*URSI AP-RASC 2019, New Delhi, India, 09 - 15 March 2019*

# Gravity Wave Behavior Associated With Strong Convective Activities During Tropical Cyclone Aila

Soumyajyoti Jana and Animesh Maitra
Institute of Radio Physics and Electronics, University of Calcutta
mantu.abc@gmail.com, animesh.maitra@gmail.com

## Abstract

Atmospheric gravity waves are generated by the interplay of earth's gravity and buoyancy effect on an air parcel. The zonal and meridional wind and temperature perturbation observed in the troposphere and stratosphere exhibits signature of gravity waves. The seasonal analysis of gravity wave activity has been made for the present tropical location, Kolkata (22.5726° N, 88.3639° E) using radiosonde data. Gravity wave generated due to intense tropical cyclone Aila has been investigated using COSMIC radio occultation data over the Indian region. The gravity wave energy calculated from temperature profile perturbations shows a significant enhancement during the cyclone which is accompanied by a low outgoing long wave radiation (OLR) indicating the presence of strong convective activities. An intrusion of water vapor into the lower stratosphere over the cyclone affected region is detected from Stratosphere- troposphere Processes And their Role in Climate data (SPARC).

## 1. Introduction

Atmospheric gravity waves are excited in the lower atmosphere, and transport energy and momentum while propagating to the upper atmosphere resulting to various exchange processes between different layers of the atmosphere. Intrusion of water vapor into the stratosphere has significant impact on the climate change [1-3]. Previous studies revealed that during deep convection and cyclonic storms, water vapor rich air from the upper troposphere enters to the lower stratosphere (LS) and ozone rich air from the lower stratosphere intrudes into upper troposphere (UT), the phenomenon being known as stratosphere-troposphere exchange (STE) [1,2]. Both upward and downward movement of energy occurs during deep convection. The effects of the cyclonic storm Aila in the lower stratosphere (18-25 km) has been studied over Kolkata (22°34′ N, 88°29′ E) which is located near the land ocean boundary and experiences heavy convective events in the pre-monsoon and monsoon period [4,5]. The present study also shows the seasonal analysis of gravity wave activity over Kolkata in the UT and LS and reveals the impact of the STE processes causing water vapour intrusion in the stratosphere during the cyclone Aila. Kinetic and potential energy have been estimated from radiosonde measurements obtained by the Indian Meteorological Department. The data of the radio occultation measurements, pertaining to a remote sensing technique, are utilized in the study to obtain the potential energy at lower stratosphere over the storm affected region.

## 2. Data and methodology

The temperature data obtained from GPS radio occultation (RO) offer excellent altitude resolution of about 20 m [6]. In the present study, we have utilized radio occultation measurements of Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) from the COSMIC Data Analysis and Archive Center (CDAAC) over the Aila affected region in India and adjoining Bay of Bengal (BoB) region. A grid size of 2° x 2° has been considered covering the region from latitude range 4° N to 45° N and longitude range 65°E to 100°E. The height range of 18 to 25 km has been taken to obtain the height profile of gravity wave energy.

Horizontal wind information and temperature data are obtained from radiosonde to estimate the atmospheric kinetic and potential energy. The radiosonde data for the station VECC Kolkata (station identifier: 42809), during 2010-2016 has been utilized to obtain wind and temperature profile to investigate the seasonal pattern of gravity wave activity.

The convective phenomena can be indicated by outgoing long wave radiation (OLR) measurements. OLR observations are made with the Advanced Very High Resolution Radiometer (AVHRR) aboard the NOAA polar orbiting spacecraft. The OLR data are taken from the NOAA data achieve.

The ECMWF data at 91 model levels are taken to observe the temperature, wind and specific humidity during the storm Aila. The data are taken from web portal of Stratosphere-troposphere Processes And their Role in Climate (SPARC) (http://www.sparc-climate.org/data-center/data-access/sparc-ipy/). The data are available for 6 hourly temporal resolutions with a grid size of 0.25°x0.25°.

## 3. Results

### 4.1. Seasonal analysis of gravity wave activity over Kolkata

For the seasonal study of gravity wave over Kolkata radiosonde data has been divided into four seasons, which are pre-monsoon (March to May), monsoon (June to September), post-monsoon (October and November), and winter (December to February) for the study at this tropical location.

### 4.1.1. Convective characteristics from OLR

For the present study the OLR values are taken to indicate the dominance of convective events throughout the four seasons for Kolkata. The low OLR values indicate the high convection.

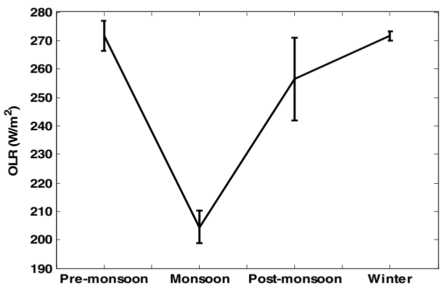


**Figure 1.** Seasonal OLR variation during the period of 2010-2013.

Figure 1 indicates that monsoon months of Kolkata which are characterised by OLR value less than 220 W/m$^2$ demonstrating deep convection [6]. Pre-monsoon, post-monsoon and winter months are characterised by OLR value above 250 W/m$^2$. Smaller value of OLR indicates colder cloud top temperature and stronger convection [6].

### 4.1.2. Seasonal variation of energy profile over Kolkata

The gravity wave energy at different height ranges is calculated from temperature and velocity perturbation data using the following relation.

$$E_0 = \frac{1}{2}[\overline{u'^2} + \overline{v'^2} + \overline{w'^2} + \left(\frac{g}{N}\right)^2 \overline{\left(\frac{T'}{T}\right)^2}] \quad 1(a)$$
$$= E_k + E_v + E_p \quad 1(b)$$

$E_k$, $E_v$ and $E_p$ are kinetic, vertical and potential energy respectively.

Where,

$$E_k = \frac{1}{2}[\overline{u'^2} + \overline{v'^2}] \quad 2(a)$$
$$E_v = \frac{1}{2}[\overline{w'^2}] \quad 2(b)$$

$$E_p = \frac{1}{2}[\left(\frac{g}{N}\right)^2 \overline{\left(\frac{T'}{T}\right)^2}] \quad 2(c)$$

Here u' and v' corresponds to the perturbation components of Zonal and Meridional wind. $\bar{T}$ and $T'$ represent the mean and perturbation of atmospheric temperature respectively. $g$ and $N$ are respectively acceleration due to gravity and Burnt Vaisala frequency [6-8]. Here the vertical velocity perturbation has been neglected as it is negligible at the upper troposphere and lower stratosphere [6].

The seasonal variation of total energy has been estimated over Kolkata for upper troposphere (6-10 km) (Figure 2(a)) and lower stratosphere (18-25 km) (Figure 2(b)) during the period 2010 to 2016. It is observed that for both the height ranges energy is higher for monsoon months compared to other seasons. The upper troposphere and lower stratosphere are characterised by high energy of 35 J/kg and 12.5 J/kg respectively. The standard deviation is higher in lower stratosphere than the upper troposphere. The height range 10-16 km has been excluded from the study as very sharp fluctuation of temperature occurs at the tropopause which lies within this height range [6].

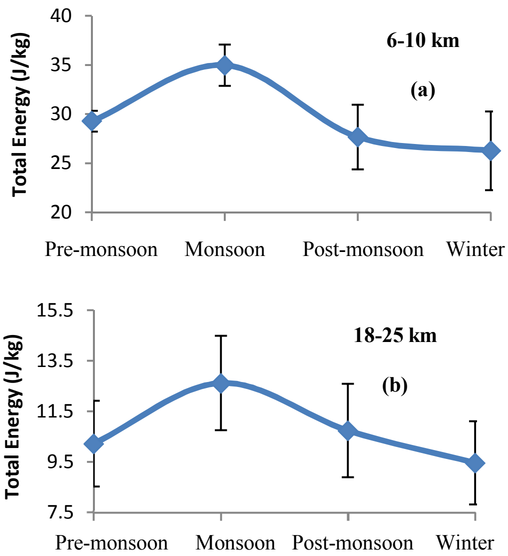


**Figure. 2** Statistical energy profile plot

### 4.1.3. Monthly variation of wind shear over Kolkata

The wind shear is analysed for two different height ranges as considered for energy calculation for the period 2010 to 2016. In the upper troposphere (6-10 km), the normal wind shear is positive (eastward) which reverses in the monsoon (Figure 3) yielding in higher gravity wave energy (Figure 2(a)). Whereas in the 16-25 km range the wind shear is generally negative (westward) which reverses to some extent during monsoon and energy increase can be seen for this height range (Figure 2(b)).

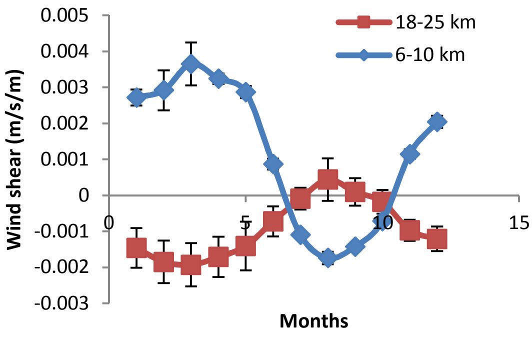


**Figure. 3** Wind shear over Kolkata.

## 4.2. Gravity wave activity over Kolkata and its adjacent region during an intense tropical cyclone Aila

Aila evolved from a tropical disturbance in the central Bay of Bengal (BoB). The disturbance slowly organized over a period of 2 to 3 days and became a tropical storm on the early hours of 23 May 2009. Figure 4 (a) shows the path of the cyclone over BoB and adjacent region of West Bengal where Aila made its landfall.

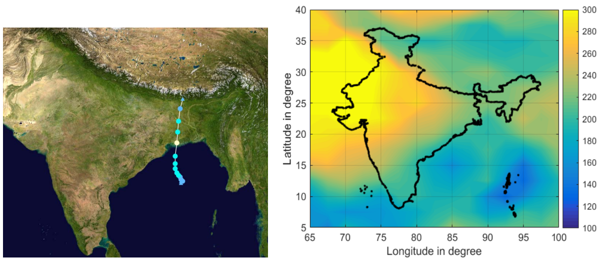


**Figure 4.** (a) Path of the cyclone Aila (23-27 May, 2009) from NASA. The dotted line shows the storm track. (b) Average OLR (W/m$^2$) over Indian region during Aila (22-27 May, 2009).

### 4.2.1. Observation from OLR

For the present study, OLR values are taken to indicate the dominance of convection during the tropical cyclone Aila. The OLR data during 22-27 May 2009 are plotted compositely to show the affected region by the cyclone. It is observed from Figure 4(b) that Aila affected region is characterised by very low OLR values [6].

### 4.2.2. Vertical energy distribution

#### 4.2.2.1 From COSMIC

Temperature perturbations using COSMIC-RO data have been estimated considering the vertical wavelengths less than 7 km. The potential energy ($E_p$) has been calculated from the temperature perturbations obtained from GPS RO measurements using the relation (2(c)).To investigate the enhancement of potential energy in the LS (18-25 km) during the cyclone, $E_p$ has been calculated for the two time spans before Aila (8-15 May) and during Aila (22-27 May, 2009).

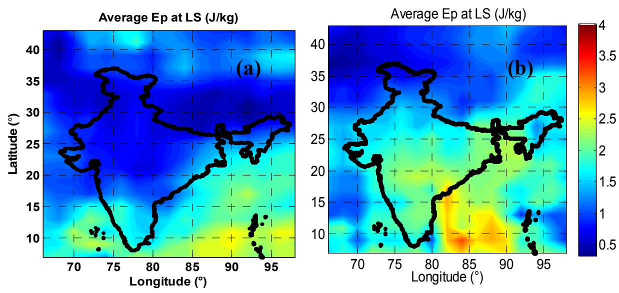


**Figure 5.** Contour plots of average potential energy (J/kg) between the height range 18-25 km before ((a) 8-15 May, 2009) and during ((b) 22-27 May, 2009) the tropical cyclone Aila.

It is observed that there is an increase of $E_p$ during the cyclone period over Bay of Bengal and adjacent areas of West Bengal where Aila made its landfall (Figure 5) compared to the time span before the storm.

#### 4.2.2.2 From SPARC

SPARC data also show increase in potential energy during the storm that gradually decreases after the cyclone period, as shown in Figure 6.

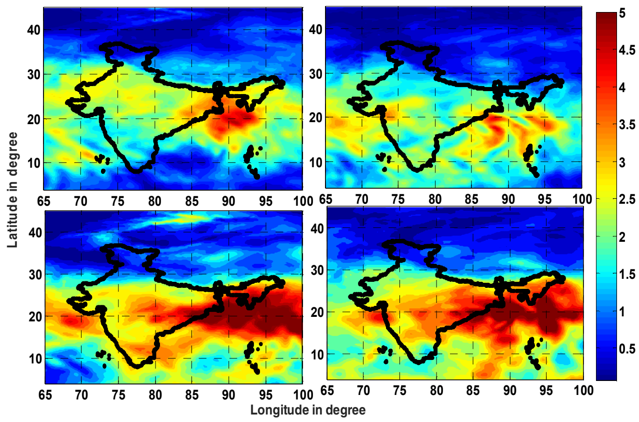


**Figure 6.** Contour plots of average potential energy (J/kg) between the height range 18-25 km (a) before Aila on 20 May 2009, (b) during Aila on 22 May 2009, (c) after Aila on 25 May 2009, and (d) 26 May 2009.

### 4.2.4. Specific humidity distribution at lower stratosphere over the storm path

To study the intrusion of water vapour, the specific humidity data from SPARC are examined in the lower

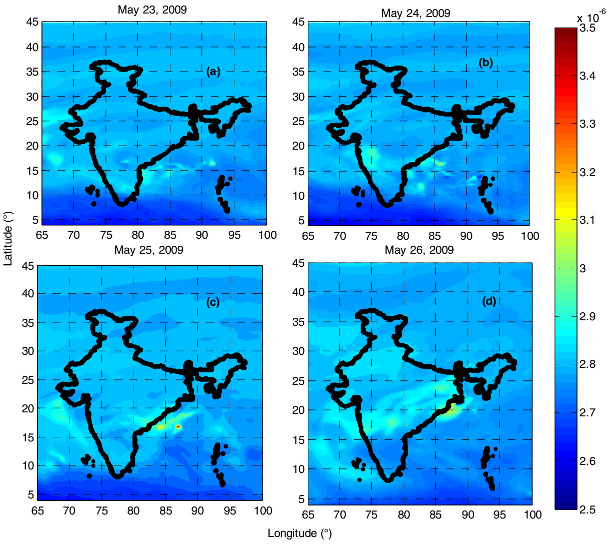


**Figure 7.** Contour plots of average specific humidity between the heights ranges 18-25 km during the tropical cyclone Aila: (a) 23 May 2009, (b) 24 May 2009, (c) 25 May 2009 (d) 26 May 2009.

stratosphere (18-25 km) over the Indian region during Aila. It is observed from Figure 7 that there is an increase of specific humidity during the cyclone period over the cyclone path. The upward energy propagation associated with the cyclone is the driving force which carries water vapour from UT to LS. This results the specific humidity to rise over the cyclone affected region.

## 4. Conclusions

Study of Gravity wave characteristics over the present location shows that convection is the main source of the gravity wave. This convection causes the gravity wave to propagate upward up to lower stratosphere. Very low OLR values can be seen over the cyclone path which show strong convective activities. This has a role in enhancing of the gravity wave energy in the lower stratospheric region as observed from the dry temperature profiles of GPS RO measurements. The water vapour intrusion occurs simultaneously with an energy enhancement during the deep convection associated with the cyclone.

## 6. Acknowledgement

This work has been supported by the grants under the projects entitled “Studies on aerosol environment at Kolkata located near the land-ocean boundary as a part of ARFI network under ISRO- GBP” (Grant No: SPL:GBP:ARFI:37)

## 7. References

1. E. A. Ray, and K. H. Rosenlof, “Hydration of the upper tropop-sphere by tropical cyclones,” *Journal of Geophysical Research*, **112**, 2007, D12311, doi:10.1029/2006JD008009.

2. M. Riese, F. Ploeger, A. Rap, B. Vogel, P. Konopka, M. Dameris, and P. Forster, “Impact of uncertainties in atmospheric mix-ing on simulated UTLS composition and related radiative effects,” *Journal of Geophysical Research*, **117**, 2012, D16305, doi:10.1029/2012JD017751,2012.

3. S. Solomon, K. H. Rosenlof, R. W. Portmann, J. S. Daniel, S. M. Davis, T. J. Sanford, and G. K. Plattner, “Contributions of Strato-spheric Water Vapor to Decadal Changes in the Rate of Global Warming,” *Science*, **327**, 2010, pp. 1219-1223.

4. T. Bhishma, V. Naresh Krishna, and A. N. V. Satyanarayana, "Study of thermodynamic indices in forecasting pre-monsoon thunderstorms over Kolkata during STORM pilot phase 2006–2008," *Natural hazards,* **56.3**, 2011, pp. 681-698.

5. S. Chaudhuri, "Preferred type of cloud in the genesis of severe thunderstorms—a soft computing approach," *Atmospheric Research,* **88.2**, 2008, pp.149-156.

6. Robert A. Vincent, and M. Joan Alexander, "Gravity waves in the tropical lower stratosphere: An observational study of seasonal and inter annual variability," *Journal of Geophysical Research: Atmospheres* **105**.D14, 2000, pp-17971-17982.

7. Christian Rocken, and Randolph H. Ware. "A global morphology of gravity wave activity in the stratosphere revealed by the GPS occultation data," *Journal of Geophysical Research* **105**.D6, 2000, pp. 7257-7273.

8. T. Tsuda, M.V. Ratnam, P.T. May, M.J. Alexander, R.A. Vincent, and A. MacKinnon, "Characteristics of gravity waves with short vertical wavelengths observed with radiosonde and GPS occultation during DAWEX (Darwin Area Wave Experiment)," *Journal of Geophysical Research: Atmospheres,* **109**.D20 ,2004.