# Multi-Year CMOR Observations of the Geminid Meteor Shower

A.R. Webster • J. Jones

**Abstract**  The three-station Canadian Meteor Orbit Radar (CMOR) is used here to examine the Geminid meteor shower with respect to variation in the stream properties including the flux and orbital elements over the period of activity in each of the consecutive years 2005 – 2008 and the variability from year to year. Attention is given to the appropriate choice and use of the *D*-criterion in the separating the shower meteors from the sporadic background.

**Keywords**  meteor · orbital elements · radar · *D*-criterion

## 1  Introduction

Located near Tavistock, Ontario (43.26N, -80.77E) and operating at a frequency of 29.85 MHz, the three-station Canadian Meteor Orbit Radar (CMOR) has been in place for over a decade accumulating a considerable amount of data relating to meteor orbits, sporadic and shower (Jones et al, 2005). Here, observations of the Geminid meteor shower are used from an extended four year period (2005 – 2008) to cover the full range of solar longitude over which there is significant activity. The shower is known for its consistent return each year and the objective here is to look for variability in the waxing and waning stages in a given year and from year-to-year.

## 2  Observational Data

The radar is a back-scatter system and, aside from the occasional down-time for maintenance or weather events, operates continuously with a wide-angle all-round view of the sky. While sporadic meteors are widely spread in elevation and azimuth, the position of a detected shower meteor is governed by the shower radiant direction resulting in an effective "echo-line" on which the observed meteor lies (Kaiser, 1960). As the radiant rises, passes through transit and sets, the echo-line moves with it in a perpendicular fashion and with a minimum range which increases with the radiant elevation. As a result of this motion, the observed radar echoes move in range over the period when the radiant is above the horizon leaving a characteristic range-time "signature"; this is illustrated in Figure 1 for the Geminid shower. It will be noted that from the latitude of the radar site, this signature covers a total period of about 16 hours with a gap of about 3 hours centred on transit time.

In developing and applying the analysis routines, data from the year 2008 were first used over the anticipated period of significant activity, 251° to 267° in Solar Longitude (S.L.); the routines were then applied to the years 2005 – 2007 to complete the picture. The approach taken is illustrated in

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Figure 2. The first filter employed (rather generous) restrictions on the values of Right Ascension (*RA*), Declination (*Dec*) eccentricity (*e*) and semi-major axis (*a*). The final selection of Geminid meteors made use of the *D*-criterion.

The application of the first filter to the 2008 data is shown in Figure 3, where the "range-time" signature of the Geminids is apparent, as is the peak in shower activity around 261° S.L.
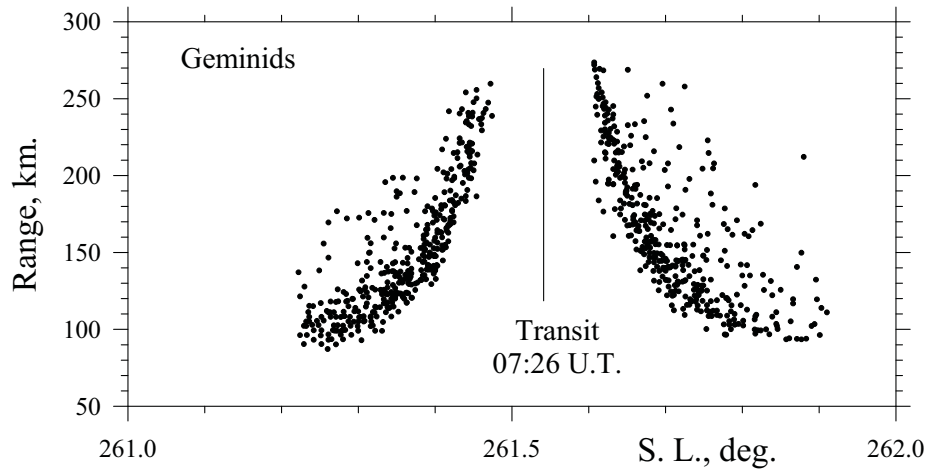


**Figure 1**. The "range-time" signature of the Geminid shower; the sharp minimum range will be noted.
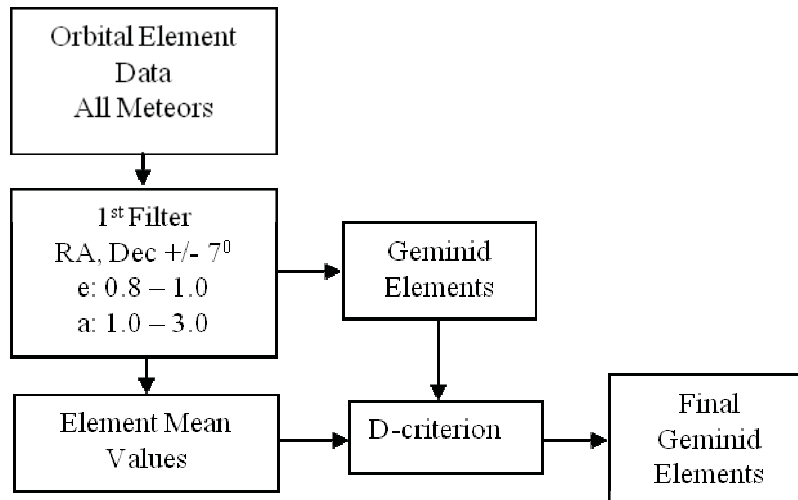


**Figure 2**. Extraction of Geminid meteors from the total observed.
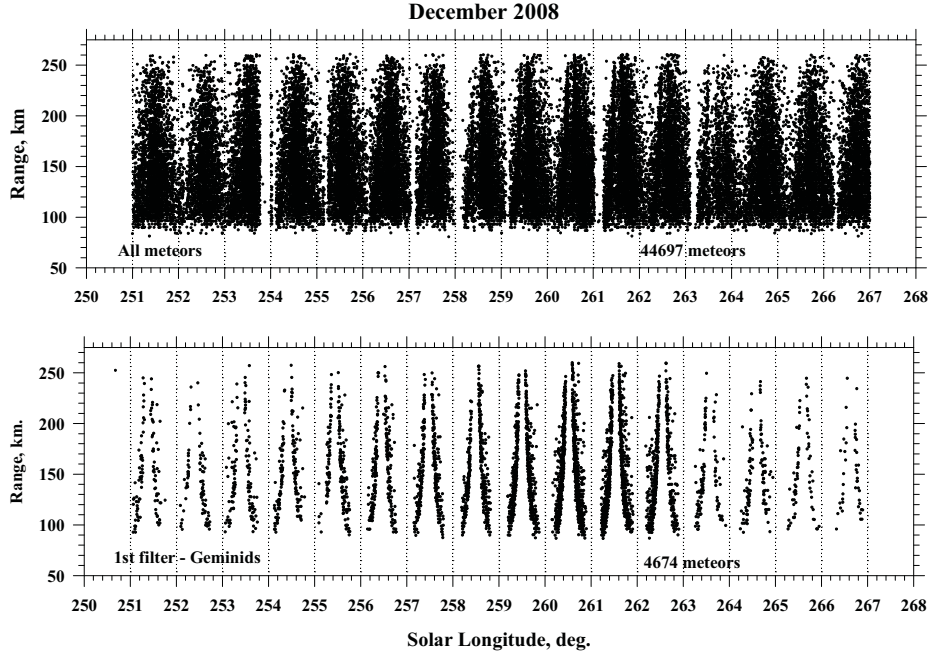
**December 2008**



**Figure 3.** Total observed meteor echoes over the period 251° to 267° in S.L. in 2008 (top) and those extracted by the 1st filter (bottom).

The limits imposed in this first cut were deliberately made fairly wide to ensure that a high fraction of the Geminids present were selected, in the expectation that some sporadic meteors would be included. With this in mind, the application of the oft-used *D*-criterion was thought to be appropriate in reducing this contamination. The three versions based on the 5 orbital elements, *q*, *e*, *i*, *ω*, *Ω* commonly used were examined; Southworth and Hawkins (1963), Drummond (1981) and Jopek (1993) shown below ($D_{SH}$, $D_D$ and $D_J$ respectively), i.e.,

$$D_{SH}^2 = (e_1 - e_2)^2 + (q_1 - q_2)^2 + \left(2\sin\frac{I_{21}}{2}\right)^2 + \left(\frac{e_1 + e_2}{2}\right)^2 \left(2\sin\frac{\Pi_{21}}{2}\right)^2 \tag{1a}$$

$$D_D^2 = \left(\frac{e_1 - e_2}{e_1 + e_2}\right)^2 + \left(\frac{q_1 - q_2}{q_1 + q_2}\right)^2 + \left(\frac{I_{21}}{180^0}\right)^2 + \left(\frac{e_1 + e_2}{2}\right)^2 \left(\frac{\Theta_{21}}{180^0}\right)^2 \tag{1b}$$

$$D_J^2 = (e_1 - e_2)^2 + \left(\frac{q_1 - q_2}{q_1 + q_2}\right)^2 + \left(2\sin\frac{I_{21}}{2}\right)^2 + \left(\frac{e_1 + e_2}{2}\right)^2 \left(2\sin\frac{\Pi_{21}}{2}\right)^2 \tag{1c}$$

where $\Pi_{21}$ and $\Theta_{21}$ involve *i*, *ω*, and *Ω*. Application in turn of these to the data from the 1st filter results in the *D* values shown in Figure 4. The reference values used for the orbital elements were the mean values of the accepted meteors except for the longitude of the ascending node where the solar longitude at the time of occurrence is appropriate.
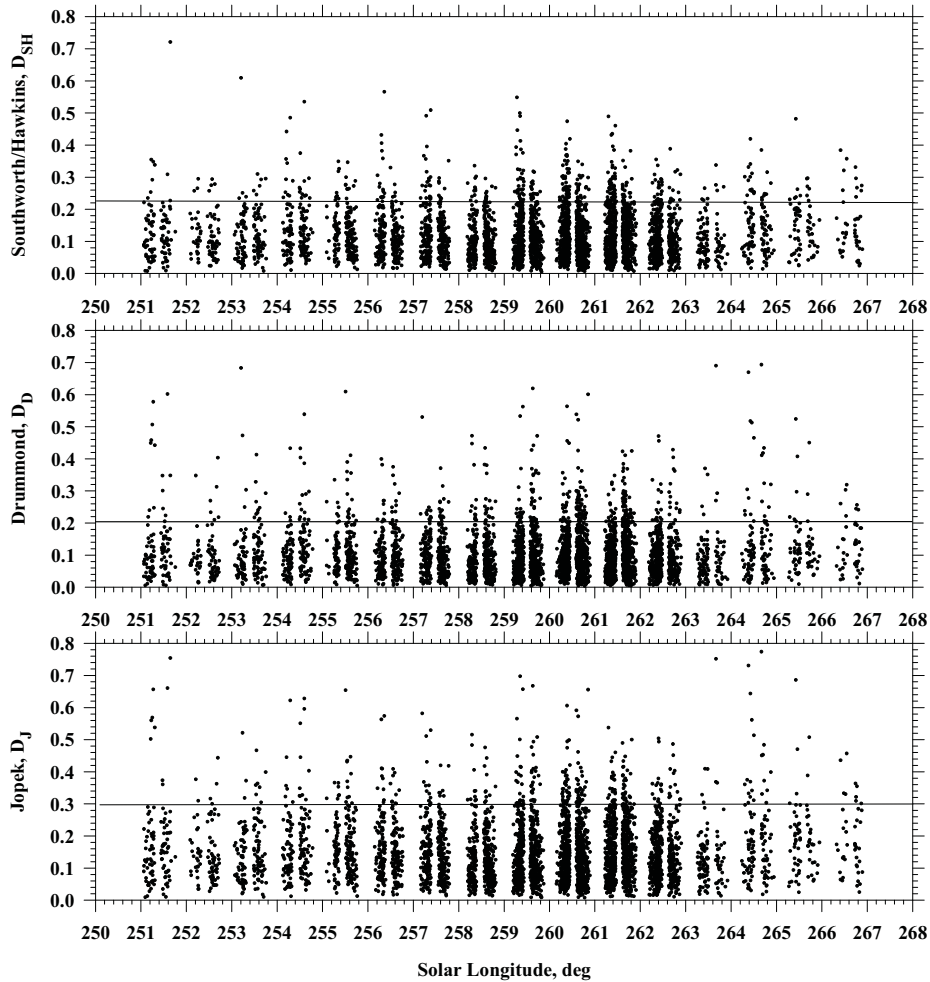
**Figure 4**. The *D*-criteria values as applied to the meteor orbital elements after the application of the 1st filter. The 90% cut-off values of $D_{SH} = 0.24$, $D_D = 0.21$ and $D_J = 0.30$ will be noted (see text and Figure 5.).

As can be seen in Figure 4, while the distributions are similar, the appropriate cutoff value to be used would be somewhat different. A better idea of this may be obtained from Figure 5 showing the differential and cumulative distributions for each of the criteria. In deciding what value of *D* to use for accepting the data, visual examination of Figure 4 suggests that at the time of the Geminid maximum, a significant number of shower meteors have *D* value higher than that normally used in this kind of application. Further, the waxing and waning of the activity in Figure 4 suggests that most of the meteors belong to the Geminid shower. Given the evidence in Figures 4 and 5, it was decided to apply a value of 0.21 to the Drummond data corresponding to the acceptance of ~90% of the meteors. This resulted in the reduction of presumed Geminids from 4674 to 4272 (Figure 6).

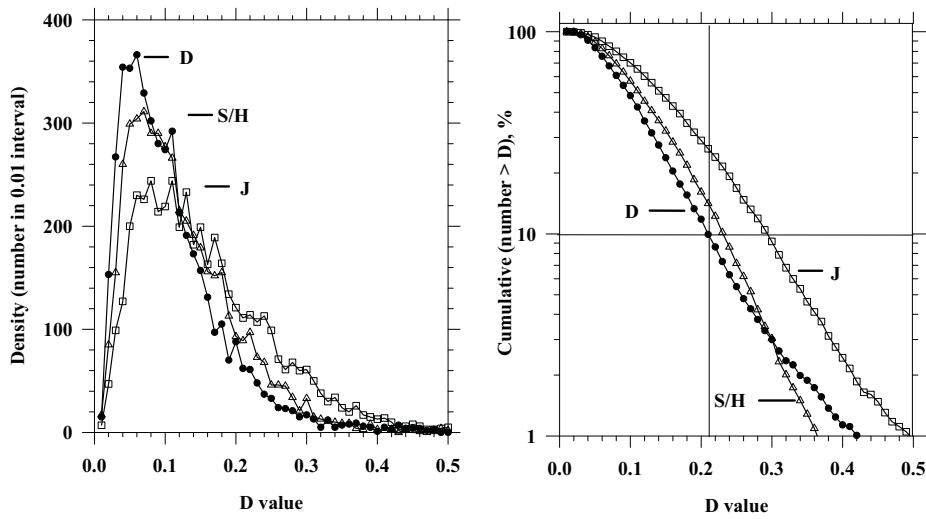**Figure 5**. The differential (left) and cumulative (right) distributions of the three *D*-criteria $D_{SH}$, $D_D$ and $D_J$.
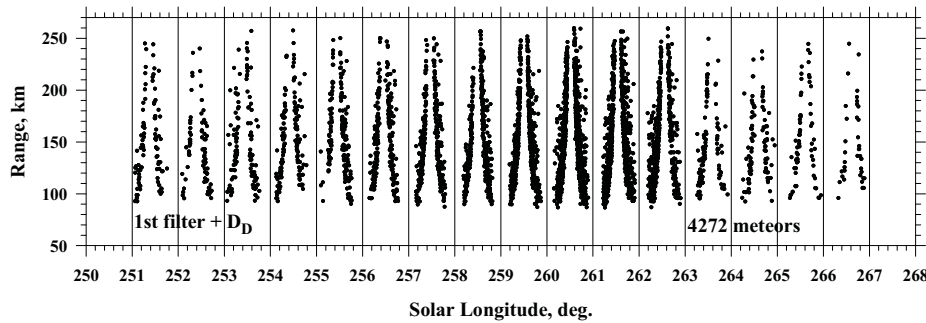


**Figure 6**. The range-time distribution of selected meteors after applying the 1st filter and the Drummond *D*-criterion with $D_D = 0.21$ cut-off (2008 data).

These remaining 4272 meteors in 2008 were assumed to represent a good estimate of the total observable Geminids with little contamination from other sources. The resulting echo rate, that is the total number of Geminid meteors seen by the radar over the period of significant activity, is presented in Figure 7, expressed in terms of the rate before and after transit and the total for a given night's observation. It will be remembered that the effective observing periods amounted to about 6.5 hours each before and after transit and the numbers presented represent a total for these periods.
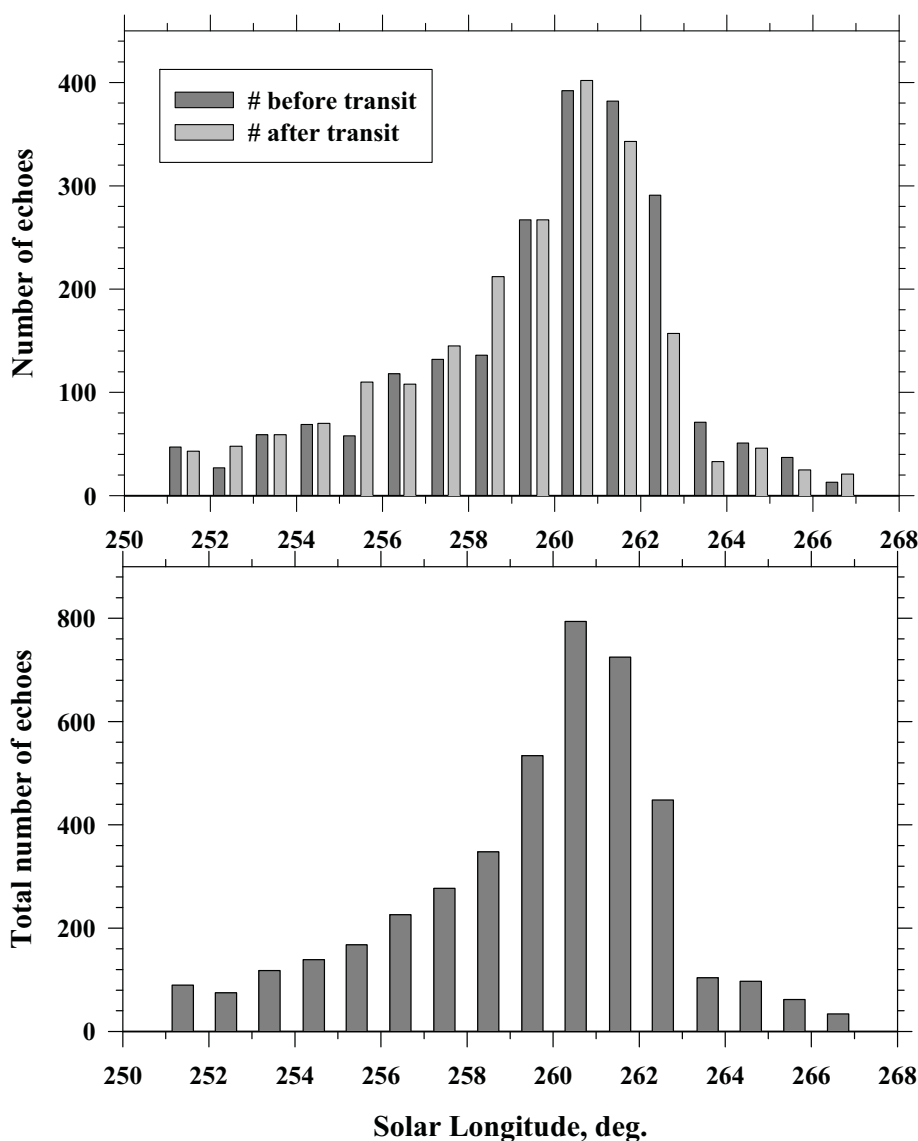
## Geminids, December 2008



**Figure 7**. The echo rate seen by the radar over the period of significant activity; the rate before and after transit (top) and the total rate for each night (bottom).

The same routines were then applied to the data from the years 2005-2007 and the results consolidated into the activity shown in Figure 8. Again, for clarity, the total results for each night also are presented here. Since the transit time repeats every year, the fractional 0.25 day in the year causes a regression in the transit about 0.25° in Solar Longitude from year-to-year resulting in the "filling-in" seen in Figure 8. The classic rise to a maximum at about 261° in S.L. followed by a rapid fall in activity is apparent with little in the way of fluctuations. The residual activity at both ends of the observing period appears to be genuine.
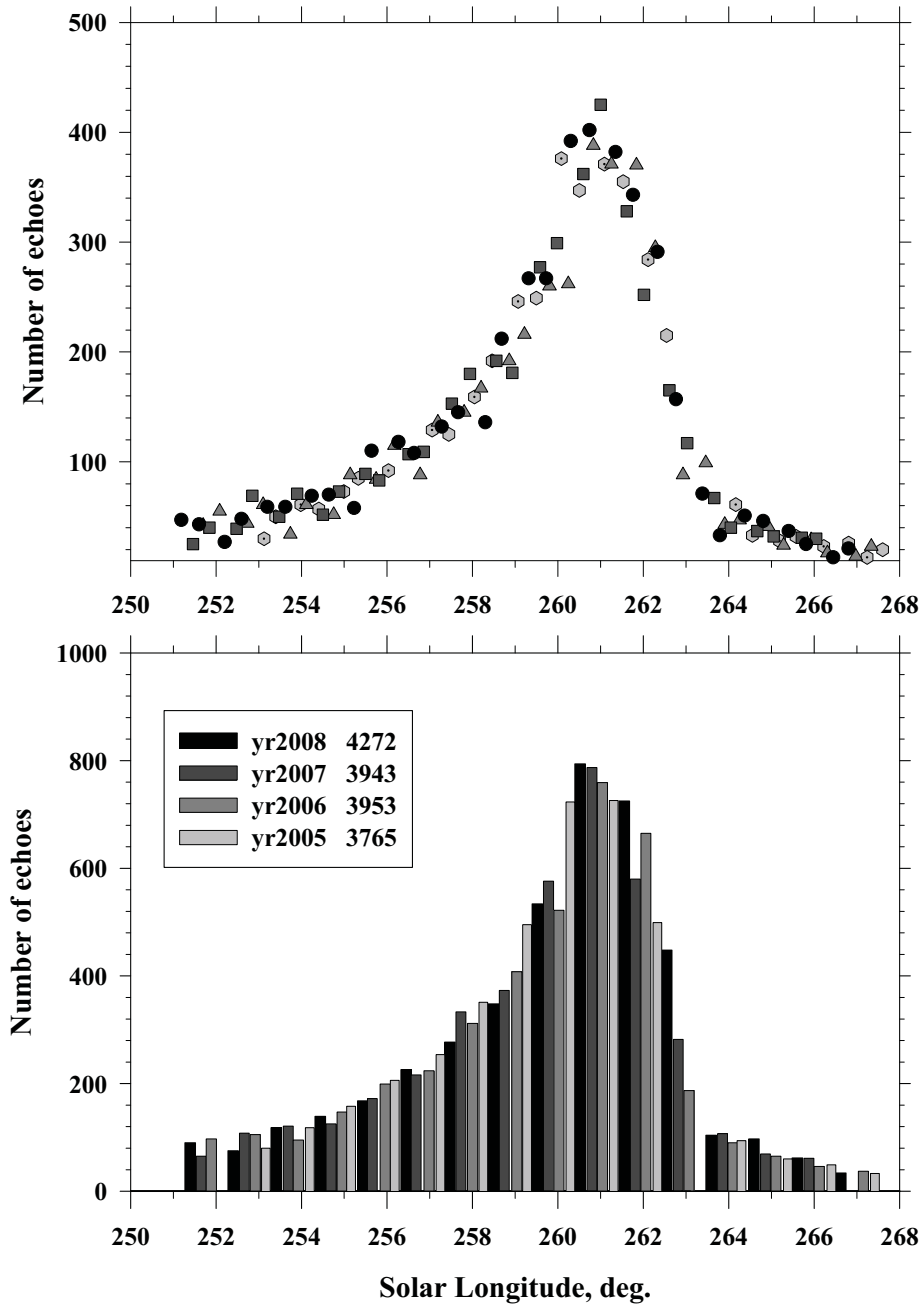
**Figure 8**. The activity of the Geminid shower over the four year period 2005 – 2008 showing: (top) the individual rates before and after transit; (bottom) the total number on a given night in each year for clarity.

The remarkable consistency from year-to-year is evident; it will be noted also that results are missing for 3 days in 2005, but were they available and in line with the trend, a further 200 or so would be added to the 2005 total.

The next step was to look at the variations in the various stream parameters including the orbital elements, velocities etc. All of these were available for each of the 15933 Geminid meteors selected, and linear regression was applied to plots of each parameter versus Solar Longitude. Examination of Figure 8 suggests that activity peaks at about $SL = 261°$ and this was used as the reference point. Figure 9 gives an example of this procedure showing the variation in orbital inclination. Similar results of this exercise for all the parameters are summarized in Table 1; the quoted uncertainties are standard errors.
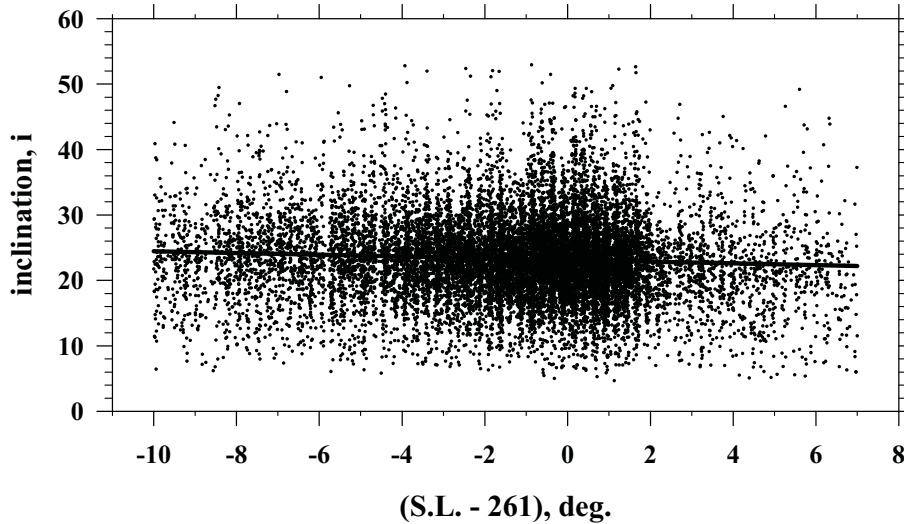


**Figure 9**. The variation in orbital inclination with Solar Longitude with $SL = 261°$ as the reference. The linear regression line is shown. All the 15933 selected Geminid meteors over the 4 year period are included.

**Table 1**. Mean Values and Variations with Solar Longitude
$y = b_0 + b_1 * (SL-261)$

| $y$ | $b_0$ | $b_1$ |
|---|---|---|
| Semi-major axis, $a$, AU. | $1.426 \pm 0.003$ | $+0.003 \pm 0.001$ |
| Eccentricity, $e$ | $0.8964 \pm 0.0003$ | $+0.0007 \pm 0.0003$ |
| Inclination, $i$, deg. | $23.13 \pm 0.05$ | $-0.13 \pm 0.02$ |
| Argument of perihelion, $\omega$, deg. | $324.9 \pm 0.04$ | $-0.06 \pm 0.01$ |
| | | |
| Right Ascension, deg. | $112.64 \pm 0.02$ | $+1.07 \pm 0.01$ |
| Declination, deg. | $31.93 \pm 0.02$ | $-0.18 \pm 0.01$ |
| | | |
| Geocentric, $v_g$, km/s | $34.35 \pm 0.05$ | $-0.02 \pm 0.02$ |
| Heliocentric, $v_h$, km/s | $33.79 \pm 0.04$ | $+0.01 \pm 0.01$ |

# 3  Discussion and Comments

The results presented here are part of the ongoing and continuous operation of CMOR over extended periods with stable properties. This allows confidence in comparative studies encompassing several years.  As with any such system, there are uncertainties in the measured quantities, but the extensive numerical data gathering properties of CMOR allow meaningful answers to be drawn.

Examining the data from a 4 year period, with separated samples before and after transit, allows ~ 8 samples per degree in Solar Longitude.  Although not entirely unexpected, the consistency of the flux of Geminid meteors from year-to-year is notable as are the relatively smooth variations from day-to-day. Given that, there is a suggestion of fluctuations in activity around the peak at $SL$ ~261° which may be consistent with the more frequently sampled results presented by Rendtel (2005) using visual observations. The residual activity at each end of the period in this study is believed to represent Geminid meteors; a separate study using CMOR suggests that such activity may extend from late November to early January (Brown et al, 2010).

The changes in the orbital elements over the duration of the shower are notably small. For example, given the evidence in the literature for decreasing magnitude distribution exponent, generally associated with the Poynting-Robertson effect, a more significant increase in the semi-major axis, $a$, might be expected as the Earth moves from the inside to the outside of the stream.

The $D$-criterion has been, and is, used extensively in looking for connections between bodies orbiting the Sun and the three versions considered here have been use with differing cut-off values depending on the observing system used. In his paper, Drummond suggested values of $D_D = 0.105$ and $D_{SH} = 0.25$ in linking meteor streams and parent bodies based on the visual, photographic and radar data presented by Cook (1973) and Marsden (1979). Williams and Wu (1993) used the Drummond version with $D_D$ again equal to 0.105. Galligan (2001) investigated the three criteria using the AMOR system in New Zealand and suggested a 90% recovery using $D_{SH} = 0.20$, $D_D = 0.18$ and $D_J = 0.23$. It might be remarked that different magnitude ranges can be involved in such studies which may influence the effectiveness; for example, AMOR has a limiting magnitude of around +13.5, CMOR of ~ +8.5 with visual and photographic usually brighter than ~ +6.0. We believe that the choice depends on the system, the interactions being studied and the quality of the data and that the use of $D_D = 0.21$ is appropriate here.

A further version of the $D$-criterion was introduced by Valsecchi et al (1999) which has found much favour in some applications. Instead of using the five orbital elements for comparison, the geocentric velocity (speed and direction in Earth oriented coordinates) is used. This is particularly useful when the data is available as direct, rather than derived, measurements. In the case of CMOR, all of the elements are derived from interferometric and time-delay measurements, though we are looking into this approach and developments. It is noted that Galligan (above) also considered this method and found it to be comparable and preferable in some circumstances.

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