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Distribution functions and statistical parameters that may be used to characterize limb sounders gravity wave climatologies in the stratosphere

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Abstract

The number of gravity wave (GW) activity climatologies in the stratosphere started to increase more than 10 years ago since the appearance of large amounts of limb and nadir satellite sounders data. There have been very few discussions regarding the adequate statistical description of GW activity in terms of a distribution function and its parameters. We put forward the question whether a general statistical functional representation adaptable to the characteristics of GW activity in diverse geographic regions and seasons exists. Here we approach this issue for two different types of limb sounders and in particular we try to find out which parameters may represent at best the climatological features. We study results for a region close to the Patagonian Andes and their prolongation in the Antarctic Peninsula, which is well-known for the generation by topography of intense stratospheric GW, specially during winter and spring. Global Positioning System (GPS) radio occultation (RO) records presently provide over 2000 profiles per day. We used 5 years of COSMIC (Constellation Observing System for Meteorology, Ionosphere and Climate) mission GPS RO data, which supplied almost 150,000 retrievals for our study. Three different distribution functions have been approached to describe the GW activity climatologies: gaussian, log-normal and gamma. The latter function has not been used in previous work. It has been shown here that it is a competitive option to the log-normal distribution. In addition, its use allows not only to quantify the GW activity level of each climatology in the stratosphere, but also to find out the number of significant modes that essentially determine it. Alternative parameters to the mean like the median may be used to characterize the climatologies. The use of the median may exhibit advantages in cases where the presence of spurious large GW activity measurements are suspected in GPS RO data. The mean is equally suitable to establish GW activity comparisons. As a priori we may not know if the above mentioned artifacts are present, in general it may be more appropriate to use the median. We perform a similar general study for data from the SABER (Sounding of the Atmosphere using Broadband Emission Radiometry) limb instrument, as it is presently also used to obtain global GW climatologies in the stratosphere. Although the observational window and data processing features are not identical for both instruments, the results exhibit many similarities.

Keywords: Gravity waves; Limb sounders; Statistical descriptions

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1. Introduction

About 20 years ago it was possible to approach gravity wave (GW) activity climatologies for a limited amount of soundings in restricted areas and times (e.g., Allen and Vincent, 1995). Recent advances in satellite remote sensing technology have begun to provide valuable information on GW, so global and regional studies in the stratosphere have spread. Satellite data acquired using limb and nadir techniques have demonstrated great potential for studying GW sources and their propagation (e.g., Wu et al., 2006), but not all instruments can optimally contribute to the construction of GW climatologies. Some of them have no reliable records for several years or they provide a fair number of profiles per day or they exhibit a poor coverage over some geographical areas.

The Global Positioning System (GPS) radio occultation (RO) technique is able to provide huge amounts of retrievals (e.g., Baumgaertner and McDonald, 2007; Alexander et al., 2010b). A GPS RO occurs whenever a transmitting satellite from the global navigation network at an altitude about 20,000 km rises or sets from the standpoint of a low Earth orbit (LEO) receiving satellite at a height of about 800 km and the signal traverses the atmospheric limb. The Doppler frequency alteration produced through the refraction of the ray by the Earth's atmosphere in the trajectory between the transmitter and the receiver is detected and then may be converted through a sequence of established procedures into profiles of diverse variables in the neutral atmosphere and ionosphere (see e.g., Kursinski et al., 1997). The technique has a typical measurement time in the neutral atmosphere of 1 min (as compared to the much longer dynamical processes), it has global coverage, all-weather and all-time capability, no recurrent need of instrumental drift or bias corrections (observations are stable in the long-term due to permanent self-calibration) and it exhibits a vertical resolution of about 1 km in the stratosphere (see e.g., Kursinski et al., 1997; Kursinski et al., 2000; Marquardt and Healy, 2005).

In April 2006, the Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC) launched six LEO satellites. The aim of the mission was to produce up to 2500 GPS RO daily with global distribution. It is still obtaining real time and post-processed vertical profiles of temperature, pressure, refractivity, and water vapor in the neutral atmosphere and electron density in the ionosphere. It has generated an extensive amount of data to support operational global weather prediction and climate change monitoring, and also to improve the study of neutral atmosphere and ionospheric phenomena, space weather, and possible relations between meteorological or ionospheric processes with solar activity (e.g., Liou et al., 2007). The number of the daily retrievals is presently exhibiting a declining trend, as the expected lifetime has already been outranged. This study uses post-processed data (product version 2010.2640) from the COSMIC mission provided by CDAAC (COSMIC Data Analysis and Archive Center). We use the atmospheric vertical profiles of temperature to construct the GW activity climatologies as explained in the following section.

We perform a similar general study also for data from the SABER (Sounding of the Atmosphere using Broadband Emission Radiometry) instrument, as it is also used to obtain global GW climatologies in the stratosphere. The SABER instrument (e.g., Mlynczak, 1997) is an infrared emission limb sounder covering the upper troposphere, stratosphere, mesosphere and lower thermosphere and is on board of the Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) satellite. Here we use temperatures from version 2.0 retrievals. SABER and GPS RO share a similar observational sensitivity regarding the horizontal and vertical resolutions, but the latter technique has a slightly better performance (e.g., Sivakumar et al., 2011; Wright et al., 2011).

GW activity is usually quantified in each individual event by calculating the mean potential energy per unit mass E_p or nearly equivalently the mean temperature perturbation amplitudes or variances. The momentum flux may be also calculated in the presence of a sufficiently high density of retrievals (e.g., Wang and Alexander, 2010; Faber et al., 2013). In general, when characterizing climatologies through E_p, the most significant statistical parameter usually seems to be the arithmetic mean (e.g., von Storch and Zwiers, 2003). Its wide use is probably related to the fact that it is easy to calculate and due to the law of large numbers we know its functional distribution and dispersion. An implicit assumption which in some processes may not be applicable is that the observations exhibit distribution symmetry. In addition, the mean may not be an adequate representation of the typical state, as for example in a scenario described by a distribution with two far away Gaussian peaks. Moreover, in the analysis of phenomena that exhibit similarities to the normal distribution but clearly are not, alternative parameters to the mean and its range of variability may be considered.

Distributions based on symmetry may have more appeal than skewed ones. The normal shape is often assumed to describe the distribution of the occurrence of diverse processes. The curve can easily be described by two values: the mean and the standard deviation. However, many cases show skewed distributions, which sometimes emerge when the observed variable cannot be negative (e.g. energy). In some cases the variability around the mean may be clearly asymmetrical, for example subtracting one standard deviation from the mean produces a negative value (see below). Such skewed curves sometimes fit the log-normal shape. Log-normal distributions are usually characterized in terms of the log-transformed variable (Johnson et al., 1994). Specifically, a random variable X is said to be log-normally distributed if $\log(X)$ is normally distributed. The distribution is skewed to the left. Two parameters are needed to specify it: the mean m and the standard