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Detection of Atmospheric Gravity Wave Activity during several Earthquakes

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Abstract

The coupling between seismic hazards and ionosphere is an important topic in research field. The perturbation in ionosphere due to earthquake is an example of seismo-ionospheric coupling. The perturbation can be analyzed through the various channels of a mechanism called Lithosphere-Atmosphere-Ionosphere Coupling (LAIC). The three channels are thermal, electromagnetic and acoustic channel. Atmospheric Gravity wave (AGW) is lie in the acoustic channel. AGW is the most reliable parameter to predict the ionospheric perturbation due to Earthquake. In this study, we compute the potential energy (Ep) associated with the gravity waves. The Ep is derived from using temperature profiles retrieved from observations of Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument on board the Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED)satellite for Tohoku Earthquake (Japan) (11 March 2011,$M_W - 9.0$), Nepal Earthquake (25 April 2015 and 12 May 2015,$M_W - 7.8$,$M_W - 7.3$), Kumamoto Earthquake (15 April 2016, $M_W - 7.0$) and Pakisan Earthquake (24 September 2019, $M_W - 5.6$). There is a significant increment in AGW activity just before all the earthqukes. the abnormal AGW activity in the stratosphere is detected before the earthquake, and the coincidence of stratospheric AGW activity with VLF sub-ionospheric perturbations provides further support to the AGW hypothesis of the LAIC process.

1 Introduction

Earthquake(EQ) prediction is the most important topic in recent years that many researchers set their goals to investigate some precursory phenomena of Earthquake's. There are some hypothetical models based on Lithospheric-atmospheric-ionospheric coupling(LAIC) mechanism which consist of three types of channels i.e thermal channel, electromagnetic channel and acoustic channel. In the acoustic channel the main acting agent is atmospheric gravity wave (AWG) which can be appears due to the atmospheric oscillation near the epicentral zone of the corresponding earthquake, these oscillation further travels to the upward direction and perturb the ionosphere [8]. All the aspects of LAIC mechanism have no perfect explanation as there is a lack of observational results to establish these theories [13, 12, 16]. In lower stratosphere, this gravity wave perturb stratospheric wind and temperature and get excited by convection system, jet streams and fronts from hundred of meters to few kilometers and its period having range from Brunt-Vaisal period to the inertial period. To examine the AWG activity in the stratospheric region, ground based have been used to observed the wind fields and temperature profiles are obtained from lidars. AGW energies have been studied from 1985 to 1989 by the middle and upper atmosphere (MU) radar in Japan and it is also verified that an annual variation is associated with the jet stream [10]. In the last few years there are so many papers have been already published which showed some observational evidence in the very low frequency(VLF)/ low frequency(LF) signal amplitude that can explain AGW hypothesis to some extent. In the year of 1995 Kobe EQ, Hayakawa and his team started to analysis the sunrise and sunset terminator time and found the these times are shifted some days before the earthquake happened and these times are getting normal after the EQ day [7], another one is the nighttime fluctuation in the wave before the EQ day. AGW activity is thought to be reason behind this anomalies [11]. There are a series of comparative studies like characteristics of AGW, seasonal AWG variation, AWG variation with respect to height, latitudinal variation of AWG have been already done in the [18] using MU, two medium frequency radar and lidar. These latitudinal variation of AWG are also verified by situ measurements [4, 6]. To study the AWG activity based on temperature profile [19] using global positioning system (GPS), they investigate the global distribution of potential energy over mid latitude and showed that potential energy greater in winter seasons. After that CHAMP data are used to examine the annular and inter-annular variation of AWG activity in the lower and middle stratosphere [1]. In this paper we derived the potential energy associated with AWG activity over low and mid-latitudes from the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) data. We analyse the AWG activity near the epicentral zone of the various earthquake having different magnitude. We studied AGW activity for Tohoku (2011), Nepal(2015), Kumamoto(2016) and Pakistan (2019) EQ's.

2 Data & Methodologies

To study the Atmospheric Gravity Wave activity we have chosen five earth form different years. The Tohoku Earthquake occurred near the coast of the Japan at 14:46 JST (05:46 UTC) on Friday 11 March 2011. the epicentre was located at approximately 70 kilometres (43 mi) east of the Oshika Peninsula of Tohoku(geographic coordinates $38.322°N, 142.369°E$) with an underwater depth of approximately 29 km (18 mi).The magnitude of the earthquake is 9.0 M_w. Two earthquakes occurred in Nepal in the year 2015.The first earthquake occured at 11:56 Nepal Standard Time or 6:11 UTC on 25 May 2015.Its epicentre was located at east of Gorkha District at Barpak, Gorkha (geographic coordinates:$28.23°N, 84.731°E$) with a depth of 8.2 km.The magnitude of the earthquake is 7.8 M_w.The second earthquake occurred in Nepal on 12 May 2015 at 12:50 pm local time (07:05 UTC). The epicentre was located at on the border of Dolakha and Sindhupalchowk, two districts of Nepal(geographic coordinates:$27.837°N, 86.077°E$) with a depth of 18 km .The magnitude of the earthquake is 7.3 M_w .THE Kumamoto Earthquake occured in central Kyushu (geographic coordinates:$32.75°N, 130.76°E$), Japan at 01:25 JST on April 16, 2016 (16:25 UTC on April 15) with a depth of 10 km. The magnitude of the main shock of the earthquake 7.0 M_w and the forshock earthquake magnitude of 6.2 M_w which was occured onm 14 April, 2016.The Kashmir Earthqauke occured in Pakistan at at 16:02 local time (11:02 UTC) on 24th September 2019.The epicentre was located at Azad Kashmir (geographic coordinates:$33.106°N, 73.766°E$) with a depth of 10 km. There are some studies made on these earthqukes using the VLF signal anamoiles, atmospheric gravity wave and Total electron content (TEC). The studies are made by [3, 5, 14] using VLF signal during Tohuku Earhquake, Nepal earthquake and Kumamoto earthquake respectively. ULF/ELF magnetic field variation duing kumamoto earthquake studied by[15].The anamolies in TEC during earthquake observed by [9] during Tohuku Earhquake,Nepal earthquake and Kumamoto earthquake respectively.The AGW activity during earthquake studied by [2] for Nepal and [21] for Kumamoto earthquake.

We have used temperature profiles retrieved from observations of Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument on board the ThermosphereIonosphere Mesosphere Energetics and Dynamics (TIMED)satellite for the Earthquake region. In this study, we compute the potential energy (Ep) associated with the gravity waves from the temperature profile. According to [22, 17] the satellite based gravity wave analysis can be made by these method. At First the computation of background has been made by fitting the individual temperature profile fitted by Least square fit(LSF). The estimation of LSF is made by taking the logarithm of the individual profile. Then a three degree polynomial is fitted with logarithm profile and subtracted the fitted profile and logarithm proile to get the residual. To remove the noise and other waves a 4 km box filter is applied to the residual and then the filtered residual is added back to the fitted profile. The antilog of the final fitted profile is called the LSF.The sum of the wave number 0-5 components is considered as the background temperature(T_0). The perturbation temperature(T') is obtaining by Subtracting the original profile to background temperature (T_0) profile.Now the gravity wave associated E_p is easily obtained by the values in the equation1.

$$E_P = \frac{1}{2}(\frac{g}{N})^2(\frac{T'}{T_0})^2 \quad (1)$$

where g is the acceleration due to gravity and N is the Brunt Vasala Frequency defined by

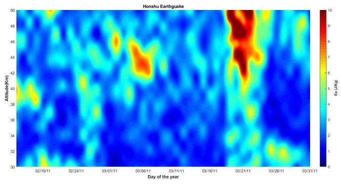
$$N^2 = \frac{g}{T_0}(\frac{\partial T_0}{\partial z} + \frac{g}{c_p}) \quad (2)$$

where z is the altitude and c_p is the specific heat at constant pressure. At first the Time altitude variation of the gravity have been shown in the Figure 1a for all Earthquake. Figure 1a.a) shows that the E_p is significantly increased around 42-45 km around 6 March, 2011 during Tohuku earthquake, Japan. Figure 1b shows the E_p is significantly increased around 36-37 km around 11 April 2015 and 34-36 km around 8 May, 2015 during Nepal earthquake. Figure 1c.c) shows the E_p is significantly increased around 40-42 km around 6 to 8 April 2016 and around 15 April , 2016 during Kumamoto earthquake. Figure 1d.d) shows the E_p is significantly increased around 46-48 km on 5 and 6 September 2019 and 21 to 23 September, 2019 during Pakistan earthquake.

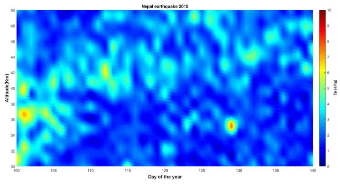
3 Latitudinal and longitudinal variation of E_P

We computed a four dimensional E_P values are computed for all the following periods and region
1) i)date -01 March to 31 March 2011 ii) latitude from 20° to 60° iii) longitude from 130° to 160° iv) 30-50 km
2) i)date- 8 April to 31 May 2015 ii) latitude from 20° to 40° iii) longitude from 70° to 110° iv) 30-50 km
3)i) date- 1 April to 30 April 2016 ii) latitude from 15° to 40° iii) longitude from 120° to 140° iv) 30-50 km
4)i) date- 1 September to 30 September 2019 ii) latitude from 20° to 50° iii) longitude from 70° to 110° iv) 30-50 km
The values of the E_P at 42,43 and 44 km were computed from the 4 dimensional E_P matrix for Tohuku Earthquake and we observed that E_P is maximum at the epicentral region on 5 March 2011 and 6 March 2011 at an altitude 43 km and on 4 March 2011 and 5 March 2011 at an altitude 44 km. The values of the E_P at 35,36 and 37 km were computed from the 4 dimensional E_P matrix for Nepal Earthquake and we observed that E_P is maximum at the epicentral region from 11 April to 14 April 2015, 17 April 2015, at

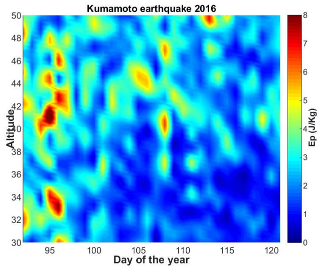
an altitude 36 km and for 22 April 2015, 26 April 2015 at an altititude 35 km. The values of the E_P at 43,44 and 45 km were computed from the 4 dimensional E_P matrix for Kumamoto Earthquake and we observed that E_P is maximum at the epicentral region on 6 April 2016 and 15 April 2016 at an altitude 43 km. The values of the E_P at 46 km was computed from the 4 dimensional E_P matrix for Pakistan Earthquake and we observed that E_P is maximum at the epicentral region on 22 September 2019 and 25 September 2019 at an altitude 46 km. The observed results are shown in the Figure2a, 2b, 2c, 2d, 2e.



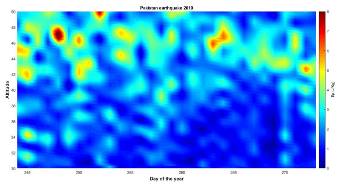
(a) Potential Energy variation during the month of March for Tohoku Earthquake 2011



(b) Potential Energy variation during the month of April and May for Nepal Earthquake 2015

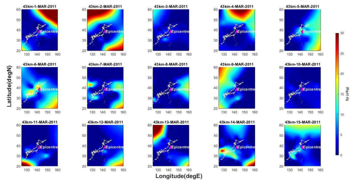


(c) Potential Energy variation during the month of April for Kumamoto Earthquake 2016

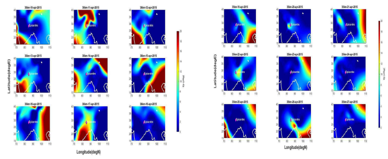


(d) Potential Energy variation during the month of September for Pakistan Earthquake 2019

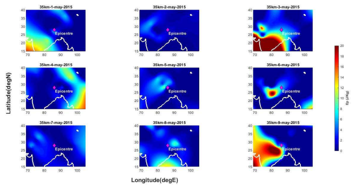
Figure 1. Potential Energy associated with Gravity wave variation during Tohoku, Nepal, Kumamato and Pakistan Earthquake



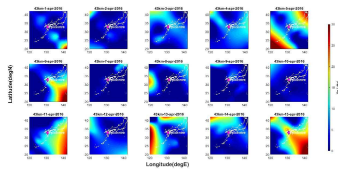
(a) Potential Energy maps during 01-15 March at 43 km for Tohoku Earthquake 2011



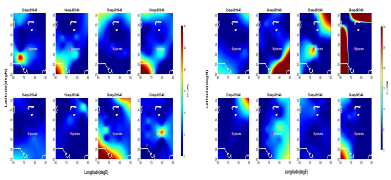
(b) Potential Energy maps during 10-27 for 35 and 36 km for Nepal Earthquake 2015



(c) Potential Energy maps 01-09 May at 35 km for Nepal Earthquake 2015



(d) Potential Energy maps during 01-15 April at 43 km for Kumamoto Earthquake 2016



(e) Potential Energy maps during 12-31 September for Pakistan Earthquake 2019

Figure 2. Potential Energy associated with Gravity wave variation during Tohoku, Nepal, Kumamoto and Pakistan Earthquake

4 Conclusion

The Atmospheric gravity wave (AGW) activity mainly enhanced before all the earthquake. The enhancement of AGW activity mainly observed between the height 35-45 km. According to [21] the increment in E_P mainly due the precursory effect of earthquakes not related to any type of space weather phenomena for all region earthquakes. From a previous work of [2] the computation of AGW using OLR data, the enhancement mainly occurred before the EQ day for second Nepal earthquake which validate the results corresponding to this paper. VLF anomalies([5]) also observed before the earthquake which also support these AGW effects.

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