from the areas occupied by the longitudinal magnetic field of corresponding polarity with the strength over 10 G and was averaged over all magnetograms obtained during the day. Two main peculiarities in the magnetic flux variation deserve special motion. They are 1/ an impulsive, rather than monotonous character of its growth and 2/ the presence of magnetic

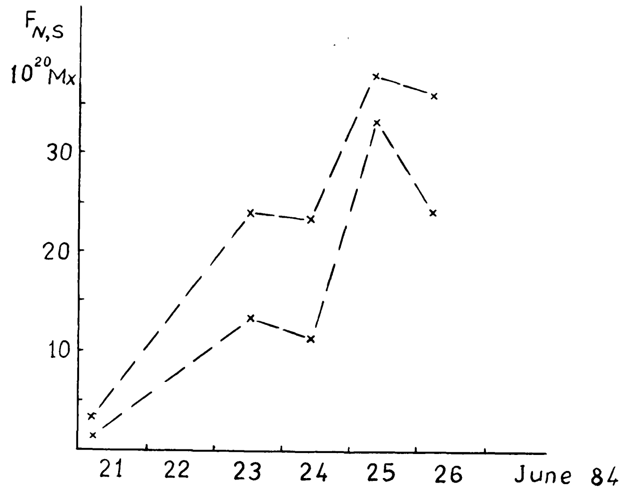

Fig. 3: Magnetic flux variation in the evolving AR. The flux of a positive magnetic field prevails.

flux disbalance, i.e. an excess of the positive magnetic field flux in the course of the entire period during which the AR development was observed.

The impulsive character in the magnetic flux variation during the AR development was pointed out by Pflug in his earlier work (1980). In our case the presence of two peaks of magnetic flux enhancement is due to the following factors. On 23 June there occurred the main emergence of AR magnetic flux accomanied by a massive appearance of systems of arch-like filaments and by an enhancement of the network of descending material, on the whole, throughout the AR, as pointed out by Grigoryev and Selivanov (1986). On 25 June the flux enhancement was due to a growth in magnetic field strength in the main sunspots reaching maximum values. We want also to mention here an important fact that the behaviour of the magnetic flux variation fits in quite well with the histogram of the distribution, for that period, of the number of flares in that region, as given in a paper by Sattarov et al. (1985).

The observed disbalance of magnetic flux in the AR was accounted - in one attempt of ours - for by the contribution of the background magnetic flux because the observed AR was produced in the background field of positive polarity. Thus, for 21 June in which case the amount of disbalance was small compared with the other days, we find that the background field strength at each point of our magnetogram must be $\sim$10 G. Taking into consideration that the background field is distributed non-uniformly over the solar surface and is concentrated in a magnetic network which covers about 1/4 of the entire observable surface, the required strength must be $\sim$40 G. Both the first and, to a larger extent, the second values are recorded quite well by our magnetograph, with its sensitivity to the longitudinal magnetic field is $\sim$1 G; there-fore, the observed disbalance is not possible to explain by the presence of such a background field. Thus, we must conclude that part of the field lines of the observer AR is closed into other regions. An inspection of Hα-filtergrams reveals a stable system of fibrilles in the E-W portion near the following sunspot which seems to indicate there is such a closure of part of the field lines from the f-spot to the other AR located eastward of the observed one.

4. INTERPRETATION AND CONCLUSIONS

The afore-going observational evidence pertaining to the AR development stage, taken together, is in favour of the mechanism for magnetic flux emergence from beneath the photosphere. This is confirmed by the following considerations.

The evolution of the longitudinal and transverse magnetic field distribution reflects the emergence of the main flux tube from below the photosphere. In this case the separation of the main hills of the magnetic field increased by a factor of about 1.5 from 21 to 26 June. Since emergence of new magnetic flux is occurring in the already existing background magnetic field, due to processes of reconnection between their field lines as low as the convection zone we do not observe the picture of emergence of the magnetic loop top itself into the photosphere.

Also, the observations show a strong fragmentation in the magnetic field distribution, which indicates that the magnetic flux tube is not a single and a homogeneous one but consists of a great number of individual flux tubes. A single flux tube is able to emerge within the reaches of one or two supergranules, and its orientation in space will be determined by local conditions for interaction between magnetic and hydrodynamical forces.

The systems of Hα -fibrilles indicate there is a closure of the field lines between the main sunspots and magnetic hills at the AR center for 23 June; as for 24 June, connection through the field lines the main sunspots to each other. The spatial orientation of the individual tubes may be strongly influenced by the twist of the main tube which looks like a bundle of individual tubes. The inclination of the inversion polarity line of the longitudinal magnetic field to the axis of the sunspot group in the early stage of development, which is traceable on our magnetograms, provides evidence for the existence of such a twist. Emergence of individual flux tubes that received a different orientation, may lead to reconnection of their field lines, and this seems to ensure the flare activity in the evolving AR.

Individual flux tubes emerging at the AR center are responsible for the observed subsystem of magnetic field. Their emergence also accounts for the observed motions of magnetic hills and related pores and minor sunspots. The emergence of these tubes is occurring until they merge with the main bundle of nearly vertical (at their bases) (in p- and f-sunspots) tubes where magnetic buoyancy ceases its action.

A very important observational fact that confirms the main simulations of magnetic flux emergence from beneath the photosphere, as developed by Parker (1979), is provided by the simultaneous enhancement of the mass downward flow with increasing magnetic flux in the AR.

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DISCUSSION

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Согласно теории магнитоконвекции, которая в настоящем времени является общепринятым взглядом, магнитный поток всплывает из под фотосферы как крупномасштабное поле, которое впоследствии фрагментирует. В последнем времени, однако, результаты исследований в области турбулентной конвекции указывают на другую точку зрения, а именно, что магнитный поток всплывает как мелькомасштабные поля, из которых в последствии формитуется крупномасштабное поле. Ваши наблюдательные результаты поддерживают вторую точку зрения.