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A DECADE OF AIRGLOW OBSERVATION OF MESOSPHERIC FRONTS OVER THE BRAZILIAN EQUATORIAL REGION

Emanuel Barbosa de Carvalho [1*], Igo Paulino [1], and Cristiano Max Wrasse [2]

[1]Universidade Federal de Campina Grande - UFCG, Campina Grande, Paraíba, Brazil
[2]Instituto Nacional de Pesquisas Espaciais - INPE, São José dos Campos, São Paulo, Brazil

[*]Corresponding author: emanuelbarbosadecarvalho@gmail.com

ABSTRACT. Mesospheric fronts were observed over São João do Cariri (7.4ºS, 36.5ºW), in the northeast region of Brazil, from September 2011 to June 2021 using an all sky airglow imager. The occurrence of the mesospheric fronts presented a well defined seasonality with maximum in the Spring period of ten consecutive years. In addition, an anisotropy was observed in the preferential propagation direction, in which most of the front propagated to the northeast. These results suggest that the seasonality and anisotropy can be produced due to either the location of sources or the filtering process associated with the wind system. Other important aspects like the statistics of trailing waves and ripples observed simultaneously were reported as well.

Keywords: mesospheric bore; atmosphere dynamics; airglow imager; gravity waves, ripples.

INTRODUCTION

Mesospheric fronts are gravity waves with a well defined front, pronounced in amplitude, spatially extended, followed or not by trailing waves and not necessary in a wave-like structure (Brown et al., 2004). Mesospheric fronts can be classified as bore, wall or simply front (Dewan and Picard, 1998). This phenomenon has been mostly observed using airglow cameras in low (e.g., Isler et al., 1997; Medeiros et al., 2001, 2005, 2016, 2018, Fechine et al., 2005, 2009; Narayanan et al., 2009; Carvalho et al., 2017), middle (e.g., She et al., 2004; Smith et al., 2005) and high latitudes (e.g., Nielsen et al., 2006; Bageston 2011a, 2011b; Giongo et al., 2018). The mesospheric fronts can propagate for long horizontal distances into ducts with small dissipation of energy (Dewan and Picard, 2001), thus they are important in the transport of energy and momentum for long distances in the atmosphere. The formation of these ducts depends on the background atmosphere conditions and thermodynamics. A thermal duct can be produced due to changes in the temperature profile structures (e.g., Sarkhel et al., 2021); Doppler ducts are produced due to the vertical wind shear (e.g., Fechine et al., 2009) and a dual duct can appear when both temperature and wind are relevant for the formation (e.g., Bageston et al., 2011a).

Most of the recent advances on the mesospheric fronts came from case studies using multi instrument observations, in which the focus is primarily to describe the events, the propagation conditions of the atmosphere and the formation of the ducts (Medeiros et al., 2016, 2018;Smith et al., 2017; Hozumi et al., 2018; Thurairajah et al. 2021; Mondal et al. 2021) and/or identify possible sources of them (Mehta el al., 2017; Giongo et al., 2018). Theoretical studies have also been developed giving some directions for further investigations (e.g., Dewan and Picard, 1998, 2001; Laughman et al., 2009). Another important topic of research on mesospheric fronts is the appearance of convective and dynamic instabilities in the Mesosphere and Lower Thermosphere (MLT) when they interact with the background atmosphere (e.g., Fritts et al., 2020 and references therein).

In contrast, publications using long term observations are rare, consequently, some aspects of mesospheric front events are poorly understood, such as seasonality and solar cycle dependency. Based on it, the present work aims to give some relevant statistical findings on mesospheric fronts using airglow observations over the northeast of Brazil from 2011 to 2021. For instance, the seasonality of the occurrence, preferential propagation direction and presence of trailing waves and ripples simultaneously to the front will be reported and discussed. INSTRUMENTATION AND OBSERVATION aims to describe the methodology and define some important aspects used in this study. In RESULTS AND DISCUSSION, the results are presented with the characteristics of the registered fronts, preferential propagation direction, and seasonal occurrence of the phenomena. In SUMMARY are highlighted the main contributions of this work and summarized the results.

INSTRUMENTATION AND OBSERVATION

In this work, near infrared OH airglow images were collected at São João do Cariri (7.4ºS, 36.5ºW) from 23 September 2011 to 15 June 2021 from a Charge-Coupled Device (CCD) all-sky imager. Images with an integration time of 15 seconds and a temporal sample of about 2 minutes were used. The imager uses a fisheye lens which allows us to make images with 180° of field of view. The instrument is equipped with a telecentric system of lenses which projects the light orthogonal to the interference filters mounted on a filter wheel. After that, the lights pass through a system of lenses to reconstruct the image on the CCD chip. The CCD temperature is set to cooled by a Peltier cooler at -70 ºC. The whole system is controlled by a microcomputer. The CCD has 6.45 cm^2 of area with resolution of 2048 X 2048 pixels, back-illuminated and binned on-chip down to a resolution of 512 x 512 pixels to enhance the signal to noise ratio. It has high quantum efficiency (~70% in the visible), high linearity (0.05%), low thermal (0.5 electrons/pixel/second) and reading (15 electron/pixel) noises. Details about the imager have been published elsewhere (e.g., Paulino et al., 2011).

Using the whole period of observations (23 September 2011 - 15 June 2021), characteristics of the mesospheric fronts were tabulated, such as: (i) the start and end time of the observations, (ii) the period of cloudiness, (iii) the interval of time when the fronts crossed the field of view of the imager. Double checking of the observed fronts was done using OI6300 that comes from different altitudinal ranges, it was considered a mesospheric front if the structure was observed only in the OH images. Additionally, in the confirmed fronts, it was investigated the presence of (a) trailing waves following the fronts; (b) the presence of ripples simultaneously to the passage of the front in the images and (c) the uniformity of the background of the images. The fronts were identified using the conditions stated by Brown et al. (2004).

Figure 1 shows two examples of mesospheric fronts. Figure 1a shows an example of a front followed by trailing waves 28 June 2019 over São João do Cariri, and Figure 1b shows an example with the presence of ripples while a front was propagating on 16 September 2015.

The next step of the methodology was the calculation of the amount of Valid Observation Hours (VOH) per season, the seasonal average, and their respective standard deviations. VOH is defined as the amount of hours in which the sky was cloudless. The usage of this quantity as stated above aims to reduce possible misleads that could come out from the difference in the amount of time when it was actually possible to observe the sky for each season, since there is no uniformity between the seasons in this specific aspect.

The identification of the propagation directions was done by tracing a line perpendicularly to the front in the best observed image. Then, it was calculated the clockwise angle from the north (azimuth). Table 1 shows the conventions used.

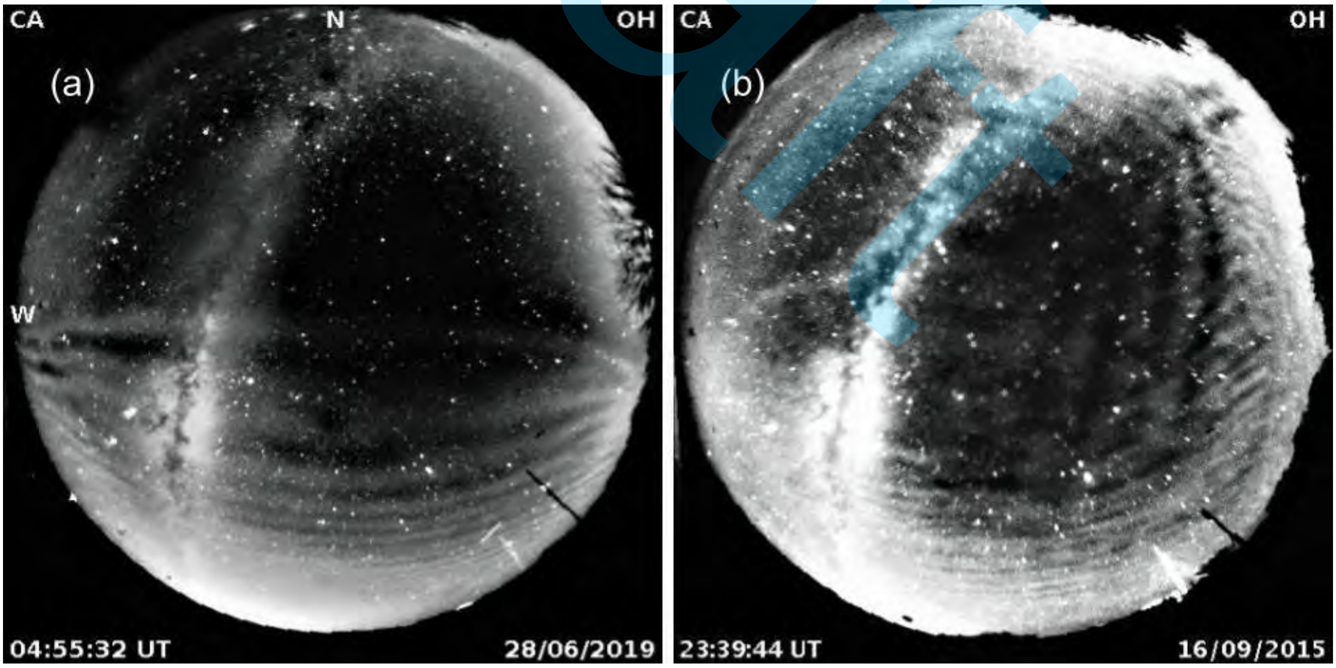

Figure 1 - (a) Front propagating to North followed by trailing waves, registered at June 28th, 2019; (b) Front propagating to East followed by trailing waves and with presence of ripples in the all-sky field of view, registered at September 16th, 2015 over São João do Cariri

Table 1 - Conventions relative to the angles and directions of propagation of the bores.

Direction	Angle
North	Bigger than 337.5 and smaller than 22.5
Northeast	Between 22.5 and 67.5
East	Between 67.5 and 112.5
Southeast	Between 112.5 and 157.5
South	Between 157.5 and 202.5
Southwest	Between 202.5 and 247.5
West	Between 247.5 and 292.5
Northwest	Between 292.5 and 337.5

As this study was carried out in Brazil, the calendar data is based on Southern Hemisphere seasons. To determine the beginning and end of the seasons from 2011 to 2020 was considered the convention provided by the Astronomy Department of Instituto de Astronomia, Geofísica e Ciencias Atmosféricas da USP and for the year of 2021 was taken a date based on the other year dates of beginning of the seasons.

RESULTS AND DISCUSSION

From 23 September 2011 to 15 June 2021, 246 fronts were observed. Regarding the season, as shown in Figure 2a, (i) 13.00% of the fronts occurred in Summer; (ii) 20.74% in Autumn; (ii) 30.08% in Winter and (iv) 36.18% in Spring. Figure 2b shows that, out of the total amount of fronts, 87.8% of the fronts were followed by trailing waves, 19.9% of them occurred with presence of ripples in the field of view of the imager and only 4.9% of the fronts had non uniform color when propagated through the images (a front was considered non uniform in its aspect when, for example, the front appeared in the images firstly as a well pronounced in amplitude bright band but as the time passed this band became a dark band, the same kind of change may also occur when a dark band becomes a bright band as time passes).

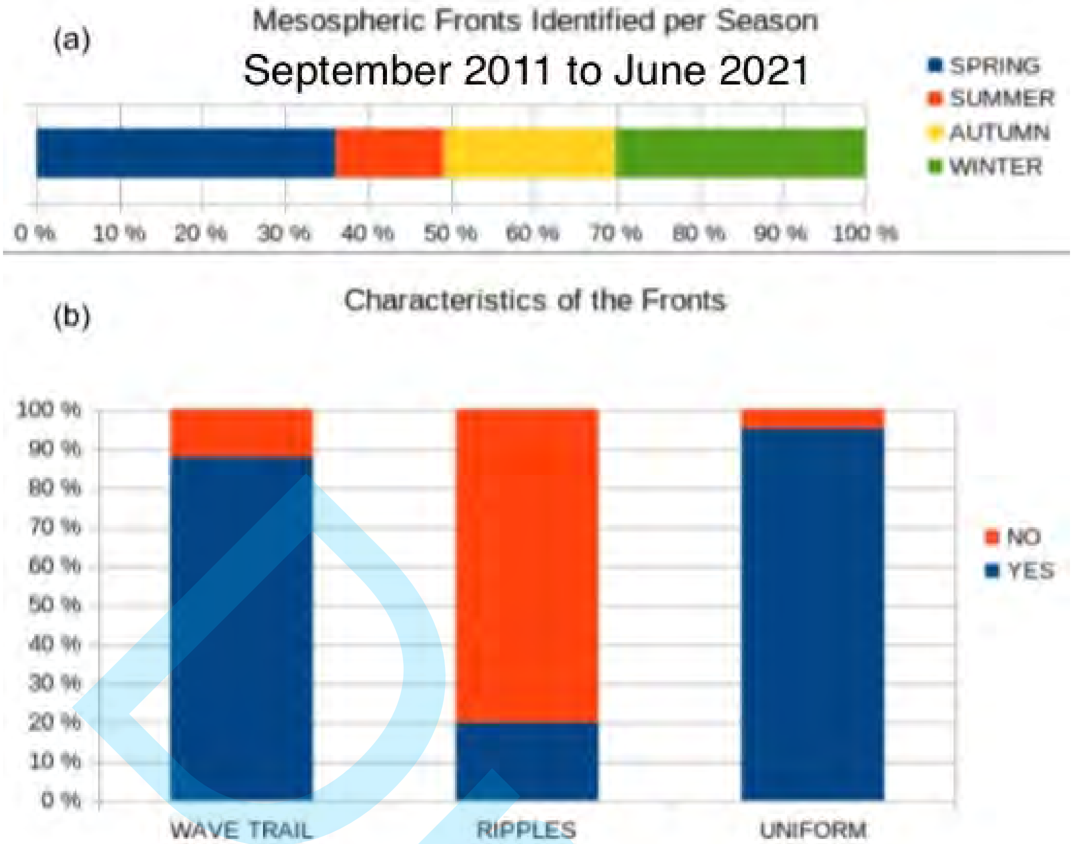

Figure 2 - General information about the mesospheric fronts.

The fact that this amount of fronts are followed by trailing waves points out that the sources of these fronts must be far from the observatory, since presence of trailing waves indicates that there is loss of energy.

The occurrence of ripples implies that the front could be interacting with the background producing dynamical and convective instabilities (e.g., Fritts and Rastogi, 1985; Medeiros et al., 2018). Given that in our data this phenomenon has low rates of occurrence, it is possible to point out a low frequency of these instabilities in this region associated with the passage of the mesospheric fronts.

Figure 3 shows the propagation direction of the fronts. For every season, at least 58.82% of the fronts were propagating to the North, Northeast, or Southeast. All-year data shows that fronts propagating to those directions represent 63.82% (16.67% to North, 26.42% to Northeast, and 20.73% to Southeast) of the identified fronts. Therefore, it is possible to state Northeast, Southeast and North as the preferential propagation directions of mesospheric fronts over São João do Cariri. The fact appointed by this graphic can be related either to the location of the sources of the fronts or to the needed physical conditions for its canalization. As small-scale as medium-scale gravity waves observed over São João do Cariri presented also a quite similar anisotropy in the propagation direction (Campos et al., 2017; Essien et al., 2018). Those authors also suggested that the location of the sources and the filtering by the wind system as possible mechanisms to explain the observed anisotropy.

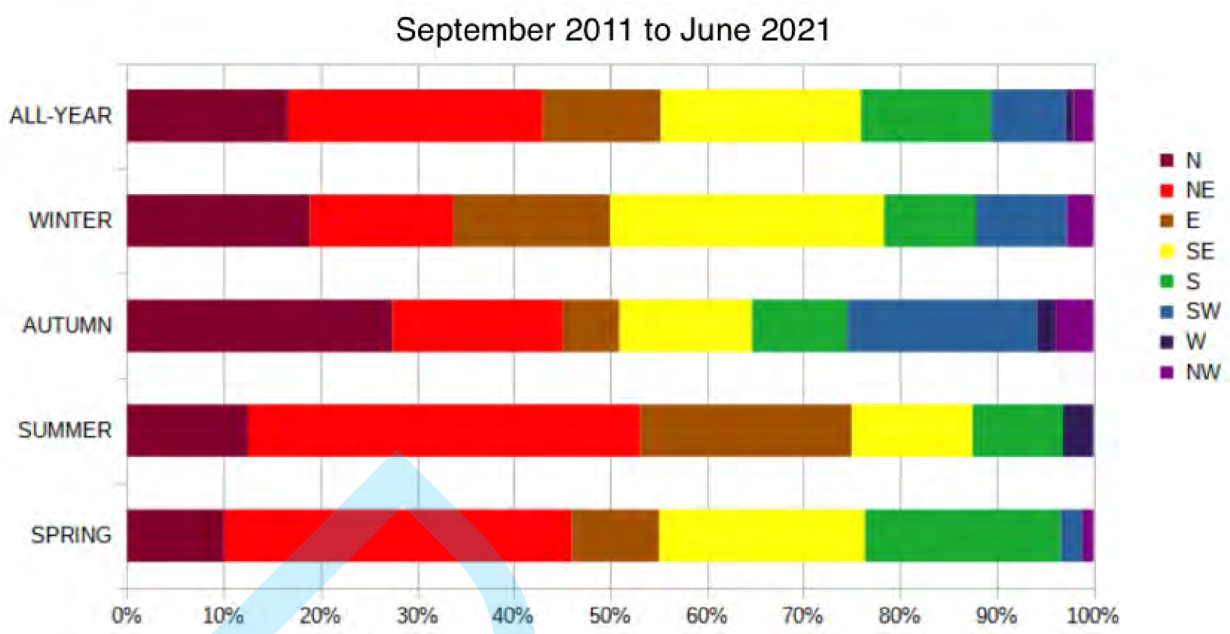

Figure 3 - Registered mesospheric fronts by propagation direction per season and all years long.

Looking at the seasonal average of occurrence by VOH at Figure 4, it is seen a considerable dispersion of the data, but with a clear growth over the seasons. The seasonal average of occurrence by VOH grows and reaches its maximum value at Spring, which shows that the phenomena is more likely to occur in Spring than in other seasons. The seasonality of the occurrence of the fronts is also in agreement with other gravity waves observed at the same site (e.g., Essien et al., 2018), suggesting again that the sources of the fronts must be related to the source of other gravity wave structures.

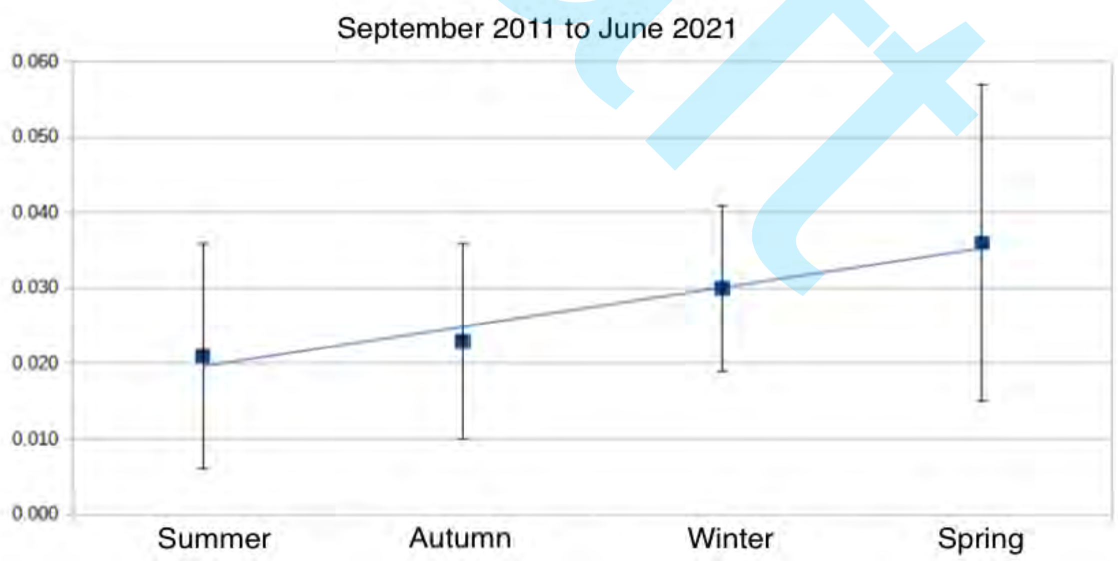

Figure 4 - Registered fronts per VOH by season. Each error bar corresponds to the standard deviation of ten values, each of them corresponding to the respective season of a year. The solid line represents the linear fit to the points.

SUMMARY

Long term observations of OH airglow images collected between September 2011 and June 2021 in the Northeast of Brazil revealed interesting characteristics of mesospheric fronts that are summarized as follows:

- The amount of fronts followed by trailing waves suggests sources far from the field of view of the imager while the low rates of ripples occurrence suggests that just a few fronts dissipates over São João do Cariri, once ripples presence is related to the dissipation of mesospheric fronts;
- The identified preferential propagation directions were Northeast, Southeast and North. Fact that can be explained either by the location of the sources of these waves or by the conditions of canalization of these waves (or both). More studies are needed to determine the predominant factor that makes these directions preferential;
- The occurrence by VOH average grows over the seasons reaching its maximum average at Spring, pointing that there is a seasonality in the occurrence of the phenomena for the years 2011-2020.

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The airglow images used in this study can be accessed on-line at the site of the Instituto Nacional de Pesquisas Espaciais (INPE) http://www2.inpe.br/climaespacial/portal/original-image-video/.

The table used to define the seasons of each year from 2011 to 2020 is available at https://www.iag.usp.br/astronomia/inicio-das-estacoes-do-ano.

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