DYNAMICS OF SOLAR SURGE DURING ITS DESCENDING STAGE

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ABSTRACT Using the basic picture and formula presented in Paper 1[1], and taking into consideration that 1) during the descending phase a weak magnetic field must be used and 2) the effect of atmospheric resistance must be allowed for near the end, the dynamical features of a solar surge during its fall are satisfactorily explained.

1 INTRODUCTION As pointed out in Paper 1[1], there is still no complete theoretical explanation of the dynamical features of solar surge. The 'helium seed effect' cannot explain the accelerating phase of the ascending motion, and cannot explain the descending phase. As for the descending motion, there has hardly been any theoretical calculation, and the main difficulty has been the lack of a suitable mechanism that can describe the dynamical features during the descent. Based on observations relating to small surges, Poy [2] and certain qualitative explanations of the downward motion regarding it to be caused by weak magnetic field and atmospheric resistance, but he made no specific calculations.

The main feature during the downward motion is that the descending velocity is less than that of free fall, and this suggests the existence of resistance in the direction opposite to gravity. But when studying the downward motion, we must note several differences in physical conditions between the downward and upward phases. We shall illustrate these differences using the surge WY 18511 A as an example.

The ascending motion of the surge causes a weakening of the magnetic field and the increase in the mechanical energy, the loss of energy in work done by atmospheric resistance etc. during the ascent comes from dissipation of the magnetic energy in the active region. Estimates for the various energy losses are:

(a) When the surge reaches its maximum height, the increase in mechanical energy $\Delta E = \frac{1}{2} M e_0^2 \sim 1.2 \times 10^{23}$

(b) Under isothermal approximation at temperature of $10^8 K$, energy loss due to work done by expansion is $W = \int \rho dx = \frac{M}{\mu} RT \int \rho \frac{dv}{v} = \frac{M}{\mu} RT \ln \frac{v_i}{v_f} \sim 6.5 \times 10^{23}$

(c) The value of $E_0$ is determined by the work done by expansion, atmospheric resistance and magnetic field strength. Assuming $E_0 = 10^{23}$ erg, $8 \times 10^{23}$ erg, and $8 \times 10^{23}$ erg, we get $\frac{E_0}{E} \sim 10^3$.

\[ E_0 \approx \frac{1}{2} M e_0^2 \sim 1.2 \times 10^{23} \text{ erg} \]

\[ E = \int \rho dx = \frac{M}{\mu} RT \int \rho \frac{dv}{v} = \frac{M}{\mu} RT \ln \frac{v_i}{v_f} \sim 6.5 \times 10^{23} \text{ erg} \]

\[ E = E_0 + \Delta E \]

\[ \Delta E = \int \rho dx = \frac{M}{\mu} RT \int \rho \frac{dv}{v} \]

\[ W = \int \rho dx = \frac{M}{\mu} RT \int \rho \frac{dv}{v} \]

\[ R = \frac{h}{2} \left( 1 + \frac{m}{d} \right)^{\frac{5}{2}} \]

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Calculation of the surge density shows that the surge front throughout the descending phase (24000 - 8000 km) is situated in a region of uniform ambient density, hence we can use formula (21) of [1] and with suitable approximation, we have

$$m = \frac{1}{\pi} \left[ 187 + \frac{2}{\sqrt{14000 - \frac{h}{d}}} \right]^{\frac{\pi}{2}}$$

$$\frac{dm}{dt} = \frac{1}{\pi} \left[ 187 + \frac{2}{\sqrt{14000 - \frac{h}{d}}} \right]^{\frac{\pi}{2}}$$

Combining (2), (3) and (4) we have:

$$\frac{d}{a} \left[ \frac{\rho}{a} \right] \frac{d^2}{dt^2} \left[ \frac{h + \frac{m}{a}}{d^2} \right] = \frac{3R^2B^2}{4aM} \left[ \frac{h + \frac{m}{a}}{d^2} \right] \left[ 187 + \frac{2}{\sqrt{14000 - \frac{h}{d}}} \right]^{\frac{\pi}{2}} - \frac{g}{a}$$

Here, all constants except \( B_o \) are taken to have the same values as in [1], and the initial conditions for the descending phase are to be determined by \( V = 0 \).

From (3), (4) and (5) we can find the theoretical curve of variation of the surge velocity with height for \( H > 16000 \) km or \( h > 1000 \) km.

When the base of the surge has fallen to below 16000 km, there will be a sudden increase in the ambient density (log \( \rho \) from -10.02 to -7.77 in Becker's model) hence a sudden increase in the resistance, which will be far greater than gravity and will cause the velocity of the base to decrease suddenly to zero. Also from calculation the matter density in the surge then will be \( \rho = 10^{-7} \), about the same as the ambient density, resulting in a mixing of the surge matter with the surrounding, and a gradual decrease in the surge mass \( m \) and length \( s \). Hence, we can approximately regard \( \rho/H \) as a constant, and find that \( \rho \) varies with a uniform acceleration of \( a_1 \) (\( -0.049 \) km s\(^{-2}\)), at this time the expansion of the front becomes also approximately uniform at \( a_2 \) (\( -0.012 \) km s\(^{-2}\)). Therefore the acceleration of the front is \( \rho = a_1 + a_2 = -0.061 \) km s\(^{-2}\). For \( H \) less than 16000 km then we have approximately

$$V' - V_f = 2a(H - H_f)$$

This gives the variation of \( H \) in the range \( H = 16000 - 8000 \) km.

### RESULTS AND DISCUSSIONS

Table 1: Observed Values During the Descending Phase of Surge

<table>
<thead>
<tr>
<th>( H ) (km)</th>
<th>24000</th>
<th>21000</th>
<th>19000</th>
<th>17000</th>
<th>15000</th>
<th>13000</th>
<th>11000</th>
<th>9000</th>
<th>7000</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V ) (km/s)</td>
<td>0</td>
<td>-39</td>
<td>-31</td>
<td>-40</td>
<td>-45</td>
<td>-81</td>
<td>-55</td>
<td>-62</td>
<td>-65</td>
</tr>
</tbody>
</table>

Table 2: Calculated Values (\( B_o = 800 \) G)

<table>
<thead>
<tr>
<th>( a ) (km)</th>
<th>( m ) (km)</th>
<th>( H ) (km)</th>
<th>( \sigma ) (km/s(^2))</th>
<th>( dH ) / ( dt ) (km/s(^{2}))</th>
<th>( V ) (km/s(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>15000</td>
<td>10829</td>
<td>21029</td>
<td>-24.9</td>
<td>21.7</td>
<td>-2.4</td>
</tr>
<tr>
<td>12000</td>
<td>101756</td>
<td>23574</td>
<td>-30.7</td>
<td>20.6</td>
<td>-10.2</td>
</tr>
<tr>
<td>10000</td>
<td>12271</td>
<td>23121</td>
<td>-35.7</td>
<td>19.8</td>
<td>-18.0</td>
</tr>
<tr>
<td>9000</td>
<td>12566</td>
<td>22566</td>
<td>-43.5</td>
<td>18.7</td>
<td>-24.4</td>
</tr>
<tr>
<td>8000</td>
<td>12947</td>
<td>21947</td>
<td>-48.3</td>
<td>17.7</td>
<td>-29.8</td>
</tr>
<tr>
<td>7000</td>
<td>13281</td>
<td>21328</td>
<td>-52.9</td>
<td>16.3</td>
<td>-34.6</td>
</tr>
<tr>
<td>6000</td>
<td>13626</td>
<td>20756</td>
<td>-56.7</td>
<td>14.9</td>
<td>-39.1</td>
</tr>
<tr>
<td>5000</td>
<td>13965</td>
<td>19165</td>
<td>-60.4</td>
<td>13.7</td>
<td>-43.3</td>
</tr>
<tr>
<td>4000</td>
<td>14222</td>
<td>17566</td>
<td>-63.9</td>
<td>12.6</td>
<td>-46.4</td>
</tr>
<tr>
<td>3000</td>
<td>14461</td>
<td>15966</td>
<td>-66.2</td>
<td>11.6</td>
<td>-49.1</td>
</tr>
<tr>
<td>2000</td>
<td>14698</td>
<td>14356</td>
<td>-68.6</td>
<td>10.7</td>
<td>-51.1</td>
</tr>
<tr>
<td>1000</td>
<td>14998</td>
<td>12756</td>
<td>-70.9</td>
<td>9.8</td>
<td>-53.1</td>
</tr>
</tbody>
</table>

Fig. 1

Comparison between observations (squares +5/8 4; circles +7/8 4) and the theoretical curve (solid line). For the surge \( W15511A \), dashed line is the line of free fall.

We took \( B_o = 600 \), 800 and 1200 G in our theoretical calculations; the observed data are those of \( W15511A \) obtained by Hoy [5] at Sac Peak, see Table 1. We found that the best agreement is given by \( B_o = 800 \) G (see Fig. 1), the calculated values are given in Table 2. From the comparison we derive the following conclusions:

1. The picture of surge motion put forward in [3] can equally satisfactorily explain the features during the descending phase of the surge, that is, applying the physical mechanisms of Maxwell stress in the re-connected field and the explosive expansion of the surge matter and taking into account the weakening of local field and the effect of atmospheric resistance. During the descending phase, we can explain all the dynamical features of a surge. For different surges with different sets of physical conditions, different parameters and models should however be used in the calculation.
Both observations and calculated results indicate that there is an obvious weakening of the field before and after a surge. We can take the view that the energy of the upward motion of a surge comes from the dissipation of the magnetic field.

To conclude, we shall discuss a frequently observed feature, namely, the tendency to re-appear in the same locality over a period of time and the tendency for these recurrent surges to get weaker and weaker [5]. Let us estimate the diffusion time of the local field in an active region,

\[ T = \frac{4\pi \rho}{\sigma} \]

We take the anomalous conductivity for an unstable region, \( \sigma = 10^5 \), and we take the linear scale of the region considered \( l = 10^6 \). We obtain

\[ T \approx 10^8 \sim 10^9 \]

Comparing this with the time of ascent of \( \approx 5 \times 10^6 \), observed in Mo 18531, shows that the dissipation of magnetic energy during the ascent comes mainly from the nearby field, the field will not have time enough to have diffused near. This naturally causes the weakening of the field during the descent and accounts for the gradual weakening of successive surges in the same locality. This precisely what Hoy observed [6] in 6 successive surges in Mo 18531. These all occurred within a period of two hours, consistent with the above estimate of \( T \).

According to the picture presented here, as a surge returns to the solar surface, part of its mechanical energy will be converted into heat, another part will be converted into magnetic energy as the surge matter presses on the magnetic lines at the surface, and this provides a possible excitation mechanism for the next surge.

**REFERENCES**


