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A comparison between ground-based observations of noctilucent clouds and Aura satellite data

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ABSTRACT

A comparison is made between ground-based observations of noctilucent clouds (NLCs), obtained with a network of automated digital cameras, and Aura satellite data (the MLS instrument). The Aura data (water vapor and temperature) demonstrate reasonable values around the summer mesopause fostering NLC formation in June through August, when supersaturated air conditions occur. The temperature decrease leads, in general, to amplification of the NLC brightness. The 2- and 5-day planetary waves, extracted from the Aura temperature field, have definite influence on the brightness variations of NLCs. The temperature behavior around the summer mesopause at 60°N demonstrated a remarkable feature, namely, in 2007 the minimum of a Gaussian fitted seasonal temperature variation was observed, on average, 14 days earlier and was broader than the corresponding minimum in 2008. The different temperature climatology resulted in different seasonal variation of NLCs in 2007 and 2008; in particular, the maximum of a Gaussian fitted seasonal variation of the NLC brightness cycle in 2007 was advanced by 12–29 days relative to that in 2008.

1. Introduction

The highest clouds in the Earth's atmosphere are noctilucent clouds (NLCs) formed around the mesopause in the 80–90 km altitude range. These clouds are a beautiful nighttime optical phenomenon occurring during the summer months at mid- and high latitudes. NLCs consist of water ice particles of 30–100 nm in radius that scatter sunlight and thus NLCs are readily seen against the dark twilight arc from late of May until September (Gadsden and Schröder, 1989).

Satellite observations have discovered polar mesospheric clouds (PMCs) covering the entire polar mesopause region above a 70° latitude during summertime (Donahue et al., 1972). Sometimes, some "patches" of PMCs (similar to icebergs from a continent) extend to mid-latitudes and become visible from the Earth's surface as NLCs. But it is poorly understood so far what characteristic sizes of such patches are and which processes are responsible for their formation.

Planetary atmospheric waves are one of the major players in the middle atmosphere producing strong disturbances of the basic state of the atmosphere. The temperature disturbances of 1–8 K due to planetary waves (Espy and Witt, 1996; Pogoreltsev, 1999) yield a correlation between the probability of NLC appearance and the combined effect of stationary, 16- and 5-day planetary waves (Kirkwood and Stebel, 2003). The 5-day period in NLCs has been detected using ground-based observations from Western Europe (Gadsden, 1985; Kirkwood and Stebel, 2003). Dalin et al. (2008) have demonstrated a clear influence of the 2- and 5-day planetary waves on the occurrence frequency,

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geographical distribution and brightness variations of NLCs observed with a network of automatic cameras located along a 55–56° latitude circle around the globe.

The signatures of the 2- and 5-day planetary waves were also observed in PMCs from satellite data (Merkel et al., 2003, 2008). The authors have used the SNOE satellite and TIMED (SABER instrument) spacecraft data to observe PMCs at high latitudes 68–80° and retrieve temperature variations, respectively. Merkel et al. (2008) have found that during the 2002 and 2003 summer mesosphere seasons the temperature perturbations due to 2- and 5-day waves were small (2.0–3.5 K), but had a significant effect on the PMC brightness variation. Von Savigny et al. (2007) have reported on simultaneous measurements of the quasi 5-day wave in NLCs and the mesopause temperature. Their analysis has employed the Envisat satellite limb scattering measurements to detect NLCs/PMCs in the latitude band between 60° and 80° and the Aura satellite data to measure the mesopause temperature. They have found that for some periods (before and around the solstice) the quasi 5-day wave signatures in NLCs were likely caused by quasi 5-day wave signatures in the temperature field. Also, von Savigny et al. (2007) have noted high variability of NLCs (2–3 days) for certain intervals of the 2005 NLC season and questioned whether this variability may be related to the 2-day planetary wave.

In the present paper, for the first time, we compared ground-based observations of NLCs with the hemispheric network of automatic cameras and the Aura (the MLS instrument) satellite data to obtain information on humidity and temperature regime as well as to retrieve the planetary wave propagation around the mesopause in summer of 2007 and 2008.

2. Data source

After several years of experience in Moscow and Novosibirsk (Russia), an international network started to work in 2004 in Moscow, Novosibirsk and Lund (Sweden) to continuously monitor NLCs. This network has been extended for successive years, and at present it includes cameras situated in Port Glasgow, Scotland (55°N56′; 04°W41′), Athabasca, Canada (54°N44′; 113°W19′), Kamchatka, Russia (53°N04′; 158°E37′), Novosibirsk, Russia (54°N52′; 83°E06′), Moscow, Russia (56°N00′; 37°E29′), Vilnius, Salakas and Vidiskes, Lithuania (average coordinates 55°N00′; 26°E00′), Aarhus, Denmark (56°N10′; 10°E12′) in 2007 and 2008. Each camera operates from the end of May until middle of August and takes images every 1 min at night during high NLC season (June 10–July 25). The detailed description of the network of NLC cameras and operation schedule can be found in Dalin et al. (2008). The most important feature is that these NLC cameras are located along approximately the same latitude circle of 55–56°. Such geographical camera locations provide comparable NLC observations (due to equal twilight illumination conditions, as well as very similar physical conditions in the mesopause since temperature, vertical and horizontal winds are latitude dependent), and provide us with the possibility to study the NLC activity on continental scales, including effects due to gravity and planetary waves.

The following characteristics of NLCs are included into the resulting statistics for a given season: time of appearance and disappearance of NLCs, brightness, morphological forms of NLCs, weather conditions. The NLC brightness is visually estimated on a traditional 5-point scale. Detailed description of estimating the NLC parameters can be found in Romejko et al. (2003). Note that weather conditions are of importance for the NLC statistics, and we carefully select nights with good and bad weather in order to determine a real absence of NLCs on a given night.

Another data source is the Microwave Limb Sounder (MLS) instrument onboard the NASA Aura satellite which is currently operating (Waters et al., 2006). On 15 July 2004, Aura was launched into a near-polar (98° inclination), sun-synchronous orbit 705 km above the Earth, with ascending and descending equator-crossing times at 13:45 and 01:45 local time, respectively. The orbital period is about 100 min. Since the Aura orbit is nearly fixed at solar local time, Aura makes measurements for a given point in the atmosphere twice a day (ascending and descending transversals); the number of orbits per day is around 14.6. The temperature and water vapor data of the MLS instrument from 1 June to 15 August 2007 and 2008 are used in this study. The description on the MLS temperature product and its validation can be found in Froidevaux et al. (2006) and Schwartz et al. (2008). The validation of water vapor data is described in detail by Read et al. (2007) and Lambert et al. (2007). The Aura/MLS data ver.2.2 were obtained from the NASA public web-site: http://disk.sci.gsfc.nasa.gov/Aura/data-holdings/MLS/ml2t.002.shtml.

3. Methodology of the data analysis

It is important to note that the Aura data (and data of any satellite) are discrete and asynchronous in nature, the universal time of an observation and longitude is mutually dependent; satellite's orbital tilt results in irregular sampling between ascending and descending nodes (Salby, 1982). Also, since the number of orbits per day is non-integer, there is a phase drift of the longitudinal nodes for any particular latitude circle for subsequent days. Besides, data voids usually exist. To overcome many of these problems one can make an interpolation of asynoptic satellite observations in space (in longitude and latitude) and time on a fixed grid, retrieving a twice-daily sequence of synoptic maps (Rodgers, 1976); this technique is employed in the present paper.

We apply a double Fourier transform (in longitude and time) to the temperature field for each latitude (horizontal spacing in latitude is 1.5°) from $-50°$ to $+68°$ and height from 20 to 110 km. Riggin et al. (2006) have employed the same procedure in the analysis of the SABER data onboard the TIMED satellite. The time resolution of a sequence of synoptic maps is 12 h. The vertical grid is defined on 29 levels, with the vertical resolution varying from 3 km in the stratosphere to 12–14 km around the mesopause. Since 15 longitudes are sampled twice a day, the periodic oscillations with zonal wavenumbers from -7 to 7 are possible to retrieve, with the Nyquist frequency being 1 day^{-1}.

The time series of temperature amplitude and phase (expressed as a complex amplitude for westward propagating zonal wavenumber one, W1) is filtered by a 5-pole bi-directional Butterworth filter, in the frequency domain that passes periods between 4 and 7 days, to retrieve the 5-day component. By using a filter with complex coefficients, there can be extracted westward traveling waves only; by employing a bi-directional filter, the artificial phase shifts are eliminated. In the same manner, temperature perturbations due to a westward traveling 2-day planetary wave of zonal wavenumber 3 (W3) have been obtained by applying a band-pass filter to reveal oscillations with periods between 1.7 and 3.2 days.

The planetary wave analysis has been performed on both the nighttime and daytime data to get as high temporal resolution as possible (12 h) to avoid a possible aliasing effect in the Fourier analysis for the 2-day planetary wave. Thus, time series of temperature field perturbations due to the westward propagating 2- and 5-day planetary wave, as a function of height and latitude, are derived. Then, only periodic oscillations along a 60°N latitude circle are chosen to be compared with observations of NLCs. Estimations of the NLC brightness are compared to temperature disturbances, and finally the linear regression analysis is employed