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Propagation of short-period gravity waves at high-latitudes during the MaCWAVE winter campaign

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Abstract. As part of the MaCWAVE (Mountain and Convective Waves Ascending Vertically) winter campaign an all-sky monochromatic CCD imager has been used to investigate the properties of short-period mesospheric gravity waves at high northern latitudes. Sequential measurements of several nightglow emissions were made from Esrange, Sweden, during a limited period from 27–31 January 2003. Coincident wind measurements over the altitude range (∼80–100 km) using two meteor radar systems located at Esrange and Andenes have been used to perform a novel investigation of the intrinsic properties of five distinct wave events observed during this period. Additional lidar and MSIS model temperature data have been used to investigate their nature (i.e. freely propagating or ducted). Four of these extensive wave events were found to be freely propagating with potential source regions to the north of Scandinavia. No evidence was found for strong orographic forcing by short-period waves in the airglow emission layers. The fifth event was most unusual exhibiting an extensive, but much smaller and variable wavelength pattern that appeared to be embedded in the background wind field. Coincident wind measurements indicated the presence of a strong shear suggesting this event was probably due to a large-scale Kelvin-Helmholtz instability.

Keywords. Atmospheric composition and structure (Airglow and aurora) – Meteorology and atmospheric dynamics (Middle atmospheric dynamics; Waves and tides)

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1 Introduction

The MaCWAVE (Mountain and Convective Waves Ascending Vertically) program was designed to investigate the influence of gravity waves of various scale sizes on the high-latitude Mesosphere and Lower Thermosphere (MLT) region (altitude ∼80 to 100 km). Two intensive campaigns were conducted from northern Scandinavia using a variety of ground based radar, optical and in-situ rocket borne measurements centered on two key sites: Andenes, Norway (69.3° N, 16.0° E), summer 2002 and Esrange, Sweden (67.9° N, 21.1° E) during January 2003. The Norwegian measurements were conducted during July 2002 and focused primarily on wave activity in the vicinity of the cold summertime mesopause. In contrast, Esrange, Sweden was the focus of the winter-time mountain wave measurements with two main rocket salvos during January 2003. In each campaign the key goals were to quantify the seasonal effects of differing gravity wave forcing of the MLT region (Goldberg et al., 2006).

In particular, the winter-time measurements were designed to measure the structure and propagation of orographically generated waves due to expected strong eastward wind flow over the Scandinavian mountain range that separates the two main sites. The primary goal was to track the mountain waves from their lower altitude source region up into the MLT where they were expected to create instabilities and significant wave-mean flow interactions. Previous studies using balloon and airborne measurements have revealed that northern Scandinavia is a very active winter-time site for the penetration of mountain waves into the MLT region with the waves often reaching large amplitudes (Bacmeister et al.,

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1994). Significant mountain wave activity was detected during the campaign using rocket-borne falling spheres wind and temperature data (Wang et al., 2006). However, a sudden stratospheric warming occurred on 18 January, shortly before the main sequence of measurements began, which significantly altered the mean wind field around the 50 km level (Blum et al., 2006), including a shear in the zonal mean flow, that acted to block the upward penetration of mountain waves into the mesosphere. Although this shear prevented further upward penetration of mountain waves (which exhibit zero or very low phase speeds), our measurements show that it did not impede gravity waves of other origins with significantly higher phase speeds and/or different propagation directions from reaching the MLT region.

The winter time program employed a broad range of coordinated measurements from both sites including radars, lidars, and balloons to fully characterize the upstream and downstream tropospheric/stratospheric wind conditions as well as the mesospheric response primarily to gravity waves and tidal activity. As part of this program an all-sky monochromatic imaging system was deployed at Esrange to investigate short-period gravity wave activity using high resolution, sequential measurements of several nightglow emission layers occuring in the MLT region (~80–100 km). All-sky imagers have been shown to be very effective at characterizing the scale-sizes and motions of geographically extensive, short-period (<1 h) waves exhibiting vertical wavelengths >10 km (i.e. significantly larger than the airglow emission layer depths). Measurements have been primarily made at mid- and low latitudes and have revealed a rich spectrum of waves (Swenson and Mende, 1994; Taylor et al., 1995b; Wu and Killeen, 1996; Taylor et al., 1997; Nakamura et al., 1999; Walterscheid et al., 1999; Smith et al., 2000; Hecht et al., 2001a,b; Ejiri et al., 2003; Medeiros et al., 2003; Nakamura et al., 2003; Brown et al., 2004; Pautet et al., 2005). These waves usually exhibit relatively high phase speeds (typically a few ten's of meters per second) and are able to penetrate rapidly (few hours) from their tropospheric source regions into the MLT where they saturate and break, depositing significant amounts of momentum (Fritts and Alexander, 2003, and references therein). Indeed, it has been shown that as much as ~70% of the momentum transported into the MLT region is by short-period gravity waves (Fritts and Vincent, 1987). The culminating effect of this momentum deposition contributes significantly towards the closure of the mesospheric jets and the formation of the cold summer mesopause phenomena (e.g. Dunkerton, 1982; Holton, 1982; Nastrom et al., 1982; Garcia and Solomon, 1985; Fritts and Yuan, 1989a; Garcia, 1989).

Our initial goal was to search for mountain wave signatures in the MLT emissions. However, in the absence of such wave forcings we have focused on characterizing the waves that were present during this period. In particular, we have used coincident meteor radar wind measurements available from both sites, lidar temperature data, and falling sphere wind data to investigate the intrinsic properties of the wave events and to assess their propagation characteristics (i.e. freely propagating or ducted).

Optical observations of short-period gravity waves at high northern latitudes are relatively few, due to frequent "contamination" of the faint airglow data by strong auroral emissions (Clairemidi et al., 1985; Taylor and Henriksen, 1989). However, several well-defined, short-period wave events were measured primarily in the near infrared OH emission (peak altitude ~87 km) and the Na emission (peak ~90 km) with supporting data from the O_2(0,1) band (peak ~94 km). In each case the wave forms were found to be freely propagating throughout the MLT region. Previous measurements at lower latitudes appear to show a preponderance for ducted wave motion (Isler et al., 1997; Walterscheid et al., 1999; Hecht et al., 2001a,b; Pautet et al., 2005). As far as we are aware these are the first clear measurements establishing freely propagating wave motions at high latitude. These (limited) measurements highlight the importance for further coordinated wind, temperature, and wave studies to assess their nature and associated influence on the high latitude MLT dynamics via momentum deposition.

6 Summary

All-sky monochromatic image measurements of the high-latitude OH, Na, and O_2 nightglow emissions have been used to investigate the characteristics and propagation of short-period gravity wave events observed during the MaCWAVE winter campaign. Despite the frequent presence of aurora, several distinct wave events were measured and their horizontal characteristics were found to be similar to mesospheric waves observed at other latitudes. In particular, the observed phase speeds ranged from ~30 to 70 m/s and were predominantly southward consistent with wave generation mainly to the north of Scandinavia rather than by strong orographic forcing over the Scandinavian mountains separating the two observing sites at Andenes and Esrange.

Coincident meteor wind data and lidar temperatures have been used to perform a novel two-station investigation of the intrinsic properties of these waves as a function of time and to study their propagation. This analysis indicates that all of the band-type patterns were freely propagating throughout the MLT region. Although our measurements were limited to a short ~5 day period, they suggest the frequent presence of upward propagating gravity waves at high wintertime latitudes. Unusual extensive smaller-scale structures were also observed. These were found to be located in a region of strong wind shear and were judged to be due to a large-scale KH instability rather than propagating or ducted gravity waves. Further coordinated wind, temperature, and wave measurements are needed to investigate in detail the nature of the dominant short-period wave motions. If freely propagating wave motions are found to prevail then these results could have significant implications on the vertical transport of horizontal momentum by short-period gravity waves at high northern latitudes.