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# Relationship between horizontal Flow Velocity & Cell lifetime for supergranulation from SOHO Dopplergrams

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U.Paniveni<sup>1</sup>, V.Krishan<sup>1</sup>, Jagdev Singh<sup>1</sup>, R.Srikanth<sup>2</sup>

<sup>1</sup> Indian Institute of Astrophysics, Koramangala,  
Bangalore-560034, India

<sup>2</sup> Optics group, Raman Research Institute  
Bangalore-560080, Karnataka, India.

## ABSTRACT

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A study of 50 supergranular cells obtained from SOHO Dopplergrams was undertaken in order to investigate the relationship between the lifetime ( $T$ ) and the horizontal flow velocity ( $v_h$ ) of the cells. For this sample we find that the two parameters are correlated with a relation  $v_h \propto T^{0.5}$  and  $T$  is identified with the eddy turn-over time. This is in agreement with the turbulent convective model of the solar atmosphere where the velocity spectrum of supergranular field given by ' $v_h \propto L^{1/3}$ ' can be identified with the Kolmogorov spectrum for the eddy size  $L$ .

## INTRODUCTION

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Convection is the chief mode of transport of heat in the outer envelopes of cool stars such as the sun. The convection zone which lies in the sub-photospheric layers of the sun has a thickness of about 30% of the solar radius. Here the opacity is so large that energy is carried by turbulent motions rather than by photon diffusion. The convective motions on the sun are characterized by two prominent scales: the granulation with a typical size of 1000 km and the supergranulation with a typical size of 30000 km. The supergranules are regions of horizontal outflow along the surface, diverging from the cell centre and subsiding flow at the cell borders. Such outflowing regions always show velocity of approach to the observer on the side close to the centre of the disk and velocity of recession on the side towards the limb. Near the centre of the disk where the horizontal outflows are transverse to the line-of-sight, there is less dopplershift and so the image is almost uniformly grey. These high photospheric large convective eddies sweep up any shreds of photospheric magnetic fields in their path from the declining active regions into the boundaries of the cell, where they produce excess heating, resulting in the chromospheric network. The approximate lifespan of a supergranular cell is 24 hours. Broadly speaking supergranules are characterized by the three parameters namely length  $L$ , lifetime  $T$  and horizontal flow velocity  $v_h$ . The interrelationships amongst these parameters can shed light on the underlying convective processes. Cells of a given

size associated with remnant magnetic field regions live longer than those in the field-free regions (Singh et al. 1994). The lifetime of network cells was found to be larger for active-region cells as compared to that of quiet-region cells (Raju, Srikanth and Singh 1998). Diffusion-like dispersion of the magnetic flux is the dominant factor in the large scale evolution of the network. The lifetime of a supergranular cell is found to depend on the size of the cell and is larger for bigger cells (Srikanth et al. 1999). Convective motion and magnetic inhibition of motion are both stronger in active regions, thereby leading to similar speeds in all regimes (Srikanth, Singh and Raju, 1999). A positive correlation between horizontal flow velocity and cell size of a supergranular cell has been established recently by Krishan et al. (2002). The corresponding dependence of lifetime of the supergranular cell on its horizontal flow velocity is expected to be  $v_h \propto T^{0.5}$  where the eddy turn-over time i.e. the crossing time for plasma from centre to edge can be estimated from the relation  $T = L/v_h$  with  $L$  as the distance from the centre to the edge of the cell and  $v_h$  is the peak horizontal flow velocity of the cell. In this paper we report on this possible interrelationship between horizontal flow velocity and cell lifetime for supergranules.

### Source of data

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We analysed 33 hour data of full disc Dopplergrams obtained on 28th and 29th June 1996 by the Michelson Doppler Interferometer (MDI) on board the solar and Heliospheric observatory (SOHO) (Scherrer et al. 1995).

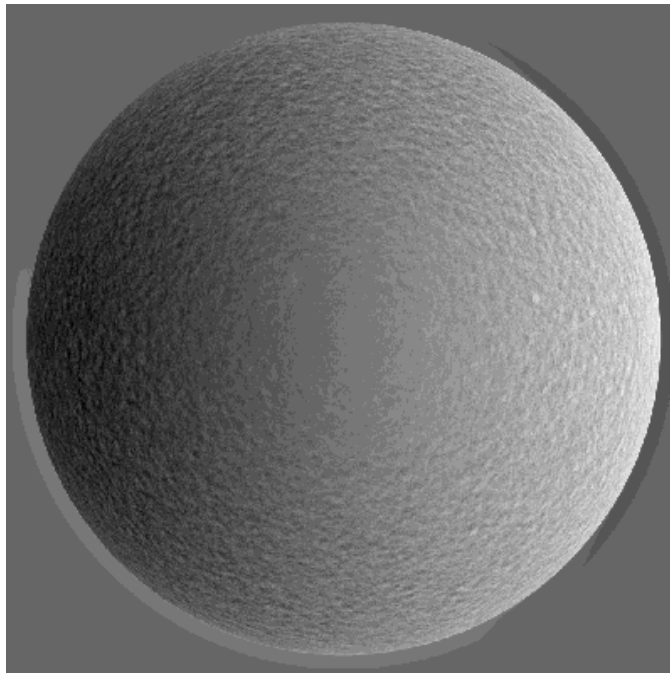


Figure 1: Processed SOHO Dopplergrams

## Data Analysis

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The SOHO full disc Dopplergram data has been obtained with a resolution of  $2''$  which is twice the granular scale. Further, the Dopplergrams are time averaged over intervals of 10 min, which is about twice the 5-minute period of oscillations. Thus the signal due to granular velocity is averaged out. Similarly the contributions due to p-mode vibrations are reduced after the time averaging. Our analysis rests on the implicit belief that time averaging removes noise significantly. Noise is reduced in our data considerably with 10-minute integration time, as judged from visual inspection and also as seen in typical supergranular velocity profile for our data (Figure 2). After the averaging, the supergranular network is brought out with a fair clarity. This procedure yielded usually six images per hour of the data. Corrections due to solar rotation are applied to the Dopplershifts. Fifty well accentuated cells lying between  $15^\circ$  and  $60^\circ$  angular distance from the disc centre were selected. Restricting to the above mentioned angular distance limits helps us discount weak supergranular flows as well as foreshortening effects.

## Data Processing

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### Supergranular cell speed

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The line-of-sight velocities in the dark/bright region of the cells are directly read off from the velocity scan. Among them the first three highest velocity read-outs and the last three least velocity read-outs were selected. The maximum cell velocity is then determined as the average of the former three values minus the average of the latter three. This furnishes a simple way to assign a peak horizontal flow velocity  $v_h$  to a given cell that is independent of large scale velocity gradients. To see this let us write  $v_{\max} = |v_h| + v_{\oplus}$  where  $v_{\oplus}$  represents contributions due to large scale gradients in the velocity field and  $v_{\min} = -|v_h| + v_{\oplus}$ . Then half the difference of  $v_{\max}$  and  $v_{\min}$  is the required peak horizontal velocity  $v_h$ . Three pairs of values were chosen to add robustness. Now, it is a fact that even a randomly noisy velocity field can, by our method of choice of three largest velocities, be biased to yield some spurious relations (eg., larger cells showing larger velocity). Hence it is of considerable importance to be certain that the data is not noisy at the level of interest. The ten-minute time-averaging removes noise to a level sufficient for our purpose. This was clear from a visual inspection of the images. More specifically, the selected three peak positive velocity points and the three peak negative points are not spiky and fit in smoothly with the surrounding flow pattern and hence the chosen peaks are with very high probability part of the velocity profile and not noise. This is depicted for a typical cell profile in Figure 2. Dopplergrams give us the line-of-sight velocity component. Geometrically it has a contribution from the local horizontal flow field  $v_h$  and vertical flow field  $v_v$ . Normally, the vertical component can be ignored because the convective upwelling, concentrated towards the cell centre, and the downflows, along the periphery of the cell, are typically much smaller. However, regions with a considerable vertical component of velocity are not improbable. For example, the upflow regions can be as broad as  $10''$  (Küveler 1983). More importantly, it follows from basic trigonometric arguments that our method of velocity selection will tend to pick up the three largest positive values from approaching flows with a considerable upflow component, and the (magnitudinally) largest negative values from receding flows with a considerable down-

ward component. Therefore, in order to account for this residual  $v_v$  contribution (where we treat upflows and downflows symmetrically for simplicity), we need to make an assumption about the relation connecting  $v_h$  and  $v_v$ . The velocity derived from our analysis is based on this assumption. In the reported literature,  $v_h$  is known to be larger than  $v_v$ . This is also supported by mass conservation law (Krishan 1999 and Krishan et al. 2002). Direct inspection of the disk center yields vertical velocities of about  $200 \text{ m s}^{-1}$ . For  $v_h = 539.15 \text{ m s}^{-1}$ , which we obtain as mean value, this implies a value closer to  $r \equiv v_v/v_h = 0.4$ . Hence this value of  $r$  is adopted for the present analysis.

## Supergranular cell lifetime

The 33 hour data is spread over 198 frames with a 10 minute interval between the consecutive frames. Only those cells which appear and disappear within the chosen period of 33 hours are considered. This excludes cells already present in the first frame and those still present in the last frame. Thus the selected cells were born a few frames after the first. A particular supergranular cell thus identified is tracked down the successive frames until it disappears completely in a particular frame. Lifetime is identified to be the time interval between its first appearance and final disappearance.

## Results

A large dispersion in the supergranular lifetime and horizontal velocity is noted. The main results pertaining to the maximum, the minimum, the mean and the standard deviation for horizontal flow velocity  $v_h$  and cell lifetime  $T$  are summarized in Table 1.(Computed using  $r = 0.4$ .)

	Max	Min	Mean	$\Sigma$
$T$ (hr)	32.00	16.00	22.00	3.0
$v_h$ (m/s)	661.06	402.33	539.15	1.8
$L$ (Mm)	42.79	17.63	27.42	5.75

Table 1: Maximum, minimum, mean and standard deviation for cell lifetime ( $T$ ) and cell peak horizontal flow velocity ( $v_h$ ) and cell size( $L$ ).

In previous studies cell lifetimes were derived by cross-correlation technique (Raju, Srikanth and Singh 1998a). The analysis was based on diffusion co-efficients of the network magnetic elements and was identified as a 'diffusion lifetime'. Estimation of lifetime by visual inspection method rests on the crossing time for plasma from centre to edge of the cell (Krishan 1999). Hence visual inspection is expected to lead to the eddy turn-over time given by  $T = L/v_h$ . Visual inspection is a fairly foolproof method, though laborious. The sample is quite small but is characteristic for different epochs and regions.

Figure (3) presents a plot of square of the peak horizontal flow velocity with  $r = 0.4$  and cell lifetime. A powerlaw of the form

$$v_h = CT^\alpha \tag{1}$$

was fitted to the data using the least squares method. For  $r = 0.4$ , we find  $C = 0.001$  and  $\alpha = 1.09$ . Its intercept gives the value of  $\epsilon \approx 1.37 \times 10^{-6} km^2 s^{-3}$ . Figure (3) clearly shows that the two parameters are well correlated and the correlation co-efficient between  $v_h^2$  and  $T$  is about 0.78.

## Discussion and conclusions

In an earlier study (Krishan 1991), it was suggested that the granulation and supergranulation are the result of energy cascading processes in a turbulent medium. Recently we showed that the velocity spectrum of the supergranular field very closely agrees with Kolmogorov's spectrum  $v_h = \epsilon^{1/3} L^{1/3}$  (Krishan et al. 2002) where  $\epsilon$  is the energy injection rate. Defining the eddy turn-over time to be the lifetime of the cell, we can write  $T = L/v_h$ . Combining with the Kolmogorov spectrum  $v_h = \epsilon^{1/3} L^{1/3}$ , we find

$$v_h = \epsilon^{1/2} T^{1/2} \quad (2)$$

Comparing (1) and (2) we see that  $C = \epsilon^{1/2}$  and hence  $\epsilon = 10^{-6} km^2 s^{-3}$  which is very close to the value of  $\epsilon$  obtained earlier by us (Krishan et al. 2002) from the velocity  $v_h$  and size  $L$  relationship with different data. Using the data of peak horizontal flow velocity of 50 supergranular cells and their sizes, we have plotted the data of  $v_h$  against  $L$  as shown in Figure (4). Its intercept gives the value of  $\epsilon \approx 5.26 \times 10^{-6} km^2 s^{-3}$  and a slope of 0.33. The correlation co-efficient for  $v_h$  and  $L^{1/3}$  of 0.68 is obtained. Thus we conclude that the supergranular velocity field is well accounted for by the Kolmogorov spectrum  $v_h = \epsilon^{1/3} L^{1/3}$  with eddy turn-over time realised from  $v_h = \epsilon^{1/2} T^{1/2}$ . A comparison of the theoretical energy spectrum of granulation ( $\propto K^{-5/3}$ ), mesogranulation ( $\propto K^{-1}$ ) and supergranulation ( $\propto K^{-5/3}$ ) (Krishan 1991 ; 1996) with the observed energy spectrum of granulation ( $\propto K^{-5/3}$ ), mesogranulation ( $\propto K^{-0.7}$ ) and supergranulation ( $\propto K^{-5/3}$ ) (Malherbe et al. 1987; Zahn 1987; Keil et al. 1994) appears to point at the phenomenon of the inverse cascade of energy operating in the solar convective turbulence.

## References

- [1] Keil, S et al., 1994, *Infrared Solar Physics*, eds. D. M. Rabin et al. p. 251.
- [2] Krishan, V., 1991, MNRAS, 250, 50
- [3] Krishan, V., 1996 Bull. Astron. Soc. India, 24, 285.
- [4] Krishan, V., *Astrophysical Plasmas and Fluids* (Kluwer, Boston 1999)
- [5] Krishan, V., Paniveni, U., Singh, J., Srikanth, R., 2002, MNRAS, 334/1, 230
- [6] Malherbe, J.M., Mein, P., Muller, R., Roudier, R., Coutard, C., Hellier, R., 1987, in Mouradian, Z., Lemaire, P. eds *Colloque Themis, College de France, 5-6 March 1987*, p.53.
- [7] Küveler, G., 1983, Sol. Phys. 88, 13.
- [8] Raju, K.P., Srikanth, R. and Jagdev Singh: 1998, Solar Physics, 180, 47.

- [9] Robert, W. Noyes, *The Sun, Our star* (Harvard University press 1982)
- [10] Singh, J., Nagabhushana, B. S., Babu, G. S. D. and Wahab Uddin, 1994, *Solar Physics*, 153, 157
- [11] Srikanth, R., Singh J. and Raju, K. P., 1999, *Solar Physics*, 187, 1.
- [12] Srikanth, R., Raju, K. P. and Singh, J., 1999, *Solar Physics*, 184, 267
- [13] Zahn, J.P., 1987, *Solar and Stellar Physics*, eds. E. H. Schröter and M. Schussler (Berlin: Springer-Verlag) p.55.

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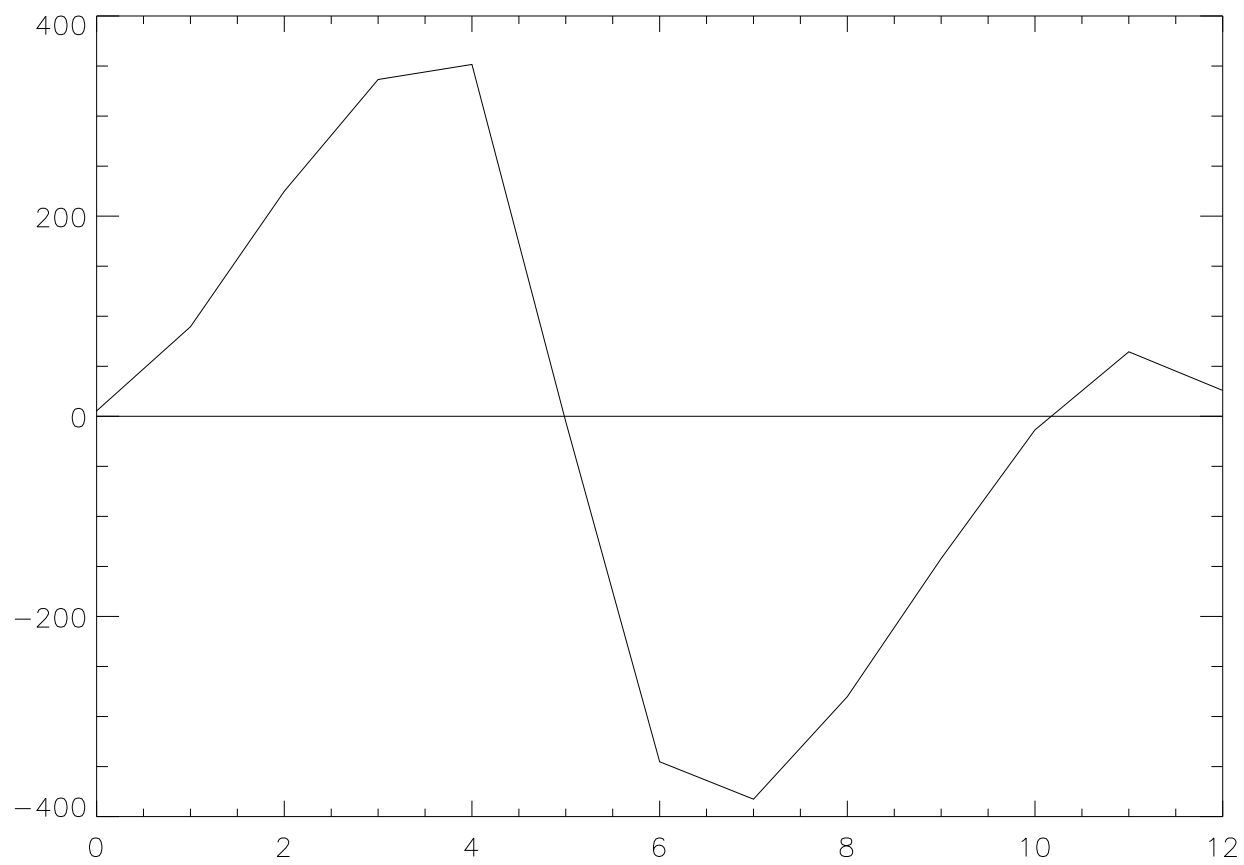


Figure 2: Profile of the line of sight velocity component  $v_L$  in  $ms^{-1}$  on the y-axis against cell extent  $x$  in pixels on the x-axis



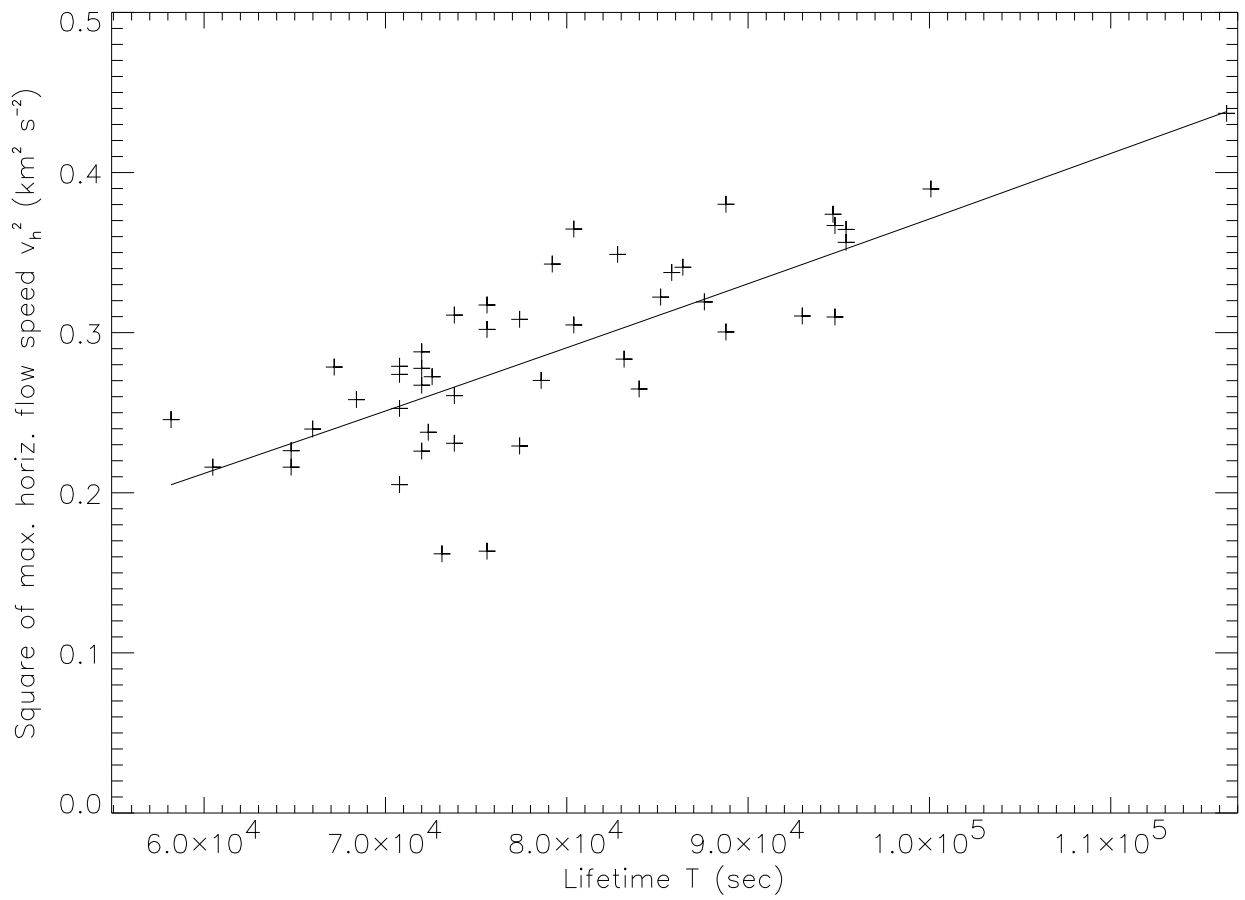


Figure 3: Plot of square of Peak horizontal velocity of the supergranular cell  $v_h^2$  against cell lifetime. The measured values are represented by the plusses. The line is based on a least squares fit to Eq. (1).

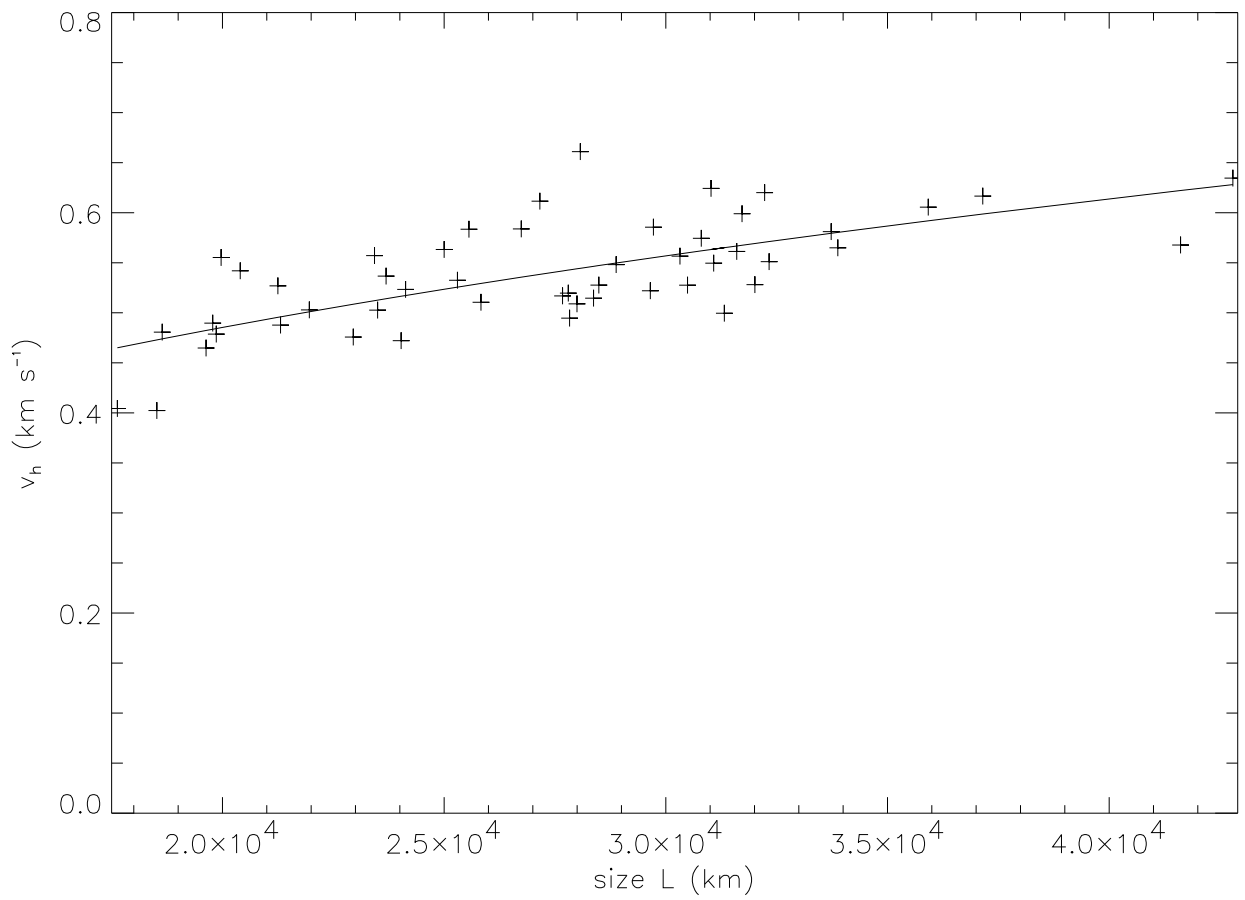


Figure 4: Plot of peak horizontal velocity  $v_h$  against cell size  $L$ . The measured values are represented by pluses. The line is based on least squares fit to the equation  $v_h = \epsilon^{1/3} L^{1/3}$