

Traditio et Innovatio



Bachelor's Thesis

At Leibniz-Institute of Atmospheric Physics at the Rostock University

Investigation of meteor decay times at different frequencies

above Juliusruh (54.6°N, 13.4°E)

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1. Introduction

From the beginning of mankind the sky was a matter of particular interest. Its phenomena played an important role in several religious embodiments and cultural developments as well as in improving agricultural abilities and seafaring by creating and improving a first predecessor of weather forecasts. The whish for observation and understanding of the sky and its processes was omnipresent. Nevertheless studying the sky is a task field nowhere near completed. The cause for the enduring lack of information about the atmosphere was the absence of technical possibilities of investigation. Not before the invention of techniques for digital data capturing it was possible to find several methods to determine the chemical composition, dynamical properties, structure characteristics and other features of the atmosphere which can be used to find new ways of observation.

The earth's atmosphere is accepted as a 500 km thick layer of gas mainly consisting of nitrogen, oxygen, argon and carbon dioxide. The exact allocation of these gases varies with altitude, and even properties like chemical bonding can differ in special heights as seen in case of the usually diatomic oxygen molecules which are converted to ozone triplets and affect the absorption of radiation considerably. This and other effects lead to a model concept of the atmosphere based on the temperature profile as follows:

Assumed is a four-layer-system as shown in Figure 1.1 and supplemented by the temperature profiles and the zonal wind profiles. The first layer is the troposphere reaching from the ground to an altitude of about 15 km. This region is characterised by a negative temperature gradient and the highest densities of atmospheric gases due to pressure and gravitation. Especially the incidence of aqueous vapour lays almost completely in the troposphere and causes that weather mostly takes place in this region. This states a problem for some observation methods, for example for LIDAR-systems which base on light pulses. These pulses would be nearly completely reflected or absorbed by clouds. An investigation of higher layers would not be possible continuously.



Fig. 1.1 Scheme of the atmosphere's layer structure added by temperature profiles and zonal wind profiles as well as typical technical objects and phenomena per altitude (Courtesy of G. Stober)

The second zone is the stratosphere covering a height range from 15 to 50 km. Due to the incidence of Ozone and its UV-absorbing character in this layer the temperature increases with altitude in higher regions. Also the velocities of zonal winds increase with height. For the investigation of regions up to this layer balloons are suitable since they are independent of weather and ,until they burst, collect data almost continuously which allows detailed profiles of for example temperature, wind, pressure, composition and others.

The area between 50 and 90 km of altitude is called Mesosphere. Its main feature is a strongly negative temperature gradient which causes a temperature minimum of the whole atmosphere in the range of the upper mesosphere. A very peculiar fact is that the temperature during summer season is lower than in the winter months. This distinguishes the mesosphere from all other layers. The Temperature drop during the mesospheric summer enables the formation of phenomena, for example ice clouds also known as noctilucent clouds (NLC) which can be used to observe winds and turbulences. Furthermore meteors usually occur in the range of the upper mesosphere and lower thermosphere. The properties of meteors and the possibility to use them for atmospherical studies will be elucidated hereafter. Induced by the dust particles which originate from the decay of meteoroids many cloud condensation nuclei are present here to facilitate the formation of NLC as Singer et al (2003) described.

The last layer is the thermosphere. It is covering the height range from 90 to 500 km of altitude. Due to unfiltered cosmic radiation and solar activities very high temperatures occur in this layer. But as a result of the low density gas molecules almost do not collide. Above 500 km the exosphere borders to the thermosphere. It is assumed as transition between the atmosphere and space.

The methods of observation which were mentioned represent only an exemplary selection of possibilities, which can be used for investigation appropriate to their profits and disadvantages. Furthermore it is possible to combine methods or locations to compare the findings, improve their results and optimally use their merits to minimise mistakes such as for example Singer et al (1994), Singer et al (2005b), Hocking et al 2002 und Hocking et al 2004 have shown.

The Method that shall be the core of this thesis is the observation via meteor radars. It can be used in the upper mesosphere and lower thermosphere. Especially the role of the radar frequency shall be determined that cause differences in the results of measurement as McKinley (1953) and (1954) described.

For the Investigation two meteor radars in Juliusruh on the island Rügen in Germany are used. Their parameters are summarised in Table 1.



Fig. 1.2 Map of locations in Mecklenburg: IAP Kühlungsborn (green), University of Rostock (violet) and Juliusruh meteor radar (orange) (http://maps.google.de)

Geographical location	54,6°N, 13,4°E
Range	70-110 km
Transmitting power	12 kW
Frequency	32,5 MHz respectively 53,5 MHz
PRF	2144 Hz
Pulse width	13,3 µs
Height resolution	2 km

 Tab. 1 important parameters of the Juliusruh meteor radars

2. Meteors

As meteors we denote the luminous effects that occur when particles of various sizes enter the earth's atmosphere, just like Unsöld and Baschek (2005) suggested. The causing particles are known as meteoroids and vary not only in size but also in chemical composition and origin. Meteoroids that do not burn out completely in the atmosphere and reach the ground are called meteorites.

When a meteoroid enters the atmosphere an almost cylindrical plasma-channel is formed behind the object. The luminous effect, a so called visible meteor, only occurs when the causing object's size exceeds a particular value, like Singer et al (2004) remark and furthermore suggest denoting the plasma trail itself as meteor, independent of the presence of a luminous effect. All meteors decay after a few seconds by diffusion.

The plasma-channels are characterized by outstanding properties in reflecting electromagnetic waves and therefore are suited very well for investigations via radar systems.

Based on the radar echoes that were recorded two typical kinds of meteors can be distinguished. Their properties were summarised by Stober (2009) as follows and before they were used by Hocking et al (2001) to filter their detected signals:

Underdense meteor echoes are characterized by a leap in signal amplitude that is caused by the sudden formation of the plasma-channel. Subsequently a rapid decay follows. Generally underdense meteors have only one peak with the amplitude A_0 .

A typical behaviour of underdense meteor echoes is shown in Figure 2.1.

The decay of a meteor that is forced by diffusion was described by Mckinley (1961) and Hocking (1999) as follows:

$$A(t) = A_0 e^{-(16\pi^2 D_a t)/\lambda^2} = A_0 e^{-\ln 2 t/\tau}$$
(1)

Here D_a is the ambipolar diffusion coefficient, t is time, λ is the radar frequency and τ is the time in which the signal amplitude drops to A₀/2. Hereafter it is called decay time. It is frequency-dependent and covers a range of 0.001-0.5s for frequencies between 30 and 50 MHz according to Hocking (1999).



Fig. 2.1 Example for a measured underdense meteor echo from Collm Meteor Radar (51.3° N, 13°E)



Fig. 2.2 Example for a measured overdense meteor echo from Collm Meteor Radar (51.3° N, 13°E)



Fig. 2.3 Example for a measured overdense meteor echoes from Collm Meteor Radar (51.3° N, 13°E)

On the contrary overdense meteors have no clear peak. After the first jump of the signal amplitude random peaks with varying amplitudes can occur for several seconds like it is shown exemplary in Figure 2.2. It is also possible that the amplitude further increases after the first jump an decreases much slower than an underdense meteor echo would. This behaviour is shown in Figure 2.3.

For further investigations and analyses only underdense meteor echoes are used because of their clear structure. Starting from equation 1 the term for the ambipolar Diffusion coefficient

$$D_a = \frac{\lambda^2 \ln 2}{16\pi^2 \tau} \qquad (2)$$

can be deduced and used to compute other physical values like volume density according to McKinley (1961) or temperature and pressure according to Hocking (1999).

Furthermore the reconstruction of the origin is conceivable by measuring the radiant and the velocity during the entrance. This is the way how a cometary origin of several meteors is found as Unsöld and Baschek (2005) describe. Another possibility is the emergence of meteoroids as fragments from collisions in the planetoid belt, which now circulate around the sun on elliptic orbits.



Fig. 2.4 Example for detected Meteors during the year 2011 from Juliusruh Meteor Radars at frequencies of 32.5 MHz and 53.5 MHz

Generally one differentiates between sporadic meteors and meteors in a shower. These distinguish mainly by their count rates and origins. While sporadic meteors usually occur time independent and randomly, meteor showers which are named by the constellation that is closest to their radiant, have fixed time intervals in which they appear for example the Quadrantides that occur in early January, the Perseids that appear in July and August or the Geminides that are detected in December.

Showers like this play an important role for the number of applicable meteor echoes per day just like they are shown in Figure 2.4. for the two meteor radars in Juliusruh. In both cases you can see local maxima in January and December and also during the summer season. The minimum is found in February. This behaviour was already described by Singer et al (2004) and Singer et al (2005b). Conspicuous is the fact that the count rate of the radar array measuring with 32.5 MHz is generally higher than the one measured with 53.5 MHz. This can be explained by the frequency dependence of the effective back scattering cross section, which allows lower frequency systems to detect echoes from very small particles.



Fig. 2.5 Height profile in dependence of the used frequency from Juliusruh Meteor Radar

The height range in which meteors are expected strongly alternates in literature. While Jones et al (1998) suggested a range from 80 to 120 km Hocking et al (2001) assume a range from 70 to 110 km. Singer et al (2008) indicate a range from 70 to 120 km. In every case the maximum count rate is expected at a height of about 90 km. Singer et al (2003) specify a frequency dependence here which announces a maximum count rate at 90 to 91 km of height for 32.5 MHz and one at 88 to 89 km of height for 53.5 MHz. The measurements at Juliusruh in 2011 have confirmed this assumption as can be seen in Figure 2.5 which shows the undifferentiated annual average.

Considering the time dependent height profile, as shown in Figures 2.6 a and 2.6 b, fluctuations can be seen which are marked especially for 32.5 MHz. This leads to the assumption that the causing effects have a bigger influence on smaller particles. Especially the lower altitude during the summer months, forced by for this altitude typically low temperatures, is conspicuous. Another conspicuity to mention is a short anticlimax in the beginning of the year which is also forced by temperature fluctuations in the mesosphere as response of a stratospheric event called "sudden stratospheric warming" or SSW which was investigated by Stober et al (2012). In both cases the lowparticle motion cause the absent of collisions which are necessary to build a plasma channel.



Fig. 2.5 Number of Meteors per day and height divided by the sum of all Meteors dependent of the Frequency measured at Juliusruh with a Frequency of a) 32,5MHz and b)53,5MHz

3. Meteor Radars

3.1 Basics

Radar is the abbreviation for "<u>Ra</u>dio <u>detection and ranging</u>" and describes a method which bases on transmission and reflection of radio waves. For this an antenna sends short regular pulses, known as primary signals below, which are reflected by suitable objects in the atmosphere and detected by receiver antennas as secondary signal. In case of a meteor radar the required reflector is a meteor trail.



Fig. 3.1 Scheme of the functionality of meteor radars (Stober 2009)

The receiver is always built of a number of antennas. This is necessary to get additional information about the localization of the reflector besides the information from the secondary signal itself just like the amplitude A_0 or the decay time τ . For this the antennas are always linked to the processing unit with equally long wires to allow the information packages to reach the computer temporally correct to be evaluated.

From duration of the signal and phase differences between the signals from two receiver antennas conclusions can be drawn about distance, elevation and azimuth of the reflecting object.

3.2 Hardware

The system that is used in Juliusruh is a SKiYMET all sky meteor radar, a commercial form of the radar interferometer that was introduced by Jones et al (1998). The reason for this construction is the necessity of at least three receiving antennas to estimate angles and distances. To minimise the mistakes of the results the distance between these antennas must amount several wavelengths which raises the probability of ambiguities. These can be reduced by installation of additional antennas with a distance of $\lambda/2$.

To optimise the accuracy of the construction a linear interferometer was suggested, that consists of three antennas in distances of 2λ and 2.5λ . The technical implementation intends a cross of two linear interferometers sharing the same central antenna like it is schematically shown in Figure 3.2. Since an angle can be determined with every combination of two antennas a very high accuracy can be reached. The usually used form of receiving antennas is a two-element Yagi antenna. As transmitting antenna, which is mostly located a few meters apart from the receiver, a three-element Yagi antenna is used.



Fig. 3.2 Schematic Construction of the interferometric antenna field (Hocking 2001)

The advantage of the SKiYMET –system is the possibility to observe the upper hemisphere almost completely. Figure 3.3 shows a generic distribution of angular locations of meteors measured above Juliusruh during one day at 32.5 MHz. An almost homogenous distribution over the azimuth can be seen.



Fig. 3.3 Angular location of detected meteors of one day from Juliusruh Meteor Radar (54.6°N, 13.4°E) at a frequency of 32,5MHz

But the Figure shows some rings of lower countrates in dependence of elevation. These only show after exclusion of meteor echoes with an ambiguity bigger then one and are a result of the chosen pulse repetition frequency of the radar.

To prohibit ambiguous attributions the pulse repetition frequency must be adjusted to the duration of the signal. For the duration perpendicular to earth's surface is valid:

$$t = \frac{2h}{c}$$
(3)

Here is h the height and c the velocity of light in medium. As an example h is assumed as the average height of a meteor (90 km). This results in the duration of

$$t = \frac{2 * 90km}{300\ 000\frac{km}{s}} = 600\mu s$$

If the pulse repetition frequency is chosen bigger than the required maximum frequency just like it occurs in Juliusruh, as can be referred in table 1, it is possible that secondary signals can be matched to more than one primary signal in dependence of phase shift and duration. That is why all meteors are parameterised with an "Ambiguity" which is consistent with the number of possible positions and allows easier filtering processes like they are described below.

3.3 Signal Sorting and Processing

As a result of several confounders and phenomena as well as technical properties of the radar system and other sources of uncertainties it is necessary that the collected data must be filtered before it can be analysed. Based on the properties of the preferred meteor echoes methods for discrimination and processing of these data sets are developed, which can be implemented autonomously by a processing unit in the measuring station after the measured data was digitalized. For this reason SKiYMET was equipped with a computer that processes the data as shown in Figure 3.4.

The specific steps of filtering Hocking et al (2001) described in two routines like it is described below:

The first method of processing consists of six steps which shall be implemented after another.



Fig. 3.4 Scheme of the processing software (Hocking 2001)

The **first step** is for preparation. It entails averaging the in-phase and quadrature components in so called time bins by computing a coherent integration over two to four time steps.

The mean value that was obtained in step one can be used in **step two** to average the amplitudes of the signals detected by each of the five receiving antennas coherently. These can be compared with the mean values of the previous time steps. Since a leap in amplitude is expected from a meteor echo it is in all probability that a secondary signal originates from a meteor that exceeds the usual fluctuations by a factor that is chosen manually. Furthermore the leap time should not last more than 0.3 seconds.

The **third step** uses the ephemerality of underdense meteor echoes. Here it is proved whether the amplitude sinks to noise level within 3 seconds.

The **fourth step** is made to examine whether the amplitude rises again after sinking back to 30% of the maximum value. As criterion a value of 70% of the highest amplitude is assumed. Properties like this are not known from underdense meteors. The signals will not be considered.

Step five is used to compare all antenna pairs to each other. For this the crosscorrelation functions are computed and examined regarding the phase's alteration rate. If this is rather small the probability that the echo origins from a meteor is very high. In this step assumedly all non-meteor echoes are rejected, even though some of the weak meteor echoes are eliminated, too.

The **sixth step** finishes the procedure. Here the data are saved in files that include an interval of 4 seconds where the highest value is reached after exact one second. The last 3 seconds show the decay of the meteor echo.

The files from step six are now committed to another routine as foundation for further processing. This is focused on refining the selection criteria for meteor echoes and restricting the selection of relevant signals. Furthermore it prepares the data for subsequent investigation and calculates physical values that are needed for interpretation of these signals.

Among others the system provides the reflector's localisation with azimuth, elevation, range and height as well as the maximum amplitude in relative units, a signal-to-noise ratio and the decay time of a signal. Furthermore it matches the moment of detection with date and time and an internal identification number.

4. Results

At centre of attention during the investigation that underlay this thesis stood the observation of decay times of meteor echoes that were detected above Juliusruh in the year 2011.

The plot of logarithmised daily mean values of decay times per kilometre of altitude in the range between 70 and 105 km (Figures 4.1 and 4.2) show quite similar run for both transmission frequencies, where longer decay times occur in a range that sinks in February, again as result of SSW that was mentioned in chapter 2 before, and rises during spring time. For 32.5 MHz this layer has a thickness of 15 to 20 km in the beginning of the year which shrinks to 10 km during summer and broadens again in autumn. For measurements with 53.5 MHz one can see that the layer of longer decay times is thinner compared to the measurements with 32.5 MHz and the mean decay times are much smaller. For both systems it can be seen that the maximum decay times decrease during summer months.

For a better comparability the average decay times per kilometer of altitude measured with 53.5 MHz were divided by the results from the 32.5 MHz-system and the quotients are plotted again in dependence of height and time. The result is shown in Figure 4.3. Since quotients bigger than one appear only sporadic and without correlation these can be left out as outliners and the Figure 4.3 proves again that longer decay times are observed with systems of lower frequency. This was expected with regards to equation (2) which produces:

$$\tau = \frac{\lambda^2 \ln 2}{16\pi^2 D_a} \sim \frac{1}{f^2}$$
 (4)

For the division of decay times measured with 32.5 MHz and 53.5 MHz is valid:

$$\frac{\tau_{53}}{\tau_{32}} = \frac{D_{a32} * f_{32}^2}{D_{a53} * f_{53}^2} = 0.369 * \frac{D_{a32}}{D_{a53}} \tag{5}$$

Thus the Figure 4.3 shows the dependence of the ambipolar diffusion coefficients' quotient from height and time, too. The area with the biggest quotients lies in winter beyond 82 km of altitude. This area rises in summer by about 5 km.



Fig. 4.1 Decay times of meteor echoes binned per day and km of altitude from Juliusruh Meteor Radar at 32.5MHz



Fig. 4.2 Decay times of meteor echoes binned per day and km of altitude from Juliusruh Meteor Radar at 53.5MHz

Above this area there is a belt of continuously small values which reaches its maximum expansion in spring and autumn when it reaches to an altitude of about 100 km. This range constricts rapidly during summer months. Above this minimum belt values between 0.6 and 0.8 are reached again but occur randomly.



Fig. 4.3 Quotient of decaytimes measured with 32.5MHz and 53.5MHz binned per day and km of altitude from Juliusruh Meteor Radar

Beneath the area of maximum values randomly distributed local minima and maxima can be recognised that appear to be outliners and not of importance.

Furthermore local minima that occur in the belt of minimum values attract attention. These appear in winter spring and autumn at regular intervals in a height up to 94 km. The regularity of these minima adverts to atmospheric waves with long wavelength. Further the numbers of detected meteor echoes per height and decay time were summed up for each month of the year 2011 and divided by the number of all meteor echoes of that month. The results of this calculation are shown in Figures 4.4 to 4.8 assorted by season.



Fig. 4.4 detected meteor echoes per height and decay time during early winter season from Juliusruh Meteor Radar at 32.5MHz on the left-hand side and 53.5MHz on the right-hand side



Fig. 4.5 detected meteor echoes per height and decay time during spring season from Juliusruh Meteor Radar at 32.5MHz on the left-hand side and 53.5MHz on the right-hand side



Fig. 4.6 detected meteor echoes per height and decay time during summer season from Juliusruh Meteor Radar at 32.5MHz on the left-hand side and 53.5MHz on the right-hand side



Fig. 4.7 detected meteor echoes per height and decay time during autumn season from Juliusruh Meteor Radar at 32.5MHz on the left-hand side and 53.5MHz on the right-hand side



Fig 4.8 detected meteor echoes per height and decay time during december from Juliusruh Meteor Radar at 32.5MHz on the left-hand side and 53.5MHz on the right-hand side

For all pictures a typical structure can be recognised that reminds of an obtuse triangle. In higher regions one can find rather short decay times. Intermediate and long decay times occur only in lower areas. Used are Meteors that were found between 80 and 105 km of altitude and decay times smaller than 0.15 seconds.

Comparing the number densities dependent on the frequency one can see a relatively broad distribution over τ for the smaller frequency while the number density for the bigger frequency concentrates on a smaller area. Especially the maximum values make this point clear very well. These can be determined as $1.3*10^{-3}$ for 32.5 MHz and $1.7*10^{-3}$ for 53.5 MHz. Again it can be seen that there are more events detected in higher regions with the 32.5MHz-system then with the antenna field using 53.5 MHz.

Furthermore the count rates were observed during the course of the year. In the beginning of the year for both cases a relatively small area was observed in which the count rates per bin are rather high. These spread during February and allow more events with long decay times at low altitudes.

During spring the count rates broaden and the most frequented bins reach a minimum of values in Mai. This allows a small rise of values in other areas, especially in those with lower altitudes.

During summer and autumn the area of high number densities reduces again so the number of events here rises again. Especially the number of events with short decay times increases. The area of long decay times is vacated and the maximum altitude in which many events are found rises until winter.

5. Outlook

With the help of the found results profiles can be computed for diffusion temperature and pressure among others. The long-dated observation and comparison with the results of other locations for meteor radars just like with the results from other methods of measurement are of major importance to improve the methods and reduce mistakes. The advancement of techniques for analysis has begun as important ideas like binning by Hocking (2002) have shown and still it is pushed further for a better comprehension of the atmosphere.

A. Appendix

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Declaration of own work

With this declaration I confirm that the presented work was done by myself and unassisted. I further certify that all the used sources and materials are cited according to the scientific regulations of publishing.

Rostock, 21.10.2013

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