Three dimensional MHD Numerical Simulations for a Magnetic Twisted Emerging Flux Tube

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It is well known that an emerging flux tube causes various active phenomena in the solar atmosphere. They are, for example, an active region formation, flares, CMEs, and so on. Twisted flux tube is important because it contains substantial magnetic energy, and is thought to be a source of violent phenomena. We have studied behaviors of a twisted emerging flux tube from the upper convection zone to the corona by means of three-dimensional MHD numerical simulations (see also Matsumoto et al. 1998, Magara & Longcope. 2001). The purpose of this study is to reproduce evolution of flux tubes in the upper solar atmosphere and to find final structure of magnetic fields in the corona. The parameters of this simulation are magnitude of twists, radius of a flux tube, and wavelength of perturbation. Here, we present results of different magnitude of twists. An S-shaped structure is formed when magnitude of twists is strong ($B_\theta = qrB_0/(1+(qr)^2)$, $q \sim 1.0$), and a helical structure is formed when magnitude of twists is weak ($q \sim 0.2$). Here, B_θ is toroidal fields, B_0 is poloidal fields, r is distance from the center axis of flux tube, and q is a parameter of magnitude of twists.

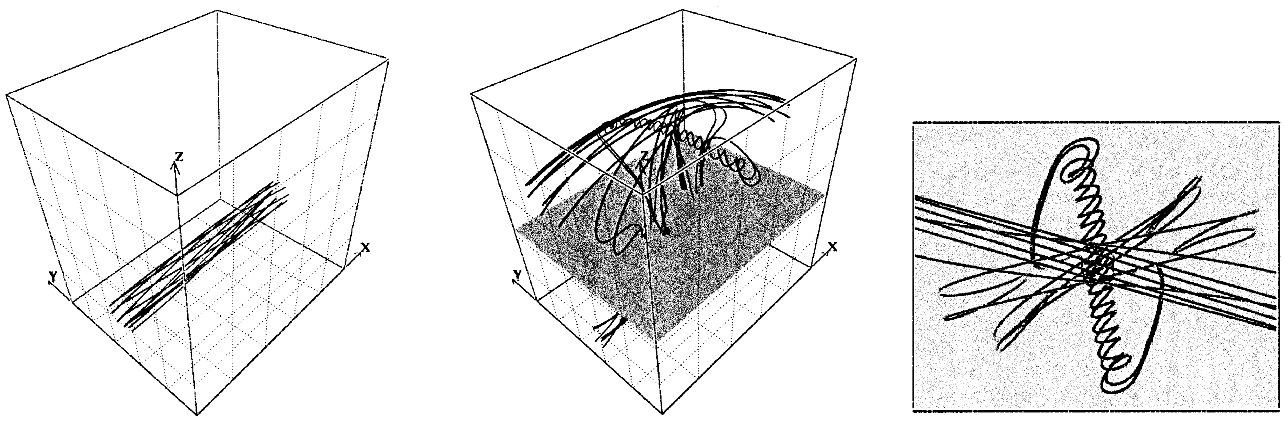

Figure 1: Simulation results of initially weak twist flux tube ($q = 0.2$). Left panel shows initial condition, center panel shows the structure after flux tube emerges, and right panel shows top view of center panel. Solid lines shows magnetic fields, and grey surface (center panel) shows the surface of the sun. The scale of boundary box is $25H \times 25H \times 25H$ (H is the scale height of photosphere). Magnetic reconnection occurred below corona (high β region), and the helical structure of magnetic fields are created.

Initially, a Gold-Hoyle force-free flux tube is embedded in the upper convection zone, and starts emerging by Parker instability with imposed small amplitude perturbation. Figure 1 shows numerical simulation results of weak twists ($q = 0.2$). Left panel shows the initial states of the simulation. Solid lines show magnetic lines of force. In this case, Magnetic fields are nearly straight. As tube emerges, convection flow occurs near the footpoints of the flux tube. This convection motion pushes magnetic fields toward the center (Figure 2). As a result of this, magnetic reconnection occurred below the corona (convective motion pushes fields effectively at high β region). The helical structure of magnetic fields are formed (Figure 1, center panel). Right panel of Figure 1 shows magnetic structure viewed from the top. Figure 3 shows strong twisted case ($q = 1.0$). In this case, reconnection does not occur because no neutral point is formed by the

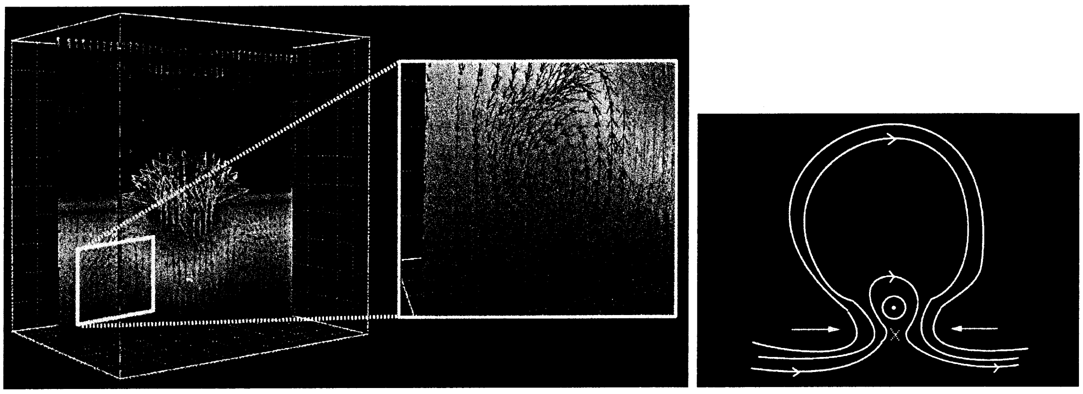

Figure 2: (Left) Velocity fields by arrows of simulation result. (Right) Schematic picture to explain the formation of the helical structure by magnetic reconnection. Arrows show convective gas motion and solid lines show magnetic fields.

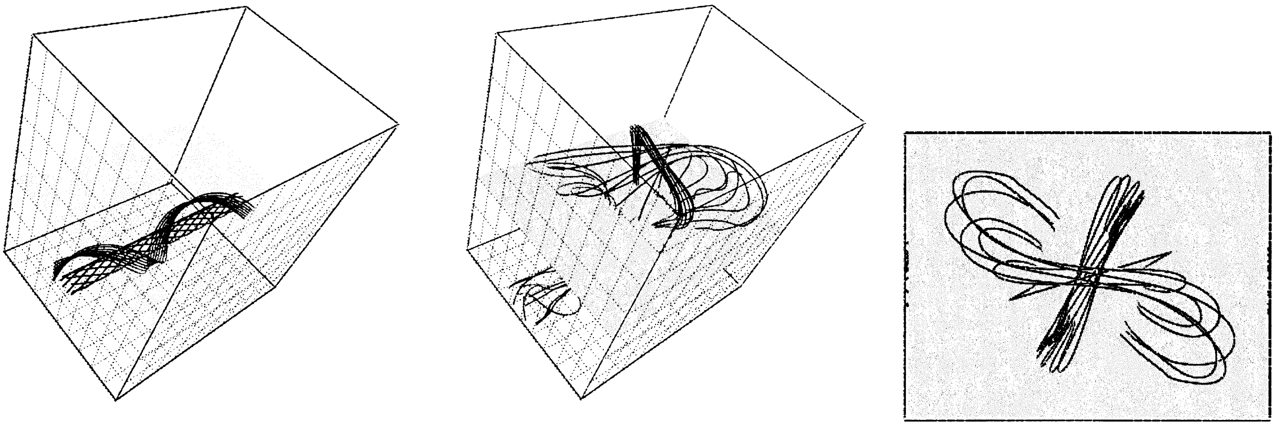

Figure 3: Simulation results of strongly twisted case ($q = 1.0$). In this case, the helical structure is not created. In comparison, An S-shaped structure is shown by strongly twisted field.

converging flow. But an S-shaped structure is formed in the corona. From these results, it is found that magnitude of twists have an strong effects on coronal magnetic structures of emerging flux.