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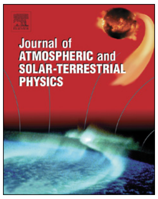

Research paper

Mid-latitude atmosphere and ionosphere connection as revealed by very low frequency signals

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ABSTRACT

Quantitative information about the effect of atmospheric influences on the variability of upper mesosphere–lower ionosphere (UMLI) region is not clearly known yet. To investigate the relationship between the lower atmosphere and UMLI region, we compared the amplitude of very low frequency (VLF) signals with the atmospheric parameters such as total column Ozone (TCO) density and stratospheric temperature at various heights for the first time for three different latitudinal regions. We show that the VLF amplitude is strongly correlated with the TCO density, stratospheric temperatures for mid-latitude propagation paths throughout the years. For high and low latitude regions, this correlation between the VLF amplitude and atmospheric parameters is poor and not significant. This study indicates the experimental observation of latitudinal dependence of atmospheric influence on the upper mesosphere.

1. Introduction

Remote sensing of the lower ionospheric region, called the D-region (60–90 km), using very low frequency (VLF) radio waves (3–30 kHz) is a very powerful technique as this method is the only viable option to monitor this region continuously and globally. VLF signals from man-made communication transmitters and natural lightning can propagate a long distance ($>10,000$ km) while reflecting back and forth within the waveguide formed by the earth surface and the lower ionosphere with small attenuation rate (2–3 dB/Mm) due to higher conductivity of the waveguide boundaries in this frequency range. Continuous monitoring of the amplitude and phase of VLF transmitter signals is very useful for the study of the upper mesosphere–lower ionosphere (UMLI) system.

The solar Lyman-α at 121.6 nm is mainly responsible for forming the normal D-region at daytime through the ionization of nitric oxide (NO). During solar flares, X-ray flux in the 0.1–0.8 nm band increases by a few orders of magnitude and ionization in the D-region overwhelms the ionization due to the Lyman-α flux (Swift, 1961; Mitra, 1974). The ionization of the upper mesospheric region during night hours is mainly due to the galactic Cosmic Rays. Atmospheric forcing from below also controls the nighttime dynamics and distribution of ions and neutral molecules as the gravity waves and planetary waves break near the mesopause region depositing maximum energy and momentum in that region (Lastovicka, 2001, 2006). Daytime reflection height of VLF signals generally varies between 71 and 74 km while the nighttime reflection height varies between 85 and 87 km (Wait, 1962; Thomson and McRae, 2009; Thomson et al., 2011; Thomson, 2010).

VLF waves have many applications especially for understanding the physical processes which leave their trace on the reflecting region, such as solar flares (Mitra, 1974; Grubor et al., 2008 and references therein), Gamma Ray Bursts (Tanaka et al., 2010; Mondal et al., 2012), solar eclipses (Clilverd et al., 2001; Chakrabarti et al., 2012; Pal et al., 2012a,b), lightning (Inan et al., 1985, 1988; Hobara et al., 2001; Kumar et al., 2008; Haldoupis et al., 2013) and others. Also there is another very important aspect of VLF monitoring to predict future earthquakes. Prior to earthquakes, lithosphere–atmosphere–ionosphere coupling is thought to take place (Pulinets et al., 2000; Korepanov et al., 2009). Seismogenic perturbations on the VLF signals have been extensively studied by many working groups (Hayakawa et al., 1996; Hayakawa and Hobara, 2010; Chakrabarti et al., 2010), but still it is uncertain whether VLF signals prior to earthquakes could be a sole potential parameter for short term earthquake prediction (Clilverd et al., 1999; Cohen and Marshall, 2012). Thus the relation between the upper mesosphere–lower ionosphere and lower lying atmosphere is an important topic to study, since the coupling mechanism between atmosphere and ionosphere is still not surely known and is under serious investigations.

There are very few reports describing the relations between

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VLF amplitude and stratospheric/mesospheric temperature (Correia et al., 2011; Silber et al., 2013; Pal et al., 2014). Silber et al. (2013) reported a high anti-correlation between the mesopause temperature and daytime VLF amplitude and showed that ~72% variability of the mesosphere temperatures and daytime VLF amplitudes could be explained by global seasonal solar irradiance changes with remaining variability from other ionizing sources.

On the other hand, coupling between the stratosphere and mesosphere or ionospheric F-region during stratospheric sudden warming (SSW) events has been reported by Goncharenko and Zhang (2008) and Goncharenko et al. (2012). They have shown a simultaneous increase in the variability of ionospheric total electron content and stratospheric Ozone suggesting the Ozone perturbations could affect the ionosphere through the modified tidal forcing.

This paper makes an effort to find any possible relation between lower lying atmosphere and upper mesosphere. We compare two years of VLF amplitude data with the atmospheric total column Ozone and stratospheric temperatures. As a result, we find a good correlation between atmospheric parameters and VLF amplitude for mid-latitude radio paths compared to high and low latitude radio paths which suggests latitudinal dependence of atmosphere and ionosphere connection.

2. Observational data

In this paper, we have analysed the VLF data for three transmitters NLK (24 kHz), NPM (22 kHz) and NWC (19.8 kHz) received at two places, Chofu (CHF, lat: 35.6°N, long: 139.5°E) and Kasugai (KSG, lat: 35.2°N, long: 137°E) in Japan for the time period of 2011–2013. These VLF receiving stations are part of the UEC's VLF/LF observation network. The position of the VLF transmitters and receiving systems are shown in Fig. 1. Two receivers at CHF and KSG are separated by a distance of about 250 km. The propagation paths under investigation can be divided into three categories: propagation paths involving the NLK transmitter are high latitude paths (sub-auroral), those involving the NPM transmitter are called mid-latitude or sub-tropical paths and the paths involving the NWC transmitter are tropical paths. All the receiving stations are equipped with identical vertical electric field antenna and SoftPAL VLF receiver. SoftPAL is a PC based software VLF receiver which continuously measures and records the phase (relative to GPS time) and amplitude of VLF signals from the transmitters (Adams, 1990). During the period of investigation, the receiver conditions were not disturbed and were thus maintained at a constant gain. Therefore the observed changes in VLF amplitudes are mostly from the change in upper mesospheric conditions.

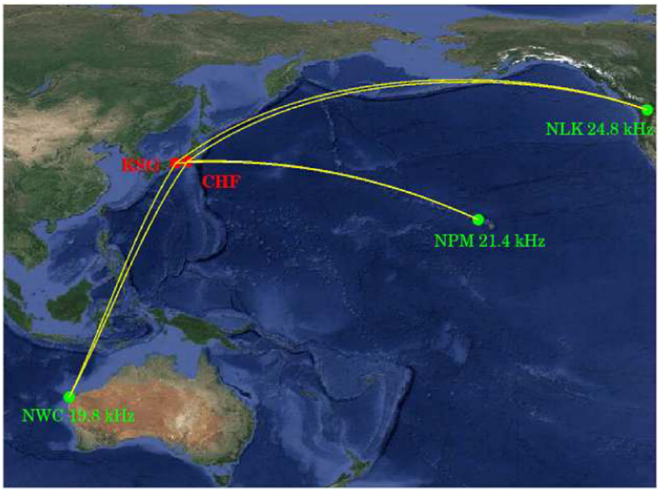

Fig. 1. Geographical location of the transmitters and receiver: involved high latitude VLF path, middle latitude and tropical VLF paths.

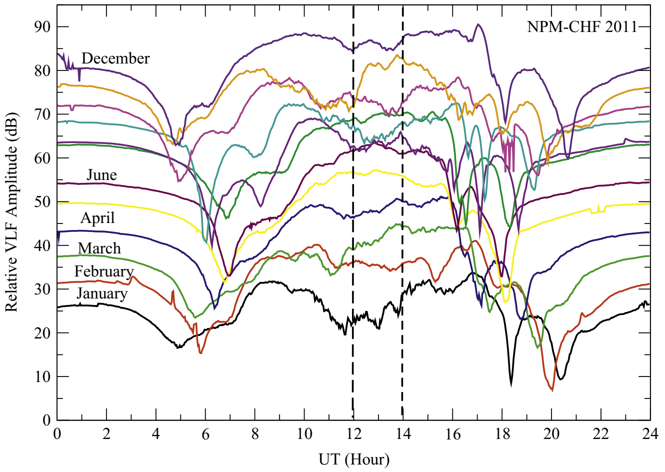

Fig. 2. Seasonal variation of VLF amplitude in terms of diurnal variations for the NPM-CHF propagation path. Black dotted vertical lines signify the time period for which average amplitude data are calculated (12–14 UT).

Amplitude and phase measurements of VLF transmitter signals typically include strong diurnal variations. For our work we analysed the amplitude part only. Instead of taking the amplitude value corresponding to a particular time, we took 2 h amplitude average from the diurnal curve of each day suitably around midnight (NLK: 11-13 UT, NPM: 12-14 UT, NWC: 14-16 UT) (shown in Fig. 2 for the NPM-CHF path as an example) throughout the years. This also helps to minimize the short-term fluctuations due to trimpi events or nighttime space weather or particle precipitation events onto the ionosphere.

To establish the relation between the upper mesosphere and lower atmosphere, we compare the nighttime VLF amplitude with the nighttime atmospheric parameters (such as Ozone density and temperature) obtained from the satellite borne instruments. Total column Ozone (TCO) density is obtained from the Ozone Monitoring Instrument (OMI) which is a nadir-viewing near-UV/visible CCD spectrometer on board the NASA's Aura satellite, launched in July 2004 (OMI AURA Level 3 data from the website http://disc.sci.gsfc.nasa.gov/Aura/). Aura flies in a near polar Sun-synchronous (98.2° inclination) orbit that crosses the equator at 0145 local time. OMI measures backscattered hyperspectral radiances in the UV/visible range of 270–500 nm in three channels (UV-1: 270–310 nm, UV-2: 310–365 nm, and visible: 350–500 nm) at spectral resolution of 0.42–0.63 nm (Levelt et al., 2006). The horizontal resolution is 13 km × 48 km for UV-1 and 13 km × 24 km for UV-2 and visible channels at nadir, and its horizontal sampling extends up to ± 1300 km from nadir, providing global coverage once a day (Pittman et al., 2009).

Stratospheric temperatures at different heights ranging from 30 km to 50 km are obtained from the Atmospheric Infrared Sounder (AIRS) Level 3 data, http://disc.sci.gsfc.nasa.gov/AIRS. The AIRS is a facility instrument on board the NASA's polar-orbiting Earth Observing System (EOS) Aqua satellite which also flies in a polar Sun-synchronous orbit (98.2° inclination) with equator-crossing time at 0130 (descending) and 1330 (ascending) local time providing global coverage twice a day. AIRS determines atmospheric temperature with a high resolution spectrometer in the thermal infrared/visible region with an accuracy of 1 K per 1 km thick layer in the atmosphere . In this study, we use Level 3 data for both OMI and AIRS (descending) downloaded with a spatial