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Studies on the Freqency Occurrence of Superrefraction and Ducting over Indian Region

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ABSTRACT
Month wise Percentage of occurrence of super-refraction at heights h≤1Km, 1Km<h≤2Km ,and h>2Km over selected Arabian sea, Bay of Bengal and land regions of India between latitudes -5^{o} S to 40^{o}N and longitudes 60^{o}E to 100^{o}E is studied using COSMIC GPS data for the years 2007& 2008. For heights h≤1Km, percentage of occurrence of super-refraction over Arabian sea has maximum value during the months April 2007 (100%) and March 2008 (90.2%); over Bay of Bengal it has maximum value during months March 2007 (66.9%), February, and May 2008 (47%); and over land region it has maximum value during months November 2007 (33.8%) and December 2008 (51.7%); For heights 1Km<h≤2Km, percentage of occurrence of super-refraction has maximum value over Arabian sea during months January, February 2007 (88%),January 2008 (79.85%); over Bay Of Bengal during months January 2007 (83.67%), December 2008(69.35%); over land region during months January 2007 (32.4%) and December 2008 (34.48%). For heights h>2Km, percentage of occurrence of super-refractions has maximum value over Arabian sea during months March2007 (46.3%), February 2008(33.84%); over Bay of Bengal during months January 2007 (47.9%) and December 2008 (32.25%); over land region during months November 2007(29.57%) &2008(25.42%). Percentage of occurrence of ducts over Arabian sea has maximum value during the month April 2007 (20%) and less than 2% during the months January, February, June to December of the year 2007. In the year 2008, Percentage of occurrence of ducts is 27.17% during the month March, 23.07% during the month April and less than 2% during the months January, June, July, August. Percentage of occurrence of ducts over Bay of Bengal is very low

I. INTRODUCTION

Radio occultation is a fairly new remote sensing method for obtaining profiles of refractivity by observing a GPS satellite in occultation from a low-earth-orbit satellite. The use of GPS satellite signals by means of radio occultation has shown a great potential for the determination of upper tropospheric and stratospheric refractivity profiles. Temperature and pressure profiles can be calculated from these refractivity profiles using the hydrostatic equation and the ideal gas law [*Kursinski et al.*, 1997]. GPS signals used in these measurements operate in the L band frequencies that are insensitive to clouds and precipitation [Solheim et al., 1999]. This feature has been considered to be one of the primary strengths of the technique, enabling RO measurements to probe deep in the planetary boundary layer (PBL), even in regions with heavy cloud covers. According to Rocken *et al.*, 2000, the data from GPS RO contributes significant amounts of information to a wide range of areas including meteorology, climate, ionosphere composition, geodesy, and gravity. The data will provide global coverage in time and space, including regions like the oceans and near the poles where there is a lack of atmospheric measurements. The Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) will provide high vertical resolution temperature, pressure and water vapor information for a variety of atmospheric process studies and improve the forecast accuracy of numerical weather prediction models. The cosmic data set will allow investigation of the global water vapor distribution and map the atmospheric flow of water vapor that is so critical for understanding and predicting weather and climate.

Anomalous propagation conditions in the atmosphere result from variations in the refractivity of the atmosphere that are closely related to changes in the temperature and/or water vapor pressure gradient. Refractivity is calculated following the formula given by Smith and Weintraub [1953], Valid at GPS frequencies:

$$N_i = 77.6\left(\frac{p_i}{Ti}\right) + 3.73\times10^5\left(\frac{e_i}{T_i^2}\right) \quad (1)$$

p_i is atmospheric pressure at level i (with radius r_i) in [hPa], T_i is atmospheric temperature at level i in [K], and e_i the water vapor partial pressure at level i in [hPa]. Based on vertical refractivity gradient dN/dh anomalous propagation conditions are classified as follows. A region with (dN/dh) > = -

39 Km^{-1} is called subrefractive. These conditions lead to radio waves being refracted away from the earth's surface. Regions with (dN/dh) between -39 Km^{-1} to -79 Km^{-1} show normal refraction. Regions with dN/dh between -76 Km^{-1} and >-157 Km^{-1} are called superrefractive [Almond and Clarke, 1973]. Ducting occurs when dN/dh <-157Km^{-1}.

$$dN/dh = N' = 77.6\ (p'/T)\ -77.6\ T'(P/T^{2}) + 3.73X\ 10^{5} (e' /T^{2}) - 3.73X\ 10^{5} T'(e /T^{3}) \quad (2)$$

The first term represents the hydrostatic variation of pressure with altitude, it is about -30 Km^{-1}. The second term will be more important closer to the surface where higher pressures are found. The third term will generally contribute to ducting at altitudes where strong gradients in e are found. The fourth term is negligible.

The nature of the duct is determined by the meteorological conditions that alter temperature and water vapor content in the region. Ducting events over the sea are traditionally separated into evaporation and elevated ducts. Evaporation ducts are caused by the rapidly decreasing water vapour with height, they occur within about 30m above the surface of the earth and are found over relatively warm water. They exhibit geographical,seasonal,and diurnal variations, with greater depths at lower lattitudes, during summer months, and during day time (Babin et al.1977). Elevated ducts can be caused by temperature and moisture inversions aloft, usually associated with subsidence of air masses . Ducts resulting from nocturnal radiative cooling are associated with temperature inversions. Dew deposition and fog development also effect the ducting conditions in the nocturnal ABL. Advection ducts may form when warm, dry continental air passes over cooler sea, thus cooling and moistening the lowest layers. When the warm air from a dry land mass moves over the cooler sea water a stable Internal boundary layer forms. As this IBL forms over water it is called a marine IBL. The moisture accumulated in the stable surface layers is a major cause of decrease in refractive index with height and formation of duct with a depth approximately equal to that of the MIBL. These are frequently surface ducts. This effect may reinforce a pre existing evaporation duct and so increase it s depth. Advection ducts can also be observed when warm moist air advected over cooler sea, resulting in the formation of sea fog with a duct near the top of fog. Over land, ducting is often caused by radiative cooling during clear nights, particularly when the ground is moist. . In addition, more localized effects such as see breezes, thunder storms, or microburst out flows can cause ducting over land (Turton et al 1988).

There has been several studies carried out on the occurrence of duct and super refraction over land region using radiosonde data [K.Chatterjee,1971; Ghouse Basha et al.,2013]. However the data over oceans is sparse and this study is unique in the sense it is for the first time providing the information over oceans using COSMIC GPS-RO data.

II. METHODOLOGY

COSMIC GPS data is taken to study frequency of occurrence superrefraction regions over India between latitudes -5^{o} S to 40^{o} N and longitudes 60^{o} E to 100^{o} E. Over Arabian sea a region lies between latitudes -1^{o} to 20^{o} and longitudes 60^{o} to 72^{o}, over Bay Of Bengal a region lies between latitudes -1^{o} to 15.45^{o} and longitudes 82^{o} to 94^{o}, and over land a region lies between latitudes 17.5^{o} to 36^{o} longitudes 74^{o} to 82^{o} are selected and refractivity values of these regions from sea level to a height of 5Km are extracted from GPS data. Gradient of refractivity is calculated for every vertical height interval of 100m and from which number of superrefraction regions occurred in each month are counted over these regions . Similarly numbers of duct regions are counted over Arabian Sea. Percentage of occurrence of superrefraction and duct regions occurred in each month are calculated as follows.

Percentage of occurrence of superrefractions (or ducts) in a given region

=[Number of superrefraction (or duct) regions] X100/Total number of refractivity profiles of that region

III. RESULTS AND DISCUSSIONS:

Fig.1 represents percentage of occurrence of super refractions over Arabian sea, Bay Of Bengal and land regions during the years 2007 & 2008. Percentage of occurrence of super refraction for heights h≤ 1Km over Arabian sea has maximum value during april 2007 (100%), march 2008(90%) and minimum value during June 2007(20%), July 2008(33%). For these super refractions percentage of occurrence is above 60% during the months January, February, March and April and less than 40% during rest of months of the year 2007. Percentage of occurrence super refractions is greater than 50% during months January, March, October and December and less than 40% during the months july, august and September of the year 2008. For heights 1Km<h≤2Km, percentage of occurrence of super refraction regions has maximum value during the months January, February 2007 (88%), January2008 (79.85%) and minimum value during the months June 2007(21%), october2008 (18.28%). Percentage of occurrence of these super refraction regions is greater than 50% during the months January, February, July, November and less than

30% during the months April, June, September and October of the year 2007. Percentage of occurrence of these super refractions in the year 2008 is greater than 50% during the months January, February, March, April, May, August and less than 30% during the months October and November. Percentage of occurrence of superrefractions in the heights h> 2Km has maximum value during the months march 2007 (46.31%), February 2008 (33.84%) and minimum value during the months August 2007 (6%), April 2008(3.2%).

Percentage of occurrence of superrefractions for heights h≤ 1Km over Bay Of Bengal has maximum value during the months March 2007 (66.9%), February 2007 (50%), May 2008 (47.25%) and minimum value during the months October 2007 (4.76%), November2007(6.8%), November 2008(14%). Percentage of occurrence of these super refractions is above 40% during the months February, March and less than 30% in the remaining months of the year 2007. In the year 2008, Percentage of occurrence of super refractions is greater than 40% during the months February, May and less than 30% during the months January, April, June, July, August, October, November, December. For heights 1Km<h≤2Km over Bay Of Bengal, percentage of occurrence of super refractions has maximum value during the months January 2007 (83.67%),December 2008 (69.35%) and minimum value during the months October 2007 (1.58%), August 2008 (6%). Percentage of occurrence of these super refractons in the year 2007 is above 40% during the months January, February and less than 20% during the months April, June, July, August, September. October, November. In the year 2008. Perentage of occurrence of superrefractions is greater than 40% during the month December and less than 20% during the months February, March, July, August, September, October, November. For heights h>2Km over Bay Of Bengal , percentage of occurrence of super refraction has maximum value during months January 2007(47.96%), December 2008 (32.2%) and less than 3.5% during the months April, June, July, August, September, October of the year 2007 and less than 5.5% during the months April, May, June, August, October, November of the year 2008.

Percentage of occurrence of super refractions for heights h≤ 1Km over land region has maximum value during months November 2007(33.8%) and December 2008 (55.038%) . Their value is greater than 20% during the months January, October. November and less than 10% during months May, June, July, August, September of the year 2007. In the year 2008, percentage of occurrence of these super refractions is greater than 20% during months March, April, September, October, November, December and less than 10% during the month june. For heights 1Km<h≤2Km , Percentage of occurrence of superrefractions has maximum value during the month January 2007 (32.4%) and December 2008 (34.48%). Percentage of occurrence of these superrefractions in the year 2007 is less than 10% during the months April to October and greater than 20% during the months January, November. In the year 2008, percentage of occurrence of these superrefractions is greater than 20% during the months November, December and less than 10% during the months from January to August and October. Superrefractions in the heights h>2Km over land region has maximum value during the month November 2007 (29.58%), November 2008 (25.4%) and less than 5% during months April to September of the year 2007 and April, May, June of the year 2008. Percentage of occurrence of ducts over Arabian sea has maximum value during the month April (20%) and less than 2% during the months January, February, June to December of the year 2007. In the year 2008, Percentage of occurrence of ducts is 27.17% during the month March, 23.07% during the month April and less than 2% during the months January, June, July, August. Percentage of occurrence of ducts over Bay of Bengal is very low and is about 3% during the month March 2007, 2% to 4% during the months March and April 2008. In remaining months of years 2007 and 2008, percentage of occurrence of ducts is zero.

IV. CONCLUSIONS

Month wise Percentage of occurrence of superrefractions at heights h≤1Km,1Km<h≤2Km ,and h>2Km over selected Arabian sea, Bay of Bengal and land regions of India between latitudes -5^o S to 40^{o}N and longitudes 60^{o}E to 100^{o}E is studied using COSMIC GPS data of the years 2007& 2008. Percentage of occurrence of superrefraction for heights h≤ 1Km over Arabian sea has maximum value during April 2007 (100%), march 2008(90%) and minimum value during june 2007(20%), July 2008(33%). For heights 1Km<h≤2Km, percentage of occurrence of super refraction regions has maxmum value during the months January2007 (88%), January2008 (80%) and minimum value during the months June 2007(21%), october2008 (18.28%). Percentage of occurrence of super refractions in the heights h> 2Km has maximum value during the months march 2007 (46.31%), February 2008 (33.84%) and has minimum value during the months August 2007 (6%), April 2008(3.2%). Percentage of occurrence of superrefractions for heights h≤ 1Km over Bay of Bengal has maximum value during the months March 2007 (66.9%), February 2007 (50%), May 2008 (47.25%) and minimum value during the months October 2007 (4.76%), November2007(6.8%), November 2008(14%). For heights 1Km<h≤2Km over Bay of Bengal, percentage of occurrence of superrefractions has maximum value during the months January 2007 (83.67%),December 2008 (69.35%) and minimum value during the months October 2007 (1.58%), August 2008 (6%). For heights h>2Km over Bay Of Bengal , percentage of occurrence of superrefraction has maxmum value during months January 2007(47.96%), December 2008 (32.2%) and less than 3.5% during the months April, June, July, August, September, October of the year 2007 and less than 5.5% during the months April, May, June, August, October, November of the year 2008.

Percentage of occurrence of superrefractions for heights h≤ 1Km over land region has maximum value during months November 2007(33.8%) and December 2008 (55.038%). For heights 1Km<h≤2Km, Percentage of occurrence of superrefractions has maximum value during the month January 2007 (32.4%) and December 2008 (34.48%). Superrefractions in the heights h>2Km over land region has maximum value during the month November 2007 (29.58%), November 2008 (25.4%) and less than 5% during months April to September of the year 2007 and April, May, June of the year 2008. Percentage of occurrence of ducts over Arabian sea has maximum value during the month April (20%) and less than 2% during the months January, February, June to December of the year 2007. In the year 2008, Percentage of occurrence of ducts is 27.17% during the month March, 23.07% during the month April and less than 2% during the months January, June, July, August. Percentage of occurrence of ducts over Bay of Bengal is very low and is about 3% during the month March 2007, 2% to 4% during the months March and April 2008. In remaining months of years 2007 and 2008, percentage of occurrence of ducts is zero.

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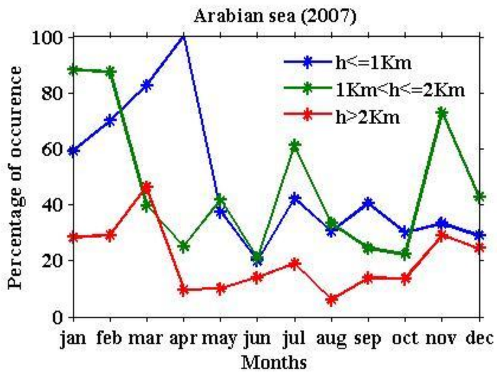

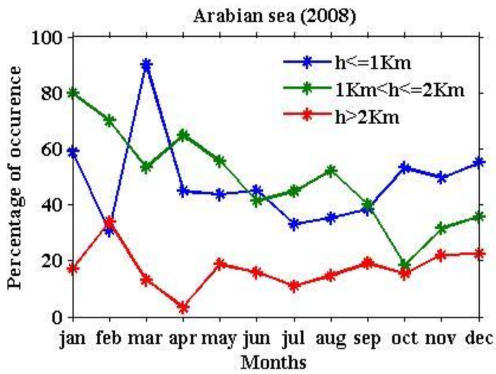

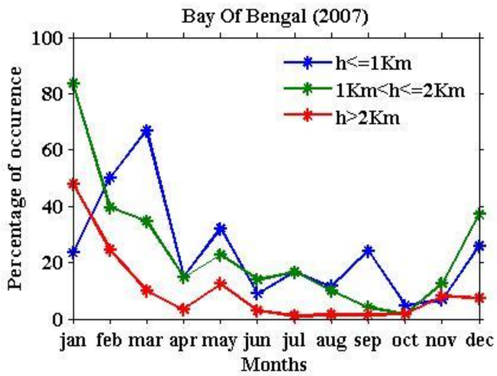

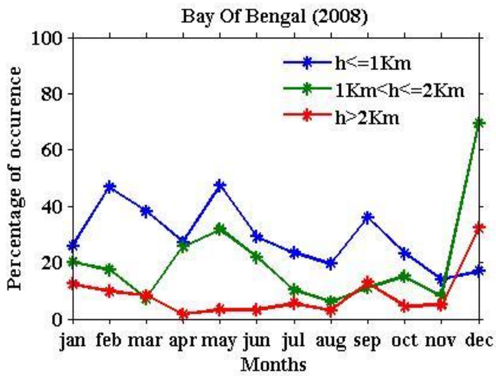

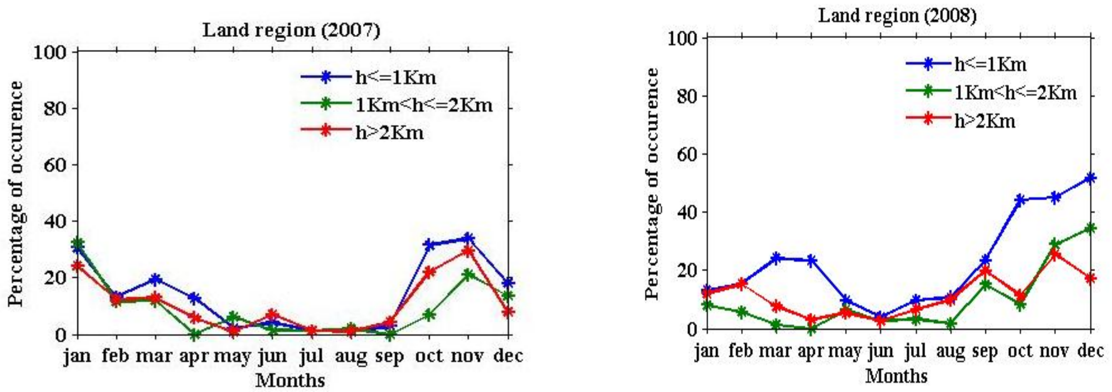

Fig.(1). Percentage of occurrence of superrefractions over Arabian sea, Bay of Bengal and Land regions at dIfferent heights during the years 2007 & 2008.

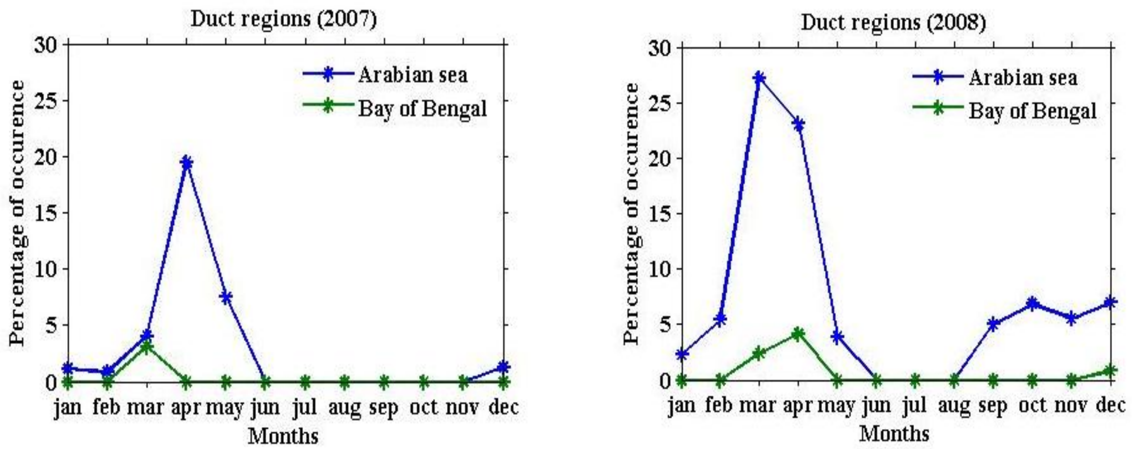

Fig.(2) Percentage of occurrence of duct regions over Arabian sea and Bay of Bengal during the years 2007 & 2008

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