A comparison of automated-search meteor results from radar observations at the Poker Flat Incoherent Scatter Radar, Sondrestrom, and Arecibo

S. J. Briczinski[1], J. D. Mathews[2], D. D. Meisel[3], and C. J. Heinselman[4]

[1]Department of Physics, University of Wisconsin-Madison, Madison, WI 53706, USA

[2]Department of Electrical Engineering, The Pennsylvania State University, University Park, PA 16802-2707, USA

[3]Department of Physics, SUNY-Geneseo, Geneseo, NY 14454-1401, USA

[4]SRI International, Menlo Park, CA 94025, USA

Abstract

While much progress has been made in understanding the radio science and meteor physics implications of meteor "head-echoes" observed with high power, large aperture (HPLA) radars, issues remain due to different analysis techniques employed. We address these issues via employing the same analysis technique to meteor observations from the Poker Flat, Sondrestrom, and Arecibo radars. We present and compare sporadic meteor parameters and in so doing observe an altitude "ceiling effect" in the 1290 MHz results relative to the 430/449.3 MHz results. We also present the first observed seasonal altitude variation from a HPLA radar.

1. Introduction

Observations of sporadic radar meteors have been of increasing interest to the scientific community as the role of meteoroids in space weather, in the aeronomy of the meteor zone, and in various aspects of the plasma physics and radio science surrounding the meteoroid interaction with the atmosphere becoming increasingly apparent [1, 2]. Additionally, the near-earth meteoroid flux can have great impact on satellite lifetimes [3] as well as contributing significantly to the metallic composition of the upper atmosphere and ionosphere [4, 5].

Because observations at different locations use different detection methods, pooling the data to determine an overall correlation between observed meteor returns and radar frequencies is difficult. To minimize discrepancies between radar facilities, we have applied the same automated FFT searching technique used at the Arecibo Observatory (AO) [6, 7] to the observations at the Sondrestrom Research Facility (SRF) and the Poker Flat Incoherent Scatter Radar (PFISR). This routine provides a low threshold for false positives (<1%) while still identifying events with signal to noise ratios below unity, maximizing the number of events positively identified.

These three facilities were chosen for our study for several reasons. The incoherent scatter radars at PFISR and SRF can be set up with observation parameters similar to that at AO. The two facilities are widely different in frequency but have similar latitudes, which maximizes the frequency variation of our results while minimizing possible spatial (latitude) dependency. In this paper we compare the observation characteristics between the three radars. The results presented from PFISR and SRF are the first reports of altitude and Doppler measurements from campaigns at these facilities and are thus unique. For PFISR these also the first meteor campaigns at the facility. We also uniquely apply the same automated searching algorithm to the observations to maximize similarities in the data sets. We then compare the meteor parameters observed at the various radars to provide further insight into the head-echo scattering theory.

2. Observations

As stated in the introduction, observed meteor parameters are seasonally varying [8]. Consequently, our goal was to conduct meteor observations within the same few weeks during the calendar year to minimize this source of variation. Micrometeors were observed over the course of two mornings on 31 July 2005 and 04 August 2005 using the zenith-pointed SRF 1290 MHz radar system at ~2.6 MW peak transmitting power. Each observation window lasted approximately four hours, 0400-0800 local time (LT). A 82 μs uncoded pulse was used with an inter pulse period (IPP) of 3.3 ms. (The 3.3 ms IPP is commonly used at SRF to accommodate increased ranges for low elevation observations, the details of which will be presented in a later paper.) The receive window was open for a time period corresponding to radial distances between 75.5 km and 170 km with a sampling rate of 1.25 MHz (0.8 μs sampling) on the first day and 2 MHz (0.5 μs sampling) on the second day. The variations in sampling rate did not produce any noticeable differences in the sporadic meteor returns and will not be mentioned in the remainder of this paper. In order to avoid aliasing the Doppler returns, the 1 MHz receive window was centered at 1290.3 MHz.

Our PFISR results are composed of two days of morning observations on 01 and 02 August 2006. The Poker Flat radar was operating at 449.3 MHz at ~0.5 MW peak transmitting power. As with our SRF observations, each observing window was composed of four hours from 0400-0800. In both instances this time period was chosen to be centered around local dawn at lower (non-polar) latitudes, thereby maximizing the sporadic meteor event rate [9]. The PF AMISR-32 beam was pointed 9 degrees off of zenith due North. A 50 μs uncoded pulse was used with an IPP of 1 ms.

Micrometeors were observed for a two hour period (0500-0700 LT) in August 2004 using the zenith-pointed Arecibo 430 MHz radar system at ~1.8 MW peak transmitting power. A 45 μs uncoded pulse was used with an IPP of 1 ms. The receive window was open for a time period corresponding to radial distances between 85 km and 122 km with a sampling rate of 1 MHz (1 μsec sampling). At all of the facilities the received "head-echo" pulses were Doppler shifted due to the 10-70 km/s meteoroid speed. Doppler speeds were obtained by fitting a complex exponential to the returned voltages, resulting in instantaneous (single-pulse) measurement errors on the order of 100 m/s [7].

3. Results and Discussion

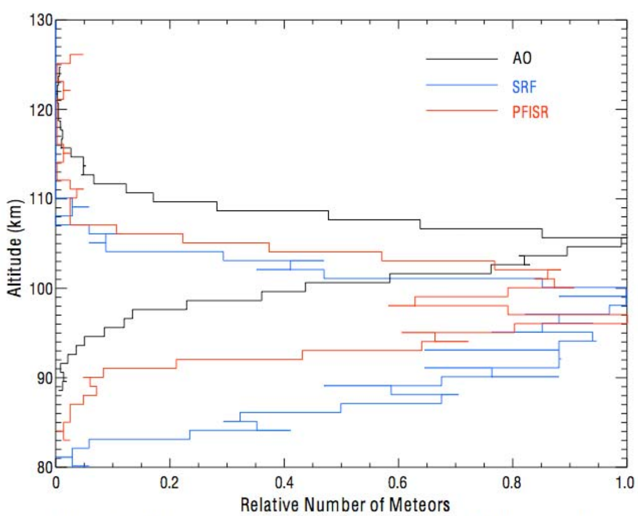

Figure 1. Meteor altitude distributions for all three radars.

Through the 8 hours of observation, a total of 271 events were detected at SRF and 443 meteors were observed at PF AMISR-32. Two hours of observation at AO resulted in 2,486 positive detections. The altitude distributions for all three radars are shown in Figure 1. The altitudes presented correspond to the radar return for which the signal-to-noise ratio (SNR) was a maximum. While the exact meteor head-echo scattering mechanism is still a point of contention [1], the results presented here are the first clear observational evidence that the radar scattering cross section is heavily dependent on the radar wavelength used. The PFISR results are the first known high latitude campaign to observe a large proportion of meteors above 100 km in altitude. All previous high latitude head-echo radar meteor observations have been conducted at frequencies much higher than those used at lower latitudes, explaining SRF's sharp observing cutoff at 105 km and its similarity in distribution to the 930 MHz EISCAT observations [10]. The similarity in altitude distributions between PF and AO indicate that these lower frequency radars have a much larger observation range than their higher frequency counterparts, with the discrepancies between AO and PF most likely due to latitude and time-of-day sampling variations. The AO altitude distribution is also consistent with previous meteor campaigns at that facility [11]. At higher frequencies, micrometeoroids must travel further down into the atmosphere before they are able to generate a high enough plasma density for detection at higher frequencies [1].

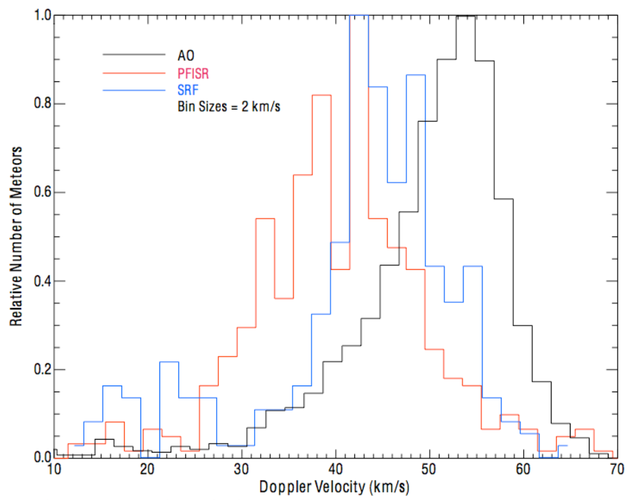

Figure 2. Doppler velocity distributions for August meteor observations.

As already noted, each positively identified meteor radar return was further utilized to estimate the Doppler speed using the technique described in Briczinski et al. [7]. The measured micrometeor Doppler (line-of-sight velocity) distributions are presented in Figure 2. The high-latitude distributions are not consistent with observed Dopplers at other radars for the same time of year, such as AO. Since the speed distributions are line-of-sight velocities, the discrepancies can be explained by the significant differences in observing latitudes. The discrepancies between the SRF and PF distributions also reinforce the likelihood of observing different micrometeoroid populations that is also observed in the high frequency altitude ceiling.

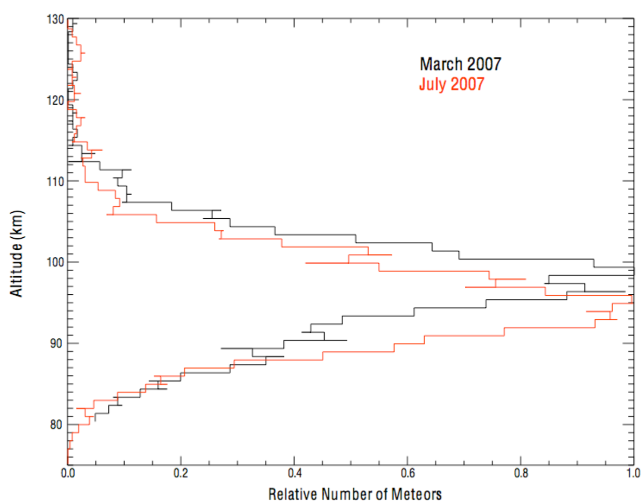

Figure 3. Seasonal altitude variation of the meteor distribution at PFISR.

The PFISR results presented in Figures 1 and 2 were obtained through an early 32 panel implementation of the radar in the summer of 2006. In 2007 PFISR began full face (96 panels) observations. Two complete 24 hour runs (0000-0000 LT) of sporadic meteor observations were conducted at PFISR, one in March 2007 and one in July 2007. A total of 883 meteors were detected in March and 1,817 events were detected in July. The altitude results are presented in Figure 3. Due to the limited window of observations from August 2006, those results are not re-presented here. All previous AO observations have had altitude distributions peaking around 105 km, regardless of the season. A 3.5 km variation in the PFISR results is a statistically significant deviation. Two other 24 hour observation campaigns at PFISR have been completed in September and December, with the analysis of these events still pending. However, the July 2007 PFISR altitude distribution helps to explain why the August 2006 distribution does not match up as well with the AO distribution considering the similarities in operating frequency.

If we characterize the radars by their effective power-aperture product divided by the system temperature (using the values in Table 1), we can obtain the quality factors (relative sensitivities) of the facilities. Using this metric, we obtain values of 1460 MW-m^2/K for AO, 18.9 MW-m^2/K for SRF and 0.67 MW-m^2/K for PF. Using these values, the hourly flux rates between AO and SRF produce comparable event rates (after taking into account the more favorable AO observing window of ~0.67 events/s at AO for near dawn). The fact that over one and a half times as many meteors are detected at PF relative to SRF despite a much lower sensitivity indicates that the radar wavelength is more important than the absolute sensitivity of the radar for a given cross section. In other words, the frequency dependence of the meteor radar cross section dominates system sensitivity in the end. The meteor scattering cross section is clearly frequency dependent [1, 12]. The lower frequency UHF radars are much more sensitive to micrometeor observations, making PFISR an important instrument for future high latitude head-echo studies (especially so when the interferometric capabilities are enabled).

4. Conclusions

We have presented results from the first systematic high latitude meteor studies at SRF and PFISR using a common automated analysis technique also employed at AO. We have compared the meteor altitude and speed distributions derived from these observations with those from AO revealing striking results. While vastly different in sensitivity, the PFISR (449.3 MHz) and AO (430 MHz) altitude distributions are similar but quite different from the SRF (1290 MHz) distribution. Specifically, relative to the lower-UHF HPLA radars, the SRF results display a profound meteor event "ceiling" not observed at the other two radars. We note that altitude displacement between the EISCAT 224/930 MHz distributions reported by Westman et al. [13] appears to be at most 5 km with the UHF "ceiling" at just about 100km. We also present the first observed seasonal variation in meteor altitude distributions at PFISR, which has not been observed at any other HPLA radar.

As a further test that the same general meteor population is being sampled by the three radars, the SRF and PFISR meteor speed distributions were similar and different from the AO result from a low latitude. While the results presented here represent a significant step forward for meteor observations, further work (such as mass determinations using decelerations) is necessary. The observations we report reaffirm previously held theories that meteor head-echo scattering is highly frequency dependent and unambiguously demonstrate that HPLA radar meteor observations suffer from a frequency dependent instrumental bias in observed altitude distributions. This bias should be studied via further multi-instrument observations and treated as an opportunity to firmly establish the scattering mechanism.

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