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# A model study of global variability in mesospheric cloudiness

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## Abstract

We have performed microphysical calculations of mesospheric cloudiness which are driven by output (vertical wind, water vapor mixing ratio and temperature) from a two-dimensional (2D) global chemical/dynamical model. The variations in the 2D model output drive variations in the simulated clouds which can be compared with cloud observations. The specific cloud observables we model are ice content, altitude, peak backscatter at 532 nm and albedo at 252 nm. We categorize these parameters in terms of their variations with latitude, solar activity and hemisphere (north vs. south). In agreement with observations, we find brighter clouds in the Northern Hemisphere (NH) relative to the south and at solar minimum relative to solar maximum. Also we find that cloud altitudes are higher in the Southern Hemisphere (SH) relative to the NH. Quantitatively, compared with observations, it appears that the model may overstate the magnitude of these variations. Thus, the entire range of observed cloud altitudes, poleward of 65–70°, is about 2 km (83–85 km), whereas the range in the calculated heights range extends up to 5 km (83–88 km). In addition, the calculated solar cycle brightness change of up to an order of magnitude appears larger than the limited available observations. Since the model $H_2O$ variation in the 80–90 km region with respect to solar activity is relatively small (10–40%), it is not the cause of our large model cloud variability. Rather, for both hemispheric variation and solar cycle changes, we suggest that the model temperature variability may be too great.

*Keywords:* Middle atmosphere; Solar cycle; Microphysics; Mesopause

## 1. Introduction

Since the late 19th century, mesospheric clouds have captured the interest of aeronomers for several reasons. First, they occur in one of the most extreme conditions of the earth's atmosphere: the very cold summer mesopause. Second, there is the continued speculation that the very existence of these clouds is due to anthropogenic influences on middle atmospheric composition and climate (Thomas et al., 1989; Thomas, 1996), although this is controversial (e.g. von Zahn, 2003).

Historically, most of the measurements of these clouds have been from Northern Europe or Canada, via ground-based observatories. In this manifestation, they have been known as noctilucent clouds (NLCs) (Fogle and Haurwitz, 1966; von Cossart et al., 1999; Lübken et al., 1996). In the last 30 years, these observations have been expanded to include ground-based measurements from Antarctica (Chu et al., 2001) as well as global satellite-based data (Thomas, 1991; DeLand et al., 2003). Thomas (1991) advocated the term polar mesospheric clouds (PMCs) to emphasize the global nature of these clouds and that is the term we use here.

Early measurements from the Solar Mesosphere Explorer (SME) (Thomas and Olivero, 1989) showed

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the existence of a well-defined season for PMC formation that was linked to the existence of the cold summer mesopause. In addition, SME data showed that clouds occurred more frequently at higher latitudes; this is generally attributed to lower temperatures as one approaches the summer pole (Thomas, 1991). Modeling studies have confirmed that MC formation depends sensitively on the climate of the high latitude summer mesopause region. Thus, observations of these clouds can provide constraints on more general properties of the atmosphere.

For example, one important PMC diagnostic is the altitude at which they are observed. Chu et al. (2001, 2003) have recently presented data and a model analysis which indicated that mesospheric clouds over the South Pole (SP) were at a higher altitude than in the Northern Hemisphere (NH). This would appear to contradict the results of Carbary et al. (1999), who found PMCs to be at the same altitude worldwide. If PMCs are truly higher over the SP, it suggests a difference in mesospheric climates between the NH and the Southern Hemisphere (SH) perhaps in the temperature. Differences in temperature and/or the water vapor abundance might also be the cause of variability in the frequency of PMC occurrence reported by several satellites. The suggestion of a warmer (or dryer) SH mesopause region might be inferred from the dimmer and less frequent clouds seen in the SH according to satellite data (DeLand et al., 2003; Hervig et al., 2003). Woodman et al. (1999) made this argument to explain the relative paucity of SH Polar Mesospheric Summer Echoes (PMSE), a phenomena related to PMCs. However, the question of north–south (N–S) mesopause temperature differences has been the subject of debate as Lübken et al. (1999) reported little difference in the Antarctic summer mesopause temperature as compared with similar data taken in the Arctic.

Recently, Siskind et al. (2003) (hereinafter S03) published an analysis of two-dimensional (2D) model results (from the NRL two-dimensional chemical/dynamical model of the middle atmosphere (CHEM2D) model), which supported the idea of a warmer SH summer mesopause. This conclusion was based upon the effects of relatively well-documented N–S differences in the summer climates of the underlying stratosphere and troposphere on gravity wave propagation to the mesosphere. They suggested that their results implied fewer and weaker PMCs and PMSEs in the SH relative to the NH. Earlier, Garcia (1989) suggested that a solar cycle should exist in mesospheric clouds with fewer clouds at solar maximum when $H_2O$ photodissociation should peak. However, neither modeling study quantified what those differences would be; that would have required a microphysical model capable of translating the calculated differences in mesopause climate into cloudiness differences. In the present paper, we do just that, i.e. we use a microphysical model driven by output from CHEM2D to more precisely quantify the expected N–S differences in mesospheric cloudiness and in the variability of that cloudiness. Our results can both validate the CHEM2D simulations as well as provide testable hypotheses suitable for observational verification.

## 2. Model approach

Our overall approach is to use a CHEM2D to specify the atmospheric basic state. The relevant outputs, $H_2O$, vertical wind ($w^*$) and temperature ($T$) are then used to drive a one-dimensional (1D) version of the Community Aerosol Radiation Model for Atmospheres (CARMA). Currently, there is no feedback from the microphysical results on the CHEM2D model; this is planned for future work. These models are described in more detail below.

The CHEM2D model and its application to the study of the summer mesopause was most recently described by S03. Since that work, we have incorporated two major changes to the model. First, the model top was extended up to 125 km ($p_{\mathrm{min}} = 2.5\mathrm{e}-5\,\mathrm{mbar}$), from about 105 km ($p_{\mathrm{min}} = 2\mathrm{e}-4\,\mathrm{mbar}$). Raising the top altitude increases our confidence in calculating winds and temperatures in the 90–105 km region. Second, we use new heating and cooling algorithms. For the mesosphere, we now use the code of Fomichev et al. (1998). This code has the advantage of allowing any value for the $CO_2$ mixing ratio and thus allows for a self-consistent calculation of the cooling rate with the model $CO_2$ densities. We still retain the detailed ozone heating rate calculation which is identical to the $O_3$ and $O_2$ dissociation rate calculation in the photochemical package. However, previously we used the diurnally averaged ozone to calculate the radiative heating; now we more properly use the daytime ozone (obtained by applying a precalculated night-to-day ratio from a 1D diurnal model). Since daytime mesospheric ozone is lower than the diurnal average, this means less heating and lower mesospheric temperatures than in S03. For the stratosphere, we use the CLIRAD scheme (Chou et al., 2001; Chou and Suarez, 2002; see also McCormack, 2003) for both heating and cooling. In this implementation, the stratospheric and mesospheric radiative schemes are merged using a weighted average between 30 and 50 km (note that this is 20 and 40 km in McCormack, 2003).

So that the model better simulates the PMC altitudes and brightness, we made some small changes to the gravity wave drag parameterization of S03. Specifically, by lowering the launch amplitudes of the waves given in Table 1 of S03, we raised the altitudes at which they saturate and break. We “tuned” the gravity wave amplitudes until the CARMA model produced clouds