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Consequences of recent Southern Hemisphere winter variability on polar mesospheric clouds

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ABSTRACT

Variations in the Southern Hemisphere (SH) winter of 2007, 2008 and 2009 had important consequences on polar mesospheric clouds (PMCs) observed in the corresponding Northern summers. Specifically, the stratospheric SH winter of 2007 was observed to be warmer than in 2008 and 2009. Using the high altitude analysis from the Navy Operational Global Atmospheric Prediction System-Advanced Level Physics High Altitude (NOGAPS-ALPHA) forecast/assimilation system we show that this warmth was linked to similar temperature increases in the high latitude summer mesosphere. These temperature changes led to a dramatic reduction in PMC occurrence (factor of 5–6) recorded by the SHIMMER instrument at sub-arctic latitudes and a factor of 2 decrease in total ice water content in PMCs seen by the SOFIE instrument on the NASA AIM satellite. Microphysical modeling confirms the overall effect of these temperature changes on PMCs at high latitudes; however, a detailed comparison of the cloud occurrence with the SHIMMER data for all three years shows that the clouds are associated with a surprisingly wide range (130–165 K) of temperatures.

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1. Introduction

It is now generally understood that the climatology of the middle atmosphere differs greatly between Northern and Southern Hemispheres. Due to greater land sea contrasts and greater topography, the North experiences more wintertime planetary wave activity, which leads to greater wave induced heating in the NH winter stratosphere, a weaker and more easily perturbed NH polar vortex, and reduced breaking of gravity waves, which contribute to the warm winter stratopause (Yulaeva et al., 1994; Garcia et al., 1992; Hitchman et al., 1989). In recent years, interest has shifted to what these differences might mean for the summer seasons in each hemisphere. Early work by Alexander and Rosenlof (1996) showed that the summer stratosphere is warmer in the SH relative to the NH due to greater gravity wave induced forcing in the southern summer. Siskind et al. (2003) showed that these stratospheric hemispheric asymmetries had mesospheric counterparts whereby there would be weaker gravity wave drag in the Southern upper mesosphere. This was suggested as a possible cause of the reduced occurrence of polar mesospheric clouds (PMCs) in the southern summer since weaker gravity wave drag would imply a warmer summer mesopause (Siskind et al., 2005a).

Most recently there has been great interest in so-called teleconnections between wintertime conditions in one hemisphere and the corresponding summer, which occurs simultaneously in the other. For middle atmospheric conditions, this interest was provoked by the unusual Southern winter of 2002. During this winter, several minor stratospheric warmings were observed (Siskind et al., 2005b), culminating in an unprecedented major warming in September (e.g. Allen et al., 2006 and references therein). At the same time, the MACWAVE rocket campaign (Goldberg et al., 2004) reported unusual conditions in the NH summer mesosphere. These included a warmer mesopause and reduced occurrence of polar mesospheric summer Echoes. Model simulations by Becker et al. (2004) and Becker and Fritts (2006) led to the suggestion that the unusually strong planetary wave activity in the Southern Hemisphere initiated a chain of events, which ultimately led to perturbations to the gravity wave drag, which produces the cold summer mesopause.

Subsequent work by Karlsson et al. (2007, 2009a and 2009b) have shown that these long range teleconnections between the winter in one hemisphere and the summer in the other occur quite often. This effect can be documented for both interannual

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variability as well as within a single season. In general, the greater planetary wave activity in the NH winter, and its large interannual variability, has a major effect on the year-to-year variability of SH PMCs. However, even though the effect is weaker, a connection between the weaker waves in the SH winter and NH PMCs could also be detected. The Karlsson et al. (2007) analysis relied on a meteorological analysis, which extended only up to 1 mb, thus excluding the mesosphere.

Here we use an analysis, which extends up to 90 km to look at interannual variability in NH PMC from 2007–2009. Section 2 presents 3 NH seasons of mesospheric cloud data from two instruments, the Solar Occultation for Ice Experiment (SOFIE) and the Spatial Heterodyne Spectrometer for Mesospheric Radicals (SHIMMER). SOFIE is on board the NASA Aeronomy of Ice in the Mesosphere (AIM) satellite (Russell et al., 2009), launched in April 2007 and as of this writing, still making measurements of the high latitude region where PMCs form. SHIMMER was the primary payload of STPSat-1, launched in March 2007 for a mission, which lasted 30 months (Englert et al., 2010). Both SHIMMER and SOFIE observed mesospheric clouds during the 2007, 2008 and 2009 Northern summer seasons, but, as we will discuss, using quite different observational techniques and from different orbits. Section 3 describes results from the synoptic analysis provided by the NOGAPS-ALPHA forecast/assimilation system. In Section 4, we describe the use of NOGAPS-ALPHA temperature, water vapor and winds to drive the Community Aerosol and Radiation Model for Atmospheres (CARMA) microphysical model. We calculate ice water content and compare that with SOFIE observations. Finally, Section 5 concludes and summarizes the major findings of this work.

2. Observations of mesospheric clouds: SOFIE and SHIMMER

2.1. SOFIE

SOFIE uses the solar occultation technique to retrieve vertical profiles of PMC extinction at eleven wavelengths ranging from the near UV to the mid IR (Gordley et al., 2009). A salient feature of SOFIE is that its observations are confined to a single latitude band. Since AIM is in a polar sun-synchronous orbit, this latitude varies in a narrow range throughout the season, increasing from 65° in late June to near 70° in August (cf. figure 3 of Gordley et al., 2009). Also SOFIE sampling remains at a single local time, near 2300 LST for the Northern summer PMC season.

Hervig et al. (2009a) gave an overview of data from the northern summer of 2007. They noted that after July 1st, there were periodic episodes of PMC decreases coincident with periodic warmings of the summer mesopause region of up to 6 K. Fig. 1 compares the frequency of occurrence for the first three Northern seasons. The SOFIE data version is 1.022. Fig. 1 shows that SOFIE is so sensitive that it often sees clouds 100% of the time. This is particularly true for 2008 and 2009. For 2007, there are periods after July 1st where the cloud occurrence frequency dips to as low as 80%. Hervig et al. (2009a) comment on these reductions in frequency and column ice mass as being consistent with a warming event which caused PMCs to sublimate. Fig. 1 shows that these mid-season cloud reductions were not pronounced in 2008 or 2009.

As described by Hervig et al. (2009b), SOFIE PMC extinctions at IR wavelengths are directly proportional to ice volume density, which given suitable assumptions for ice density, can yield the ice mass density. The vertical integral of the ice mass density yields the column ice mass, also known as ice water content (IWC). Stevens et al. (2010) and Siskind et al. (2007) have shown that the IWC is a useful quantity for comparisons between microphysical models and satellite measurements. Fig. 2 shows the SOFIE IWC for the 3 years in question. Similar to the occurrence frequencies, starting around July 1 (10 days relative to solstice), the IWC in 2007 stands out as being lower than in 2008 or 2009. This relative reduction persists until early August (around +45 days relative to solstice).

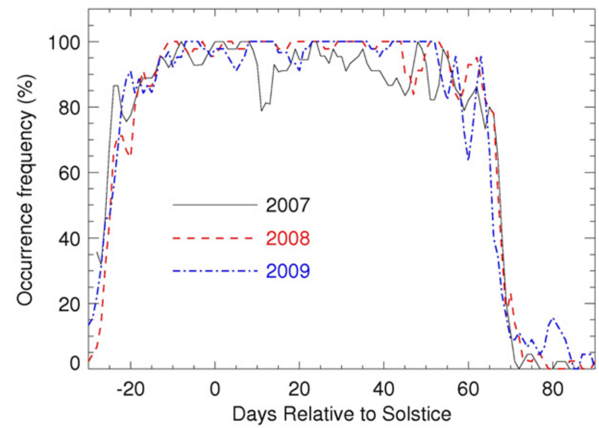

Fig. 1. Frequency of PMC occurrence observed by SOFIE for the NH summers of 2007, 08 and 09. The horizontal axis covers the period from about May 21st to September 21st. The latitude of the SOFIE occultation roughly tracks the sun and is about 66° at solstice, rising to near 80° in September (e.g. http://sofie.gats-inc.com/sofie/index.php).

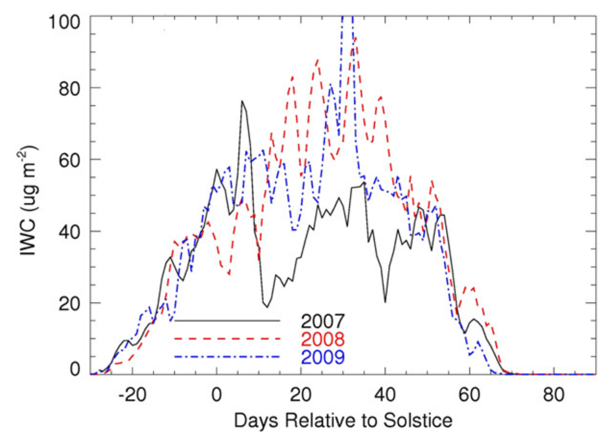

Fig. 2. PMC ice water content measured by SOFIE for the NH summers of 2007, 2008 and 2009. The *x*-axis is the same as Fig. 1.

2.2. SHIMMER

The SHIMMER data nicely complement the SOFIE data. While, like SOFIE, SHIMMER viewed clouds on the limb, instead of occultation, it viewed the scattered sunlight from the clouds. As discussed in Stevens et al. (2009), solar scattered light from PMCs occasionally enhances the Rayleigh scattered signal observed by SHIMMER near 309 nm and between about 80 and 85 km altitude. To identify PMCs we fit an exponential function to the background away from altitudes where PMCs could contaminate the fit. The imposed threshold for cloud detections is furthermore a function of the solar scattering angle to minimize the effects of lighting variations on our detections. As a result of the STPSat-1 orbit, SHIMMER records data over a wide range of local times, with a precession rate of about 1/2 h/day. Over the course of the PMC season, SHIMMER sampled all local times for which the clouds were illuminated.