Journal of Atmospheric and Solar-Terrestrial Physics ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

Characterisation of quasi-stationary planetary waves in the Northern MLT during summer

Nora H. Stray [a,*], Patrick J. Espy [a,b], Varavut Limpasuvan [c], Robert E. Hibbins [a,b]

[a] Department of Physics, NTNU, Trondheim, Norway
[b] Birkeland Centre for Space Science, Bergen, Norway
[c] School of Coastal and Marine Systems Science, Coastal Carolina University, SC, USA

ARTICLE INFO

Article history:
Received 1 July 2014
Received in revised form
11 November 2014
Accepted 5 December 2014

Keywords:
Planetary waves
MLT
SuperDARN
Meteor winds

ABSTRACT

Observations of planetary wave (PW) activity in the northern hemisphere, polar summer mesosphere and lower thermosphere (MLT) are presented. Meteor winds from a northern hemisphere chain of SuperDARN radars have been used to monitor the meridional wind along a latitude band (51–66°N) in the MLT. A stationary PW-like longitudinal structure with a strong zonal PW number 1 characteristic is persistently observed year-to-year during summer. Here we characterize the amplitude and the phase structure of this wave in the MLT. The Modern-Era Retrospective Analysis for Research and Application (MERRA) of the NASA Global Modelling and Assimilation Office has been used to evaluate possible sources of the observed longitudinal perturbation in the mesospheric meridional wind by investigating the amplitudes and phases of PWs in the underlying atmosphere. The investigation shows that neither gravity wave modulation by lower atmospheric PWs nor direct propagation of PWs from the lower atmosphere are a significant cause of the observed longitudinal perturbation. However, the data are not of sufficient scope to investigate longitudinal differences in gravity wave sources, or to separate the effects of instabilities and inter-hemispheric propagation as possible causes for the large PW present in the summer MLT.

1. Introduction

Planetary waves are global scale waves where the latitudinal gradient of the Coriolis force serves as the restoring force. They can be generated in the lower atmosphere and, due to their westward intrinsic phase speeds (Forbes, 1995), they transport energy and westward momentum as they propagate upward, growing in amplitude.

Charney and Drazin (1961) showed using a simplified analytical solvable system of the atmosphere that planetary waves can only propagate into regions where the zonal mean wind is more eastward than the zonal phase velocity of the wave. The strong westward stratospheric winds that form during summer at mid- to high-latitudes should inhibit the upward propagation of planetary waves from below. More detailed analyses showed that the relationship is more complex and that vertical planetary wave propagation can be related to the effective refractive index (e.g. Smith, 1983; McDonald et al., 2011). In the quasi-geostrophic approximation, this refractive index depends primarily on the zonal wind and its latitudinal and vertical gradients (Smith, 1983). Nevertheless, vertical planetary wave propagation through the stratosphere from below is still unlikely during summer, and several studies have shown that there is little planetary wave activity present in the middle atmosphere during summer (e.g. Alexander and Shepherd, 2010; McDonald et al., 2011).

In spite of this, signatures of planetary waves in the summer mesosphere and lower thermosphere (MLT) have been modelled and observed (e.g. Forbes et al., 1995; Espy et al., 1997; Wang et al., 2000; Smith, 2003). Since vertical propagation through the stratosphere is unlikely during summer, the existence of planetary waves in the summertime MLT is puzzling. It has been suggested that the planetary wave signatures in the MLT might arise from the breaking of gravity waves whose momentum flux has been modulated by the selective filtering of the planetary waves present in the lower atmosphere (Smith, 2003). That is, gravity waves with eastward momentum would reach their critical levels in the eastward phase of the planetary waves (as manifested in the zonal wind field), allowing gravity waves carrying westward momentum to reach the MLT, and vice versa. The gravity waves that reach and break in the MLT would deposit their momentum and force the mean wind, imprinting in the MLT a mirror image of the planetary wave in the lower atmosphere.

* Corresponding author.
E-mail address: Nora.Kleinknecht@ntnu.no (N.H. Stray).

http://dx.doi.org/10.1016/j.jastp.2014.12.003
1364-6826/© 2014 Elsevier Ltd. All rights reserved.

Free travelling planetary waves are also possible in the summer mesosphere. These waves are considered to be global normal (resonant) modes that are not maintained by particular travelling forcing effects (Andrews, 1987). As shown by Salby (1981), the amplitudes of these wave disturbances can become large locally when the background wind speed approaches their phase speeds. The most prominent travelling wave in the summer mesosphere is the so-called 2-day wave (e.g. Limpasuvan and Wu, 2003). These features take on zonal wave numbers 2–4 and tend to amplify shortly after the solstice. As discussed below, fluctuations associated with the 2-day wave are removed in our analyses so their impacts are not relevant to our results.

Additionally, in situ generation of planetary waves by the baroclinic and barotropic instabilities created by the steep wind and temperature gradients in the middle atmosphere near solstice (e.g. Plumb, 1983; Baumgaertner et al., 2008) have also been proposed as a possible source of planetary waves in the MLT. Finally, it has been suggested that the source of the planetary waves in the summertime MLT might be the winter hemisphere, where the waves duct along the near-zero wind line that stretches from the winter stratosphere into the summer mesosphere (e.g. Forbes, 1995; Espy et al., 1997; Hibbins et al., 2009). While all these mechanisms are plausible and fit the existing measurements, there has been a lack of simultaneous observations of planetary wave amplitudes and phases, as well as the underlying wind field during summer that could be used to separate the relative importance of these proposed mechanisms.

Here observations of summertime wave number 1 (S_1) and 2 (S_2) planetary wave activity in the MLT (~95 km) are derived from meteor winds recorded with a chain of SuperDARN radars using the technique described by Kleinknecht et al. (2014). The possible sources of these planetary wave-like longitudinal perturbations of the MLT meridional wind that show a stable phase behaviour from year to year are evaluated using the underlying winds from the Modern-Era Retrospective Analysis for Research and Application (MERRA) of the NASA Global Modelling and Assimilation Office (Rienecker et al., 2011). By combining these data sets we discuss which of the proposed mechanisms for the appearance of planetary waves in the summertime MLT are likely.

2. Data

In order to examine the wind and planetary wave field in the mesosphere and the lower thermosphere (MLT), meridional winds have been retrieved from the meteor winds at each of 8 SuperDARN radars (Greenwald et al., 1985, 1995) at high northern latitudes (51–66°N). Since the orientation of most of the SuperDARN radars is toward the north, the meridional component derived from the line of sight winds of all beams is used due to its smaller uncertainty. Planetary wave amplitudes with wave numbers 1 and 2 in the mesopause region (~95 km) have been retrieved from these meridional meteor winds by taking advantage of the longitudinal chain (150°W–25°E) formed by these 8 SuperDARN radars. The technique is fully described and the validation studies are presented in Kleinknecht et al. (2014). Briefly, after an initial quality check, a daily mean wind, the 24-h, 12-h and 8-h sinusoidal tidal periods and a 2-day wave period were fitted to a 4-day sliding window of the hourly meridional wind for each of the 8 SuperDARN stations. The window was shifted in 1 day intervals to retrieve the time series of daily mean meridional winds at each station. These daily mean meridional winds at each station are then fitted as a sinusoidal function of longitude with 360° (S_1) and 180° (S_2) spatial periods to retrieve the amplitude and the phase of the wave number 1 and 2 components for each day.

To quantify the lower atmosphere, the zonal and meridional winds from MERRA (Rienecker et al., 2011) have been used to monitor the wind structure in the troposphere and the stratosphere. The horizontal resolution of the MERRA data used in this study is 0.5° × 3.3° (latitude × longitude). The vertical grid consists of 72 pressure levels from the ground to 0.015 hPa (~80 km). MERRA is measurement driven up to approximately 50 km (~1 hPa), above which it is free running. For this analysis only the measurement driven region of MERRA has been used. Since MERRA outputs are produced four times a day (0, 6, 12, and 18 UT), the daily means of the meridional wind averaged over the latitude band between 51°N and 66°N were produced to minimise tidal effects and to obtain wind profiles at latitudes similar to the latitude coverage of the SuperDARN chain.

Fig. 1 shows an altitude–longitude profile of the meridional (left panel) and the zonal (right panel) wind produced by MERRA for the 18 July 2000 between the ground and 1 hPa averaged over the latitude band of 51–66°N.

Red and blue colours signify poleward (eastward) and equatorward (westward) meridional (zonal) winds, respectively. While the zonal-mean zonal wind is predominantly eastward in the troposphere and turns westward in the stratosphere due to surface and ozone heating, the zonal-mean meridional wind is close to zero throughout the troposphere and the stratosphere due to geostrophic balance. Fig. 1 also shows that there are strong

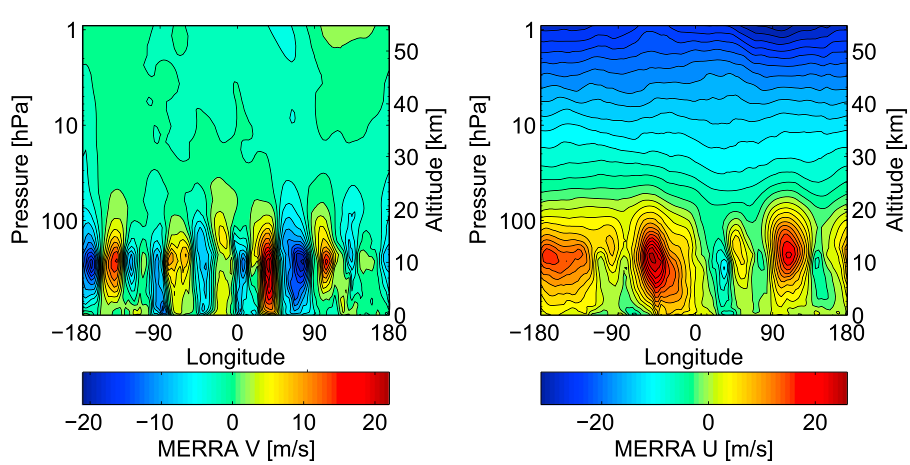

Fig. 1. MERRA meridional (left) and zonal (right) wind (m/s) for the 18 July 2000 between the ground and 1 hPa (~50 km) averaged over the latitude band between 51°N and 66°N. Red and blue colours signify poleward (eastward) and equatorward (westward) winds, respectively.

Please cite this article as: Stray, N.H., et al., Characterisation of quasi-stationary planetary waves in the Northern MLT during summer. Journal of Atmospheric and Solar-Terrestrial Physics (2014), http://dx.doi.org/10.1016/j.jastp.2014.12.003