SOFIE PMC observations during the northern summer of 2007

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Abstract. The Solar Occultation For Ice Experiment (SOFIE) was launched onboard the Aeronomy of Ice in the Mesosphere (AIM) satellite on 25 April 2007 to measure polar mesospheric clouds (PMCs) and their environment. SOFIE measures PMC extinction at wavelengths from 0.33 to 5.01 μm in addition to temperature and the abundance of five gaseous species. This work describes SOFIE observations from the northern summer of 2007, addressing measurements of temperature, water vapor, and PMC frequency, mass density, particle shape, and size distribution. These new observations are used to examine mesospheric ice particles in terms of the seasonal evolution, altitude dependence, and relationships among the various properties. SOFIE observations near 69°N latitude indicate that ice particles are nearly always present from 20 May through 28 August. Ice particles were observed to exist in a continuous layer from about 81 to 87 km altitude on average, and are often detected to altitudes above 90 km. These findings are in contrast to previous measurements, which indicated occurrence frequencies of \~40\% near 69°N latitude, and ice layers with vertical thickness of less than \~2 km. This new view of mesospheric ice is consistent with the dramatically increased sensitivity of SOFIE compared to existing instruments. Ice particles are observed to become increasingly aspherical above and below the extinction peak altitude, suggesting a relationship between...
particle shape and mass density. Size distribution profiles indicate high concentrations of small particles above the extinction peak, gradually changing to lower concentrations of large particles with decreasing altitude. Particle concentration is strongly tied to distribution width and median radius, with high concentrations corresponding to small radii and narrow widths. A strong correlation was found between water vapor and particle size, where small particles exist when H$_2$O is low, and the relationship holds when examining variability in altitude, and variability over time at one altitude.

Keywords: AIM; SOFIE; PMC; mesosphere

1. Introduction

AIM is the first satellite mission dedicated to measuring PMCs and the environment in which they form (Russell et al., 2007). SOFIE measurements are used to retrieve vertical profiles of PMC extinction at eleven wavelengths from 0.330 to 5.01 μm, temperature, and the abundance of O$_3$, H$_2$O, CO$_2$, CH$_4$, and NO. PMCs are measured by monitoring the attenuation of solar energy using broadband radiometers. In addition, SOFIE measures the radiometer difference signal for band pairs that are close in wavelength. The digitization limit corresponds to 10$^{-7}$ km$^{-1}$ in extinction for the radiometer PMC measurements, and 4×10$^{-10}$ km$^{-1}$ in extinction for the channel 2 difference signals. Laboratory and on-orbit characterization of the PMC measurements indicate noise levels corresponding to 2×10$^{-8}$ km$^{-1}$ for the radiometers and 6×10$^{-10}$ km$^{-1}$ for the channel 2 difference signals. The PMC measurement field-of-view (FOV) is 1.5 km vertically and detectors are sampled at ~145 m vertical spacing. SOFIE measurement coverage ranges from about 65° to 80° latitude (north or south) during the polar summer, and spacecraft sunrise (sunset) measurements occur in the northern (southern) hemisphere near the time of local sunset (sunrise). Gordley et al. (2008, this issue) provide a detailed description of the SOFIE
experiment. Hervig et al. (2008, this issue) discuss the use of SOFIE measurements to identify ice layers and to determine ice mass density, particle shape, effective radius, and size distribution. This work provides a broad overview of SOFIE results from the northern summer of 2007, and highlights some intriguing features in the observations. Connections are explored in some instances, but questions remain that will be the subject of future studies.

The average SOFIE measurement latitude during the 2007 northern PMC season was 68.9°N for all PMC observations. SOFIE measurements were analyzed to determine the altitude dependence of ice particle mass density ($M_{\text{ice}}$), effective radius ($r_e$), and particle shape as the axial ratio ($AR$) of a spheroid. SOFIE measurements cannot distinguish between oblate and prolate spheroids. Only the oblate solutions ($AR>1$) are discussed below, and the prolate $AR$ is generally the inverse of the oblate $AR$. In addition, SOFIE determines altitude dependent Gaussian size distributions, which are described by the total concentration ($N$), median radius ($r_m$), and distribution width ($\Delta r$, units of length). The results are based primarily on PMC extinctions, $\beta(\lambda)$, retrieved from the band 9 ($\lambda = 3.064$ μm) and band 10 ($\lambda = 3.186$ μm) radiometer measurements, and from the channel 2 difference signals ($\lambda = 1.037$ μm). Ice particles are considered to be non-spherical and references to particle size denote the radius of volume-equivalent spheres. Observations were removed when the altitude of peak ice extinction altitude ($Z_{\text{max}}$) was below 79 km (about 10% of the SOFIE observations). As discussed in Hervig et al. (2008), these observations correspond to isolated clouds at the far reaches of the line of sight, and are currently not treated correctly in the SOFIE data processing. This work also presents SOFIE temperature and water vapor retrievals. SOFIE temperatures currently retrieved from the 4.324 μm CO₂ band are known to have a warm bias of more than 7 K at altitudes near the mesopause. This bias is related to non-local thermodynamic equilibrium (non-LTE) effects.
that will be addressed in future data reduction efforts (see Gordley et al., 2008, this issue). SOFIE H₂O retrievals are immune to PMC contamination and current estimates indicate precision of better than 50 ppbv at altitudes below 95 km.

2. Results

2.1. Ice Frequency

The seasonal evolution of PMC occurrence frequency is shown in Fig. 1a. Frequency was determined as the ratio of the number of observations containing ice to the total number of observations in three-day time intervals. SOFIE indicates that ice is nearly always present over the duration of the summer season, in sharp contrast to previous observations at these latitudes. For example, PMC frequencies from a climatology based on solar mesosphere explorer (SME) observations (Thomas and Olivero, 1989) indicate about 50% occurrence frequency near 70°N in mid-summer. In Fig. 1a, SME PMC frequencies are shown for the average SOFIE latitude, and also for the time-dependent SOFIE latitude. Sampling the SME climatology at actual SOFIE latitudes (see Fig. 1e) results in fewer clouds during mid-summer and more clouds towards summer’s end, but the overall effect is relatively small. SOFIE is also compared to results based on Halogen Occultation Experiment (HALOE) observations from 1992-2005 at 65-70°N (Hervig et al., 2003), which indicate frequencies of ~40% during mid-summer. The HALOE PMC detection threshold was 3.40 μm extinction greater than 2×10⁻⁶ km⁻¹, which is equivalent to \( \beta(3.064) = 4\times10^{-5} \) km⁻¹ when adjusted to the SOFIE band 9 wavelength. SOFIE PMC frequencies were computed using only clouds with \( \beta(3.064) > 4\times10^{-5} \) km⁻¹, and these results are in good agreement with the HALOE and SME PMC frequencies. A probability distribution of SOFIE 3.064 μm ice extinction measured at \( Z_{max} \) is shown in Fig. 2, where the HALOE detection
threshold and ALOMAR lidar detection threshold (Baumgarten et al., 2008) for 50 and 35 nm radii are shown in terms of $\beta(3.064)$. HALOE would have detected about 39% of the SOFIE PMCs, while the ALOMAR lidar would observe from 76 to 91% (for 50 and 35 nm radii, respectively). The SOFIE results suggest that the previous view of lower PMC frequencies near 70°N was a result of lower instrument sensitivity.

A time-height cross section of ice occurrence frequency is shown in Fig. 3a, where three-day average mesopause altitude (altitude of the SOFIE temperature minimum), ice layer top ($Z_{top}$) and bottom ($Z_{bot}$) altitudes, and $Z_{max}$ are overlain. SOFIE shows $Z_{max}$ near 85 km in early and late season, and about 83 km in mid-season, consistent with previous observations (e.g., Bailey et al., 2005). The average mesopause and cloud top altitudes are nearly identical, except for the first and last few days of the ice season when $Z_{top}$ is about 1 km below the mesopause. The average ice layer thickness ($Z_{top} - Z_{bot}$) is observed to increase from about 4 km in early season to 7 km by mid-summer, which is due primarily to a lowering of $Z_{bot}$. Ice is detected from 65 to 100% of the time at altitudes between the average $Z_{top}$ and $Z_{bot}$, and is observed above the mesopause although less frequently. Fig. 5b shows the July average profile of ice occurrence frequency, where ice was observed ~90% of the time near the July average $Z_{max}$, and occasionally up to 2 km above the July average mesopause altitude (86.8 km). The average profiles in Fig. 5 were constructed by vertically aligning individual profiles so that $Z_{max}$ is located at the July average value of 83.2 km. This step gives more realistic profiles because variations in $Z_{max}$ cause smearing of the relative altitude dependence when averaging many observations. Of the 1093 SOFIE profiles containing ice, ~5% of these had $Z_{max}$ located above the mesopause, and 52% had $Z_{top}$ located above the mesopause. The existence of ice at such high altitudes is consistent with the availability of H$_2$O and sufficiently cold temperatures (e.g., Lubken, 1999),
and is predicted by models. It is likely that ice particles observed near and above the mesopause are associated with polar mesosphere summer echoes (PMSE), which extend from just above typical PMC altitudes (~83 km) to over 90 km. SOFIE indicates that the ice layer is typically continuous extending from about 81 km up to and above the mesopause, implying that PMC and PMSE are different manifestations of a continuous ice layer.

Between about 1 and 10 August (10 to 20 days from solstice (DFS)) ice frequencies decrease from over 80% to ~70%, between the average Z\text{top} and Z\text{bot} (Fig 3a), with an even more dramatic decrease in the frequency of bright clouds (Fig 1a). The frequency decrease is accompanied by a decrease in column ice mass abundance (or ice water content, IWC) from over 50 μg m\(^{-2}\) to ~30 μg m\(^{-2}\) (Fig. 1b). The reduction in ice frequency and IWC is coincident with a ~5 K increase in mesopause temperature and ~1 ppmv increase in water vapor at Z\_max (Fig 1d). Taken as a whole these observations are consistent with a warming event which caused a portion of the PMCs to sublime and release H\(_2\)O into the gas phase.

2.2. Ice Mass

The seasonal evolution of ice mass density is shown at Z\_max in Fig. 1b, and as a time-height cross section in Fig 4b. Although modulated by cloud thickness, IWC (Fig. 1b) generally follows the time series of mass density at Z\_max, with both quantities increasing by a factor of ~20 during the summer season. Ice layers characterized by smaller vertical extent (dZ = Z\_top - Z\_bot) are generally correlated with lower mass density at Z\_max, as evident in Fig. 4b. The relationship between M\(_{ice}\) and dZ is shown more clearly in Fig. 3, where SOFIE results are compared to model results from the Community Aerosol and Radiation Model for Atmospheres (CARMA; see Rapp and Thomas, 2006). CARMA was initialized using modeled temperature, water vapor, and vertical wind profiles near 70° N as described in Siskind et. al. (2005), and run for cloud
lifetimes from 24 to 96 hours. $Z_{top}$ and $Z_{bot}$ were found in the CARMA profiles by locating the altitudes where SOFIE PMC extinction calculated from the CARMA size distributions was equal to the SOFIE digitization limit. The CARMA results are in good agreement with SOFIE, confirming the relationship between peak mass density and vertical extent. While vertical extent is a factor in determining $IWC$, the fact that lower mass densities correspond to smaller $dZ$ appears to be a larger factor in determining total mesospheric ice content. The seasonal dependence of $M_{ice}$ is correlated in part to $Z_{max}$ with higher altitudes corresponding to lower mass densities. This relationship is more clearly demonstrated in Fig. 5a where $M_{ice}$ is shown versus $Z_{max}$. The SOFIE results are consistent with previous lidar observations (von Cossart et al., 1999, Table 2 therein; Baumgarten et al., 2007, Tables 3 and 4 therein) and model results reported by Rapp and Thomas (2006, Table 1 therein). While the lidar observations in Fig. 5a do not show $M_{ice}$ lower than $\sim 10$ ng m$^{-3}$ or $Z_{max} > \sim 84$ km, SOFIE indicates $M_{ice}$ as low as 0.1 ng m$^{-3}$ and $Z_{max}$ up to $\sim 88$ km. This difference is due in part to the enhanced sensitivity of SOFIE as discussed by Hervig et al. (2008, this issue). While higher mass densities are generally associated with larger particles, as indicated by SOFIE and by lidar measurements and model results (Fig. 5c), this relationship is only loosely constrained.

2.3. Particle Shape

A time series of ice particle axial ratio observed at $Z_{max}$ is presented in Fig. 1c, where daily mean values are consistently about 2.2 throughout the season. The particle shape at $Z_{max}$ does not appear to be related to $Z_{max}$ as shown in Fig. 5d. Fig 5e indicates that particle shape at $Z_{max}$ varies little with $M_{ice}$, except for the most tenuous layers ($M_{ice} < \sim 2$ ng m$^{-3}$) where larger axial ratios are observed. In addition, observations at $Z_{max}$ suggest that axial ratio is not correlated with effective radius (Fig. 5f). A time-height cross section of particle shape is shown
in Fig. 4c, where $AR$ is between about 2 and 3 at altitudes between the average $Z_{top}$ and $Z_{bot}$. The largest axial ratios are observed above ~87 km and below ~81 km, with $AR$ in excess of 4 observed above the mesopause. This relationship is more clearly shown in Fig. 6a, where the July average $AR$ profile is shown. The average profile indicates a minimum in $AR$ located about one km above $Z_{max}$ with increasing asphericity at lower and higher altitudes. Recall that particle shape at $Z_{max}$ is apparently unrelated to $Z_{max}$ yet the average profile indicates a clear altitude dependence. Thus, particle shape appears to be related to the relative distance from $Z_{max}$. In the classical description, there is particle nucleation, growth, and sedimentation above $Z_{max}$, accumulation at $Z_{max}$ due to a balance between upwelling and sedimentation, and sublimation as particles fall into the sub-saturated region below. Regarding the average $AR$ profile in Fig 6a., the largest axial ratios are therefore generally associated with regions of particle growth or sublimation. The height dependence of $AR$ is generally correlated with mass density, with the largest axial ratios related to low mass density, except for a small displacement of the $AR$ minimum above the peak in mass density. While there is no reason to expect the $AR$ minimum to be at $Z_{max}$, the vertical displacement is somewhat curious. FOV miss-alignment between the bands 9 and 10 measurements used to determine $AR$ is less than 40 m (Gordley et al., 2008), and other measurement errors currently cannot explain a vertical shift in the $AR$ profiles. The relationship between $AR$ and mass density for points in the July average profiles is shown in Fig. 8a, where the results are identified as above or below $Z_{max}$. Particle shape is clearly dependent on $M_{ice}$, although the results indicate different associations for observations above and below the extinction peak. This result may indicate that particle shape is governed by differing mechanisms when either growth or sublimation is occurring, with the broad generalization that growth occurs above and sublimation below $Z_{max}$. Displacement of the $AR$ minimum above $Z_{max}$
is coincident with higher particle concentrations found above $Z_{max}$ (Fig. 6c), suggesting that particle shape and concentration may be controlled by the same microphysical processes. While particle shape is apparently related to mass density and concentration, correlations are only evident when the data are examined as a function of altitude.

2.4. Size Distribution and Effective Radius

Ice particle effective radii and Gaussian size distributions are only retrieved when the 1.037 μm extinction is above the noise, which corresponds to about half of the observations at $Z_{max}$, and to altitudes typically below 86 km (see Hervig et al., 2008, this issue). Seasonal evolution of effective radii and the Gaussian size distribution parameters at $Z_{max}$ are shown in Fig. 1. The time series of effective radii at $Z_{max}$ (Fig. 1d) indicates a steady increase in particle size from average values of about 25 nm in late May to over 40 nm in late August. The increase in effective radii is corroborated by the time series of median radii at $Z_{max}$, and accompanied by a gradual decrease in particle concentrations (from roughly 700 to 200 cm$^{-3}$) and a gradual increase in distribution width (from about 10 to 14 nm) during the season (Fig. 1e and 1f). SOFIE mesopause temperatures (Fig. 1d) increase by about 5 K from mid-June through early August, although a detailed assessment of these data awaits updated retrievals which will address a known warm bias in the current results (see Gordley et al., 2008, this issue). Water vapor at $Z_{max}$ is observed to increase steadily from ~3 ppmv in late May to ~6 ppmv by early August (Fig. 1d), suggesting a connection between gas phase H$_2$O and particle size and concentration. H$_2$O versus particle size for data points in the time series in Fig. 1 is shown in Fig. 8b, where a clear correlation exists. Increasing H$_2$O in the upper mesosphere is consistent with vertical transport due to upwelling, and an additional increase is expected due to PMC evaporation (Hervig et al., 2003). Increasing H$_2$O from 3 to 6 ppmv raises the frost point temperature ($T_{ice}$) by ~2.5 K,
considering the average pressure at 83 km (0.0065 hPa). Raising the frost point should generally result in increased ice frequency and mass density, yet SOFIE does not indicate a systematic change in either quantity. It is possible that the increase in temperature suggested in Fig. 1d overwhelms the increase in $T_{ice}$, so that no measurable effect on ice mass density and frequency occurred. The correlated and steady changes in H$_2$O, temperature, and ice characteristics pose intriguing questions that will be explored in future investigations.

Time-height cross sections of effective radius and the Gaussian size distribution parameters are shown in Fig. 4. SOFIE indicates that the highest concentrations, smallest particles, and smallest widths are generally observed above $Z_{max}$. July average profiles of $r_e$ and the size distribution parameters are shown in Fig. 6. High concentrations of small particles above $Z_{max}$ is consistent with current understanding where nucleation of many small particles occurs near the mesopause. SOFIE indicates that the largest particles are below $Z_{max}$, in contrast to model results (Rapp and Thomas, 2006) which suggest that the largest particles exist at $Z_{max}$. The decrease in concentration and increase in size below $Z_{max}$ may be explained by sublimation at lower altitudes where only the largest particles survive as they fall into warmer temperatures. The July average water vapor profile (Fig 6b) indicates a steady decrease in H$_2$O from 6.5 ppmv near 80 km to 1.5 ppmv at 90 km. The altitude dependence of H$_2$O bears similarities to the vertical dependence in particle size, as demonstrated in Fig. 8b where H$_2$O is shown versus $r_e$ for data points in the July average profiles. The results do not indicate a change in the H$_2$O - $r_e$ relationship when segregating observations by altitude, except below ~81 km where H$_2$O settles to a constant ~6.5 ppmv. While this finding is based on altitude dependent observations, it is nearly identical to the relationship between simultaneously increasing H$_2$O and particle size at $Z_{max}$ in the time series in Fig. 1. Given the correlation between concentration and radius (Fig. 6c and 7c) it is not
surprising that inspection of H$_2$O versus $N$ reveals a stalwart connection, with low $N$ existing at high H$_2$O. These findings point to a fundamental connection between ice particle characteristics and water vapor, although it is not clear if water vapor controls ice or vice versa.

SOFIE indicates larger effective radii when $Z_{\text{max}}$ is lower (Fig. 5b), a trend that is consistent with lidar observations (von Cossart et al., 1999 and Baumgarten et al., 2007), and model results (Rapp and Thomas, 2006). While SOFIE results encompass the lidar observations, many SOFIE observations indicate smaller $r_e$ at higher $Z_{\text{max}}$ than the previous measurements and model results. The dominance of smaller $r_e$ in the SOFIE data set could be related to inter-annual differences in cloud season, but may be consistent with SOFIE detecting more tenuous clouds than previously observed. The later suggestion is supported by the overall trend towards smaller $r_e$ at lower $M_{\text{ice}}$, as indicated in Fig. 5c. The July average profile of $r_e$ (Fig. 6d) is compared with results from von Savigny et al. (2005) based on Optical Spectrograph and Infrared Imager System (OSIRIS) measurements. SOFIE indicates $r_e$ varying from ~27 nm at 86 km to ~52 nm at the average $Z_{\text{bot}}$, generally consistent with von Savigny et al. Note that the average SOFIE $r_e$ at $Z_{\text{max}}$ (34.7 nm) is in good agreement with concurrent lidar observations from ALOMAR (69°N) which indicate 35.0 nm (Hervig et al., 2008, this issue), suggesting that SOFIE – OSIRIS differences are likely related to inter-annual variability.

The relationships between particle concentration and $Z_{\text{max}}$, $M_{\text{ice}}$, $r_m$, and $\Delta r$ are shown in Fig. 7 for observations at $Z_{\text{max}}$. These results indicate that higher peak altitudes correspond to higher concentrations, and that large mass densities are generally characterized by high concentrations. In both cases, these patterns are in agreement with previous lidar observations (von Cossart et al., 1999 and Baumgarten et al., 2007), and model results (Rapp and Thomas, 2006). Both $r_m$ and $\Delta r$ exhibit a clear increase with decreasing concentration. In the absence of
coagulation (Rapp and Thomas, 2006), this overall pattern is consistent with diffusional
growth/sublimation that is size dependent. The saturation vapor pressure over an ice sphere \( E_a \)
increases with decreasing radius as described by the Kelvin effect (Pruppacher and Klett, 1980).
For example, \( E_a \) for a 10 nm ice sphere is 39% greater than for a 50 nm particle. When ice
growth reduces atmospheric water vapor pressure \( E_s \), particles with \( E_a < E_s \) will sublimate. As the smallest particles disappear, remaining large particles can continue to grow due to reduced
competition for water vapor, and from vapor enhancement resulting from sublimation of the
smaller particles. This process would lead to populations characterized by increasing
concentration with decreasing radius, as evident in the SOFIE observations. By inference, width
and median radius could be indicators of the ice population age, with larger radius and width corresponding to older populations.

3. Summary

SOFIE PMC measurements from the northern summer of 2007 were analyzed to
determine PMC frequency, mass density, particle shape, effective radius, and Gaussian size
distributions as a function of altitude. SOFIE indicates that ice is nearly always present near
69\(^\circ\)N latitude, in contrast to previous measurements that were less sensitive than SOFIE. Ice was
observed to exist in a continuous layer from about 81 km to the mesopause (~86.8 km) on
average, and occasionally up to 3 km above the mesopause. These results indicate that the
narrow ice layers historically identified as PMCs are actually part of a continuous ice layer that is
likely associated with PMSE which are generally observed from PMC altitudes to the mesopause
and above. SOFIE indicates that ice particle shape at the altitude of peak extinction is generally
invariant (~2.2), yet vertical profiles of particle shape show increasingly aspherical particles
above and below the extinction peak. Greater asphericity was found to generally correspond to
lower mass densities, and to some extent lower particle concentrations. SOFIE observations indicate correlated and steady changes in H$_2$O, temperature, and ice particle characteristics during the 2007 PMC season. A strong correlation was found between water vapor and particle size, and the relationship holds when examining variability in altitude, and variability over time at one altitude. This survey of SOFIE observations highlights numerous findings and sets the stage for upcoming investigations.

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References


Fig. 1.
Fig. 1. SOFIE PMC characteristics determined as three-day averages from observations in the 2007 northern polar summer. Vertical bars indicate standard deviations. a) Time series of PMC occurrence frequency for three-day intervals. SOFIE results are shown for all PMCs observed (SOFIE), and for PMCs with $\beta(3.06) > 4 \times 10^{-5}$ km$^{-1}$ (SOFIE bright). PMC frequencies from the SME climatology are shown for the average SOFIE latitude (SME$^a$), and for the actual SOFIE latitude versus time (SME$^b$). HALOE PMC frequencies based on averages for 1992-2005 at 65-70°N are also shown. b) Ice mass density at $Z_{max}$ and ice water content (IWC). c) Particle axial ratio and effective radius at $Z_{max}$. d) H$_2$O at $Z_{max}$ and mesopause temperature. e) Particle concentration at $Z_{max}$ and measurement latitude. f) Gaussian distribution median radius and distribution width at $Z_{max}$. 
Fig. 2. Probability distribution of 3.064 μm PMC extinction observed by SOFIE at $Z_{\text{max}}$ during 2007. The ice detection thresholds of HALOE and the ALOMAR lidar (assuming 35 and 50 nm particles) are shown in terms of 3.064 μm extinction (vertical dashed lines). The SOFIE threshold is also indicated.

Fig. 3. Ice mass density at $Z_{\text{max}}$ versus ice layer vertical extent from three-day averages of SOFIE results, compared to CARMA results as described in text.
Fig. 4. Time-height cross sections based on three-day averages of a) ice detection frequency, b) ice mass density, c) particle shape (axial ratio of an oblate spheroid), d) effective radius. Also shown are the Gaussian size distribution e) concentration, f) median radius, and g) width. Three-day average ice layer top, peak, and bottom altitudes are overlain in all panels (solid lines), and average mesopause heights are shown in a). White regions indicate the absence of data. (in color)
Fig 4. Continued.
Fig. 5. Scatter plots showing SOFIE PMC parameters measured at $Z_{\text{max}}$ for all PMCs observed with $Z_{\text{max}} > 79$ km. a) $M_{\text{ice}}$ versus $Z_{\text{max}}$, b) $r_e$ vs. $Z_{\text{max}}$, c) $M_{\text{ice}}$ versus $r_e$, d) AR vs. $Z_{\text{max}}$, e) AR versus $M_{\text{ice}}$, and f) AR versus $r_e$. SOFIE results in a), b), and c) are compared to lidar measurements from von Cossart et al. (1999) and Baumgarten et al. (2008), and model results from Rapp and Thomas (2006). (in color)
Fig. 6. Average profiles based on SOFIE observations during July 2007. Average profiles for ice parameters were constructed by vertically aligning individual profiles so that $Z_{\text{max}}$ is located at the July average value (83.2 km). Horizontal dot-dash lines show the average $Z_{\text{top}}$ (86.5 km), $Z_{\text{max}}$, and $Z_{\text{bot}}$ (80.0 km) as labeled in b). The July average mesopause height was 86.8 km. a) ice mass density and axial ratio, b) ice occurrence frequency and water vapor, c) concentration and distribution width, and d) effective radius and median radius. The SOFIE effective radius profile is compared to OSIRIS observations from von Savigny et al. (2005, Table 1 therein).
Fig 7. Scatter plots showing SOFIE results at $Z_{\text{max}}$ for all PMCs observed with $Z_{\text{max}} > 79$ km. a) $N$ versus $Z_{\text{max}}$, b) $N$ vs. $M_{\text{ice}}$, c) $N$ versus $r_m$, and d) $N$ versus $\Delta r$. SOFIE results are compared to lidar measurements from von Cossart et al. (1999) and Baumgarten et al. (2008), and model results from Rapp and Thomas (2006). (in color)
Fig. 8. a) Mass density versus axial ratio for points in the July average profiles in Fig. 7, labeled differently for observations above and below the July average $Z_{max}$ (83.2 km). b) Water vapor versus effective radius for points in the July average profiles in Fig. 7, labeled differently for $Z < Z_{max}$ and $Z > Z_{max}$. Also shown are the H$_2$O versus $r_e$ for three-day averages at $Z_{max}$ from the time series in Fig. 1.