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Latitudinal dependence of the variability of the micrometeor altitude distribution

J. J. Sparks[1,2] and D. Janches[1]

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[1] We present a study of the diurnal behavior of the observed meteor altitude distribution at different seasons and latitudes. The meteor altitude distribution provides an indication of where the meteoric mass deposition occurs in the mesosphere and lower thermosphere (MLT). This can be utilized to model the input of metallic constituents into the MLT and accurately understand the chemistry of this region. We show that the observed altitude distributions have distinct variability at each location: at high latitudes there is a weak diurnal and strong seasonal variability while at tropical latitudes the opposite behavior is observed. We explain these results by correlating them with the astronomical and physical properties of the meteoric flux. Finally, we discussed the potential influences that these results have on the metal chemistry and aeronomy of this atmospheric region. **Citation:** Sparks, J. J., and D. Janches (2009), Latitudinal dependence of the variability of the micrometeor altitude distribution, *Geophys. Res. Lett.*, *36*, L12105, doi:10.1029/2009GL038485.

1. Introduction

[2] The major source of metallic material responsible for a variety of atmospheric phenomena in the Mesosphere and Lower Thermosphere (MLT) originates from the ablation of sporadic meteoroids in the mass range of 10^{-11} to 10^{-4} g upon atmospheric entry [*Williams and Murad*, 2002]. This evaporated meteoric mass is the source of global layers of neutral metal atoms, sporadic E layers of metal ions, and in particular at high latitudes it is believed to provide also, after ablation and re-coagulation, meteoric smoke particles (MSP) which will act as the condensation nuclei for ice particles. The charged ice particles are the necessary precursor to the formation of noctilucent clouds (NLCs) and Polar Mesospheric Summer Echoes (PMSE) in the polar mesopause region [*von Zahn et al.*, 2002]. For a given geographical location, the properties of the meteoric flux (i.e., directionality, velocity, etc.), hereafter referred as the Meteor Input Function (MIF), is not isotropic as it originates from specific radiant distributions with specific orbital characteristics [*Jones and Brown*, 1993; *Taylor*, 1997]. Thus, it is important to understand how these characteristics manifest in the observed meteor population in order to correlate them with the atmospheric phenomena they are responsible for.

[3] The chemistry and dynamics of the MLT change rapidly with altitude [*Plane*, 2003], thus it is important to know precisely the height at which meteoric mass is deposited within this region to model accurately the related chemical processes [*Vondrak et al.*, 2008]. The meteoroid ablation profile not only depends strongly on atmospheric conditions (i.e., density and temperature) but also on the particle composition and entry velocity and angle, all of which are determined by its astronomical origin. High Power and Large Aperture (HPLA) radars observe the meteor head echo scattered back from the electrons product of the ablation process [*Dyrud and Janches*, 2008]. In this paper we use HPLA radar observations at tropical and polar latitudes to show that the altitudes at which meteors are detected have very distinct variability, both diurnal and seasonal, depending on the geographical location.

2. Experiment and Results

[4] For this work, we utilized meteor head-echo observations from two HPLA radars representing most of the seasons. These radars which utilized similar frequencies are the 430 MHz Arecibo Observatory (AO), located in Arecibo Puerto Rico (18.3 N, −66.8 W); and the 450 MHz Poker Flat Incoherent Scatter Radar (PFISR), located at the Poker Flat Research Range near Fairbanks Alaska (65.1 N, 147.5 W). The detail of the observations are described by *Janches et al.* [2003] for the case of Arecibo and by *Sparks et al.* [2009] for the case of PFISR. In both cases, we transmitted uncoded radar pulses with an interpulse period (IPP) of 1 and/or 2 msec and a sampling frequency of 1 μs (150 m altitude resolution). This observational scheme allows the precise determination of instantaneous meteor line-of-sight (LOS) velocity and altitude.

[5] Figure 1 shows a typical altitude distribution observed using the experimental setup described above. In general, the altitude distribution of meteor head-echoes is a diagnostic of the detection response function of the HPLA radar being used and it will depend on its frequency [*Close et al.*, 2002; *Westman et al.*, 2004; *Janches et al.*, 2008; *Dyrud et al.*, 2007]. Although the scattering mechanism is different, a frequency dependence is also present on meteor trail altitude distributions [*Steel and Elford*, 1991]. It is natural then, to compare the PFISR observed results with those obtained using the AO radar which utilize a similar frequency [*Janches et al.*, 2003]. By performing such a comparison, two differences are immediately obvious. The first difference is that the observations at polar latitudes resulted on meteor altitude distributions peaking at lower heights than at low latitudes (6 to 12 km lower depending on season). This is easily explained by the PFISR's lower sensitivity, compared to AO, which requires a higher meteor

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[1] CoRA Division, NorthWest Research Associates, Boulder, Colorado, USA.

[2] Department of Physics, University of Colorado, Boulder, Colorado, USA.

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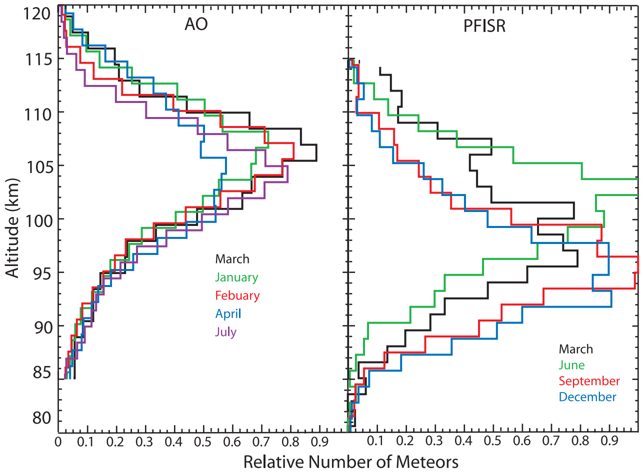

Figure 1. Observed meteor altitude distribution for all observing seasons and both AO and PFISR radars. The plots have been shifted vertically with respect to each other so altitudes line up with the same horizontal line.

head-echo electron volume density to reach a minimum detectable threshold, than the one needed to be detected by AO. This is only possible by particles with higher radar cross section (RCS) which are likely to be larger particles penetrating lower into the MLT in order to produce the required amount of electrons before ablating [*Janches et al.*, 2008; *Fentzke and Janches*, 2008]. In addition, although Arecibo should be able to detect meteors with RCS as large as those detected by PFISR, the number of influx of extraterrestrial particles decreases with meteoroid size [*Ceplecha et al.*, 1998]. Thus the lack of these larger RCS values in Arecibo's observations is explained by its much smaller collecting volume which makes it statistically unlikely to detect these larger particles. This is described in detail by *Fentzke et al.* [2008]. The second difference is that PFISR altitude distributions show a significant seasonal variability which is not present, at least with such intensity, at lower latitudes as shown by the Arecibo observations [*Janches et al.*, 2003; *Sparks et al.*, 2009]. It can be observed that during the northern summer at high latitudes (June PFISR's observations) the lowest average altitude are measured, while in winter (December) they are ∼6 km higher. Spring and Fall show also higher distributions with a peak in the distributions only ∼2 km lower than the Fall season. The June minimum in PFISR's altitude distributions is explained by the lower temperatures in the summer polar mesopause [*Lübken*, 1999; *Sparks et al.*, 2009]. The smaller variability, however, does not originate from MLT temperature differences as these should be similar between Spring and Fall.

[6] In order to determine if additional differences may be present in the altitude at which the micrometeoroid mass is deposited in the MLT at different latitudes we explore the diurnal behavior of these distributions. For this task, we perform hourly altitude distributions and estimate the height of the peak. Figure 2 shows our results at both latitudes. An additional 2-points sliding window is applied to these results. Regarding Figure 2 it is evident that besides the large seasonal variability, the altitude seems to be relatively constant for a given day at high latitudes. For the case of low latitudes (AO's observations), on the other hand, a complete opposite behavior is observed. There is no significant seasonal variability in the peak of the altitude distribution, however there is a drastic diurnal variability at all seasons where the peak varies over two atmospheric scale heights (>15 km). In the next section we discuss the origins of such a large change in the altitude at which material is deposited and its potential effects on the chemistry of the MLT.

3. Discussion

[7] As discussed by *Sparks et al.* [2009] the summer minimum in the altitude distribution at high latitudes is most likely due to the cold summer polar mesopause characterized by the lowest temperatures [*Lübken*, 1999]. This also

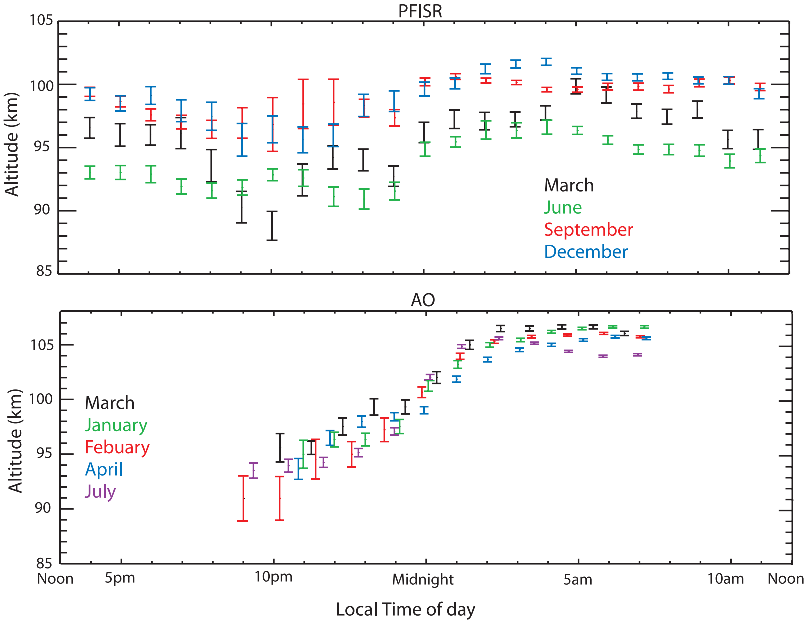

Figure 2. Diurnal Altitude distribution for all observing seasons and both AO and PFISR radars. The vertical bars represent the 1-σ errors of the altitude mean estimates.

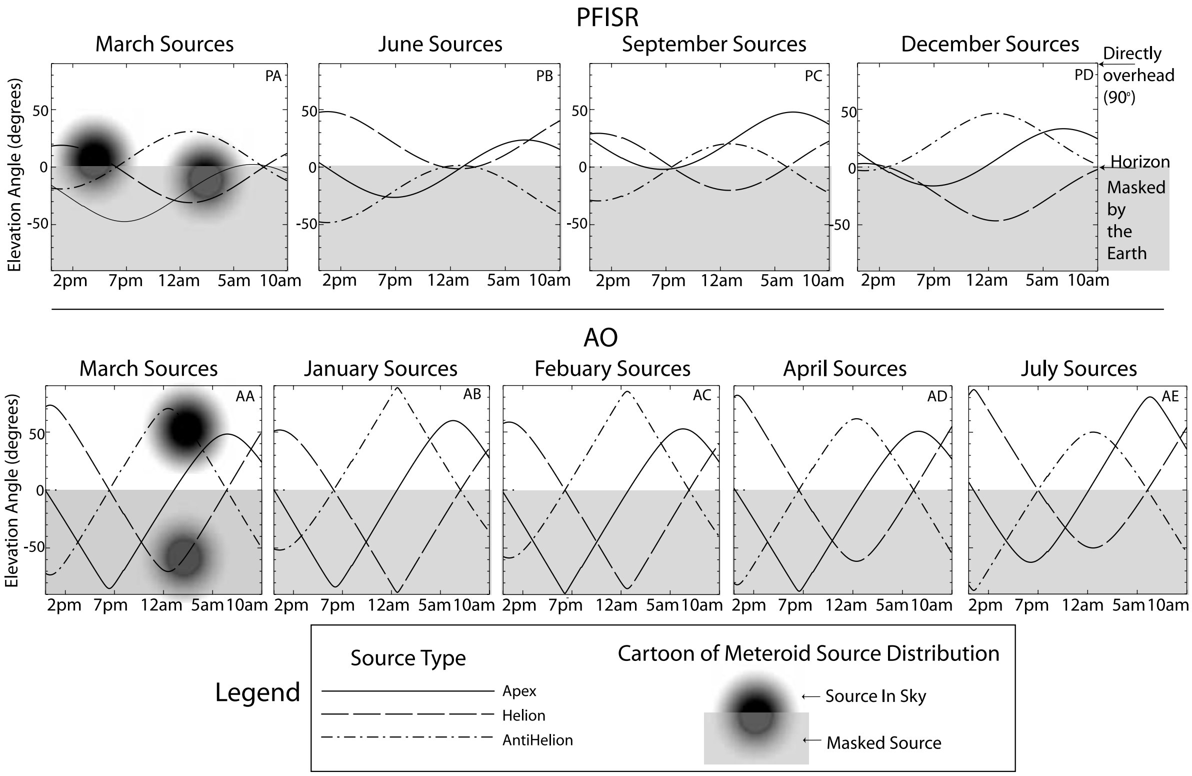

Figure 3. Elevation angles of the three main sources at both latitudes. Each source is not a point source as depicted by the lines but rather a distribution, therefore a cartoon of the distribution has been added to plots PA and AA. Note the distribution is a cartoon, in reality each source has a distribution width that is not necessarily the same. Plot set P represents the location of the sources in the sky during all of the PFISR observing campaigns. Plot set A represents the location of the sources during all of the Arecibo observing campaigns.

explains the lack of seasonal variability at low latitudes where the mesopause temperature does not vary as much as it does at high latitudes but does not explain the additional smaller variability that results on a 2 km difference between Fall and Spring/Winter in the polar region. As it is going to be discussed in this section, the origin of this variability is the same as the diurnal variability at lower latitudes and is related to astronomical origin of these particles.

[8] Particles observed by Arecibo and PFISR, as well as all the HPLA radars, are part of the Sporadic Meteor Complex (SMC) [*Janches et al.*, 2006] which is responsible for the majority of meteoric mass deposited in the atmosphere. The SMC is composed of six main directional enhancements of the meteor radiants (i.e., orbital families). These are referred to as apparent sources since they are not linked to their original parent body. These apparent sources are known as the North and South Apex, composed mainly of dust from long period comets [*Sekanina*, 1976]; the Helion and Antihelion, composed of dust from short period comets [*Hawkins*, 1956; *Weiss and Smith*, 1960]; and the North and South Toroidal composed of dust from Halley-family comets with the radiants near the ecliptic poles being from asteroidal sources [*Jones and Brown*, 1993; *Taylor*, 1997; *Taylor and Elford*, 1998].

[9] As mentioned earlier, for a meteor to be observed enough electrons need to be produced so that the resulting RCS will be above the detectability limit of the particular radar. The ionization rate of a meteor depends on its velocity, angle of entry, atmospheric density, and mass [*Fentzke and Janches*, 2008; *Dyrud and Janches*, 2008]. Figure 3 displays the elevation angle of the main three apparent sources (Apex, Helion and Anti-Helion) [*Janches et al.*, 2006] at each latitude of interest. The South and North Toroidal sources are not included in Figure 3 because modeling work reported by *Fentzke and Janches* [2008] and *Fentzke et al.* [2008] showed that the contribution from them represents only 1% of the observed flux. For PFISR, although lower in the sky during the Spring, there is always at least a portion of the sources above the local horizon through the entire day. This implies that overall the average entry angle will not significantly change. This is not the case at lower latitudes where the sources can be high in the sky during part of the day and completely below the local horizon for other periods. Since the velocity or the mass distributions of a given source are not expected to change through the day or even season, we conclude that the diurnal variability of the height distribution at low latitudes as well as its absence at higher latitudes is product of the elevation of the astronomical sources at a given geographical location. In general, the elevation angles reach a minimum for most of the sources at night (~19:00 LT) while the highest elevations are reached between local midnight to 07:00 LT. The diurnal variability of the entry angle correlates very well with that of the peak altitude measured at Arecibo shown in Figure 2 further confirming our conclusions.

[10] The large changes in the altitude at which meteoric mass ablates can produce significant effects in the chemistry

of the MLT. The MLT changes from a neutral state to a highly ionized one in a 50 km altitude span [*Plane*, 2003]. Temperatures and densities also vary significantly and rapidly. Thus, if the altitude at which the material, which is the source of the layered phenomena occurring in this region, changes significantly, it can have large impacts on the evolution and fate of these phenomena. For example, *Vondrak et al.* [2008] reported a model that considers for the first time the full treatment of the ablation and ionization of the individual chemical elements in the meteoroid. The authors showed that, if differential ablation takes place, the deposition of volatile meteoroid elements such as Na or K will occur 15 km higher than the main and less volatile elements (i.e., Si, Mg and Fe) and even higher than refractory elements such as Ca and Al. More recently, *Janches et al.* [2009] used this model to explain small temporal scale features in the received signal of meteor head echoes detected by Arecibo suggesting that this is the main process under which micrometeoroids deposit their mass in the MLT. If this is the case, the variability presented here will add an additional 15–20 km difference on the altitude where each constituent is deposited depending on time of the day, season and latitude. This effect introduces potential temporal and geographical dependence on the atmospheric chemical process that will follow after the mass deposition. Among these effects we mention the input of refractory elements like Ca, which will increase [*Vondrak et al.*, 2008, Figure 12], the fraction ionized will also increase significantly [*Vondrak et al.*, 2008, Figure 14] and the height of injection will change from the upper mesosphere to the lower thermosphere. However, to understand the full extent of these effects, as well as their temporal and geographical variability, we need to introduce these observational facts into models. This effort is under current development.

4. Conclusion

[11] We presented a study of the diurnal behavior of the observed meteor altitude distribution at different seasons and latitudes and showed that the observed altitude distributions have distinct variability at each location: at high latitudes there is a weak diurnal and strong seasonal variability while at tropical latitudes the opposite behavior is observed. We explain these results by correlating them with the astronomical properties of the meteoric flux. At different geographical locations the meteoroid entry angles vary differently with time of the day and season potentially filtering the mass/velocity particle populations and producing the distinct observed results. These results will have potentially large influences on the metal chemistry and aeronomy of this atmospheric region.

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D. Janches, CoRA Division, NorthWest Research Associates, 3380 Mitchell Lane, Boulder, CO 80301, USA. (diego@cora.nwra.com)

J. J. Sparks, Department of Physics, University of Colorado, Boulder, CO 80309-0390, USA. (jonathan.sparks@colorado.edu)