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Observations of mesospheric ice particles from the ALWIN radar and SOFIE

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A B S T R A C T

Ice particles near the polar summer mesopause are observed visually, by radar, and using various remote and in-situ techniques. This study investigates concurrent radar observations from the ALOMAR wind (ALWIN) radar and measurements from the Solar Occultation For Ice Experiment (SOFIE) onboard the Aeronomy of Ice in the Mesosphere (AIM) satellite. Mesospheric ice observations from radar are known as polar mesosphere summer echoes (PMSE), while satellite observations of these particles are referred to as polar mesospheric clouds (PMC). Comparisons of concurrent SOFIE and ALWIN observations indicate that PMC and PMSE are different manifestations of the same ice layer. The vertical extent of the ice layer is similar in the ALWIN and SOFIE records, with the primary difference that the PMSE signal peaks about 2 km higher than the PMC signal. SOFIE observations of ice particle size and concentration are used to test simple empirical proxies for PMSE which have previously been suggested based on a small number of rocket observations and microphysical modeling.

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1. Introduction

The unique thermal structure of the polar summer mesopause region has been known for decades to lead to fascinating phenomena such as polar mesospheric clouds (PMC, also called noctilucent clouds or NLC) and polar mesosphere summer echoes (PMSE). It is now well established that PMC are direct evidence of mesospheric ice particles (Hervig et al., 2001; Eremenko et al., 2005) which occur when the local temperature drops below the frost point of water ice. These particles reach sizes of up to a few tens of nanometers such that they scatter and/or absorb light effectively enough to be observed from the ground (as NLC) or from satellite platforms (e.g., Rapp and Thomas, 2006; Baumgarten et al., 2008; Hervig et al., 2009a). In the case of the radar phenomenon of PMSE, strong but indirect evidence for their close link to mesospheric ice particles comes from a wealth of independent observations (see Rapp and Lübken, 2004, for a review). Prominent examples are their exclusive occurrence in altitude regions which are supersaturated with respect to ice (e.g., Lübken et al., 2002), morphological and temporal similarities to NLC (von Zahn and Bremer, 1999; Lübken et al., 2004), in-situ observations of charged nanoparticles in their altitude range of occurrence (e.g., Havnes et al., 1996, 2001; Smiley et al., 2006; Rapp et al., 2009), active HF heating experiments (Havnes et al., 2003), and multi-frequency radar observations which have recently been used to infer ice particle radii in close agreement with independent optical observations and models (Rapp et al., 2008; Li et al., 2010).

However, as compared to PMCs, one of their most distinctive features is that PMSE are observed over a much larger altitude range with the PMCs residing at its lower edge (von Zahn and Bremer, 1999). This has been explained in the framework of the growth and sedimentation scenario, in which it is believed that the ice particles nucleate close to the mesopause ($\sim$90 km), grow by H_2O deposition onto their surface and then sediment to lower altitudes where they eventually reach large enough sizes to become detectable as PMCs. Hence, PMSE are thought of as evidence of the entire ice particle population (i.e., both small and large ice particles) while PMCs represent only those particles which exceed a minimum radius of roughly 20–30 nm (e.g., Rapp and Thomas, 2006). Due to the low sensitivity of previous optical experiments, however, direct proof of ice particles above the traditional PMC altitude range ($\sim$82–85 km) was only recently obtained by the Solar Occultation For Ice Experiment (SOFIE) which detects ice particles within the entire supersaturated region ($\sim$80–90 km) (Hervig et al., 2009a).

2. Observations

2.1. ALWIN

The ALOMAR wind (ALWIN) radar is a phased array consisting of 144 yagi antennas operating at 53.5 MHz and is located close to

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the Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR) in Northern Norway (69.17°N, 16.01°E). The radar has been in near-continuous operation since 1998 and has primarily been used for the study of PMSE (Latteck et al., 1999, 2007; Bremer et al., 2009, and references therein). The primary measured quantity is volume reflectivity (η, the absolute scattering cross section per unit volume) as a function of altitude. Absolute values of η are derived from observations of signal power making use of a delay line calibration described in detail in Latteck et al. (2007). The ALWIN vertical resolution is 300 m with a horizontal resolution of 7 km at 85 km altitude resulting from a beam width of 6° (between half-power points). ALWIN observes a reflectivity profile every ~5 min in time (and scans to off-vertical positions in between), and thus covers a complete range of local solar time (LT). Note that for convenience we will refer to ALWIN observations of PMSE volume reflectivity as "ice layer observations" in the remainder of this article.

ALWIN observations were used to determine the ice layer top altitude (Z_{top}), the altitude of peak η (Z_{max}), and the bottom altitude of the ice layer (Z_{bot}). An ice layer was identified when return (after background removal) was reported in one or more range gates. ALWIN volume reflectivity profiles were examined at the native 300 m resolution, and were also smoothed over the SOFIE field-of-view (FOV) for band 9 (the SOFIE band used to determine ice mass density). For this purpose, ALWIN reflectivity profiles were convolved over the SOFIE vertical FOV response function, with the ALWIN data interpolated to the SOFIE FOV function height scale which has ~70 m spacing. Z_{top}, Z_{max}, and Z_{bot} were determined for both the native and vertically smoothed ALWIN profiles, as discussed below. Concurrent wind measurements were obtained from a nearby all-sky interferometric (SKiYMET) meteor radar operating at a frequency of 32.55 MHz as described in Singer et al. (2004).

2.2. SOFIE

SOFIE was launched in April 2007 onboard the Aeronomy of Ice in the Mesosphere (AIM) satellite (Russell et al., 2009) to measure temperature, the abundance of five gaseous species (O_3, H_2O, CO_2, CH_4, and NO), PMCs, and meteoric smoke (Gordley et al., 2009; Hervig et al., 2009a, 2009b). The SOFIE FOV subtends ~1.6 km vertically and the tangent point sample volume length is ~290 km along the line-of-sight (LOS). SOFIE retrievals are reported on the over-sampled vertical spacing of 200 m, which results from the detector sampling frequency on-orbit. Observations are taken continuously at latitudes from 65° to 82°S (spacecraft sunset) and 65° to 82°N (sunrise) (Fig. 1). Each day SOFIE observes 15 sunsets (and 15 sunrises) at virtually the same latitude, and adjacent observations are separated by ~955 km and ~1.6 h. During mid-summer, SOFIE sunsets occur at ~1 LT and sunrises occur at ~23 LT. This work uses version 1.022 SOFIE results, which are available online (www.sofie.gats-inc.com). SOFIE measurements are used to determine a variety of ice properties including ice mass density (M_{ice}), particle shape, effective radius (r_e), and the parameters of a Gaussian size distribution (concentration (N), median radius (r_m), and distribution width (Δr)) as described in Hervig et al. (2009a). The SOFIE ice extinction measurements have precisions of 5×10^{-8} km^{-1} (Gordley et al., 2009). SOFIE observations are used to determine Z_{top} and Z_{bot}, and Z_{max} as the altitude of peak M_{ice}. This definition is different than for the radar Z_{max}, a matter which is examined below. In this work Z_{bot} was determined using the approach described in Hervig et al. (2009c), which eliminates most of the ice detections at erroneously low altitudes caused by PMCs in the near or far reaches of the LOS. In addition, PMCs with $Z_{max} < 80$ km were also eliminated since these are known to be within the far reaches of the LOS (Hervig et al., 2009a).

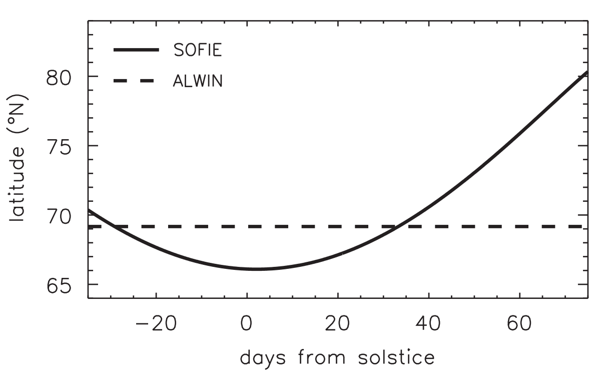

Fig. 1. Measurement latitude versus time. SOFIE results are for 2008, and are nearly identical in other years.

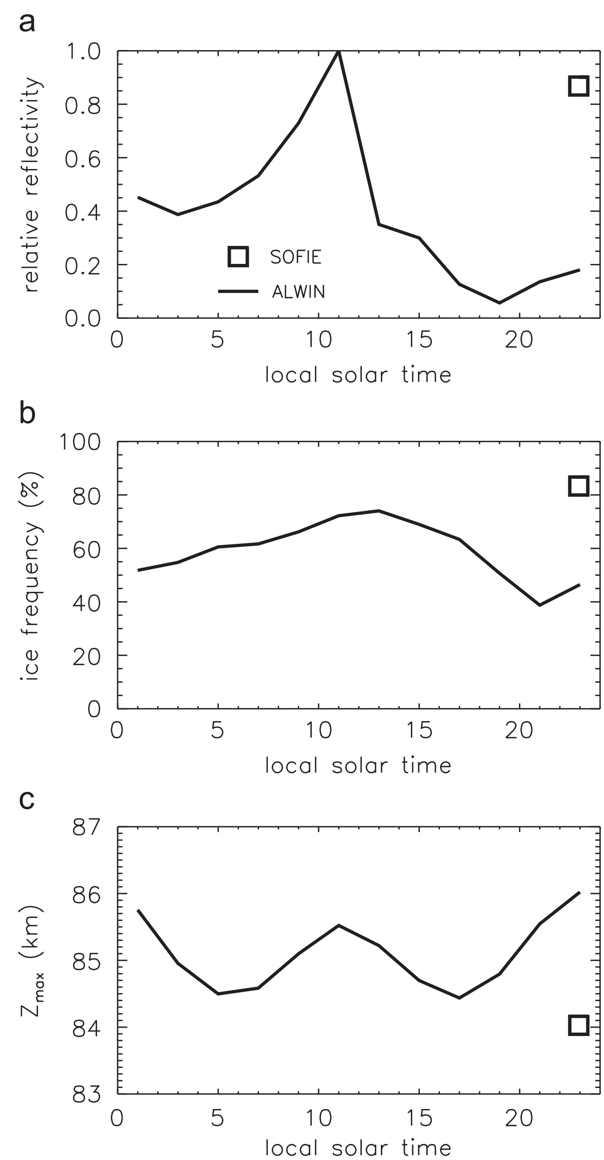

Fig. 2. Local solar time dependence of (a) reflectivity, (b) ice occurrence frequency, and (c) Z_{max}, as averages for ALWIN observations during May 22–August 30, 2008. SOFIE results near the ALWIN longitude are shown, and the SOFIE result in (a) is relative ice mass density.

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