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Ionospheric acoustic and gravity wave activity above low-latitude thunderstorms

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Abstract

In this report, we study the correlation between thunderstorm activity and ionospheric gravity and acoustic waves in the low-latitude ionosphere. We use ionospheric total electron content (TEC) measurements from the Low Latitude Ionospheric Sensor Network (LISN) and lightning measurements from the World-Wide Lightning Location Network (WWLLN). We find that ionospheric acoustic waves show a strong diurnal pattern in summer, peaking in the pre-midnight time period. However, the peak magnitude does not correspond to thunderstorm area, and the peak time is significantly after the peak in thunderstorm activity. Wintertime acoustic wave activity has no discernable pattern in these data. The coverage area of ionospheric gravity waves in the summer was found to increase with increasing thunderstorm activity. Wintertime gravity wave activity has an observable diurnal pattern unrelated to thunderstorm activity. These findings show that while thunderstorms are not the only, or dominant source of ionospheric perturbations at low-latitudes, they do have an observable effect on gravity wave activity and could be influential in acoustic wave activity.

Introduction

Recent investigations have shown evidence of the ionospheric response to acoustic and gravity waves from mid-latitude thunderstorm activity [Lay, et al., 2015]. These investigations were made over the U.S. Great Plains region, which often generates mesoscale convective systems. It is clear that thunderstorms are a major source of acoustic and gravity waves in the mid-latitude region of the U.S. Great Plains. However, because of the more complicated electrodynamics in the low-latitude ionosphere [Kelley, 2009], one cannot simply extrapolate that result to low-latitude regions without further investigation.

Our goal in this study is to understand whether these findings of ionospheric acoustic and gravity wave response to thunderstorms are similar at low latitudes. For that reason, we studied the ionospheric response to thunderstorms in Northern Argentina and South-Central Brazil, a region that also often generates mesoscale convective systems. For ionospheric measurements in this region, we use the LISN GPS receiver network (http://lisn.igp.gob.pe). For thunderstorm activity in the region, we use World Wide Lightning Location Network data (http://wwlln.net) as a proxy for thunderstorm activity.

Data Analysis

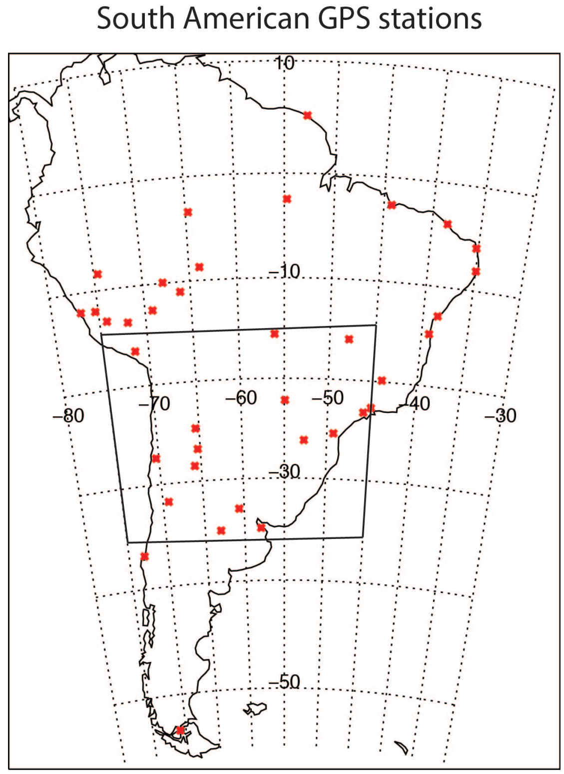

Figure 1. Map of region of interest (black square), and LISN stations used.

To detect ionospheric acoustic and gravity waves, we use receiver-independent exchange format (RINEX) files from the LISN GPS receivers to calculate total electron content (TEC). The dates used were June, July, November, and December of 2013. Figure 1 shows the region of interest for this study in the black square region. LISN GPS receivers used are shown as red dots. Although all receivers are not within the region of interest, the ionospheric pierce points (IPPs) between receiver and GPS satellite can lie in this region. We use all LISN data that contains IPPs within the region of interest during the times of interest.

The TEC data were processed in the same manner as described in [Lay et al., 2015]. Briefly, the phase differential measurement was used to provide the differential TEC. Long-term trends were removed from each receiver-to-satellite arc by subtracting a best-fit polynomial to produce a residual dTEC time series. The dTEC was filtered into acoustic (2-4 minute) and gravity wave (6-16 minute) regimes. Each filtered signal was searched for times in which the signal surpassed a given TEC threshold, indicating high-amplitude ionospheric acoustic wave (IAW) or ionospheric gravity wave (IGW) activity. These times of high-amplitude wave activity were then gridded onto a latitude-longitude grid, and counted in time for statistics. For this study, the threshold for both IAW and IGW was 0.1 TECU. This is higher than the thresholds in the U.S. Great Plains study because the fluctuations have a larger mean value, possibly due to higher absolute TEC or more significant sources of fluctuations. The grid cells used were 0.5 x 0.5 degrees in latitude and longitude.

World Wide Lightning Location Network (WWLLN) detections of lighting were used as a proxy for thunderstorm area. This is a good assumption for convective areas, since lightning requires significant convection in order to occur. If a given grid cell surpassed 3 lightning stroke counts, then that cell was included in total thunderstorm area. The threshold of 3 lightning strokes was chosen as a balance between too many and too few lightning strokes in a region. Because WWLLN has a 10% detection efficiency on average [Rodger et al., 2009; Abarca et al., 2010], a total of 3 counts actually indicates that 30 lightning strokes occurred in that cell. A WWLLN total of at least 3 lightning strokes (~30 total) in a 10-minute x 0.5 deg x

0.5 deg grid cell indicates a strong likelihood that the given cell has convective activity in it or very nearby.

Results

We compared diurnal averages of thunderstorm area to diurnal ionospheric acoustic and gravity wave activity for two summer months (November and December of 2013) and two winter months (June and July of 2013). The results are shown in Figure 2. Data for November and December is separately averaged for days with high thunderstorm activity (blue solid curve) and low thunderstorm activity (red solid curve). All data in June and July (dashed red curve) falls into the low-thunderstorm activity category. The top panel shows diurnally-averaged thunderstorm area (in 1000 km^2) versus time in UTC hours. Local time is shown on the top of the plot. The middle panel shows diurnally-averaged ionospheric acoustic wave area versus time. The bottom panel shows diurnally-averaged ionospheric gravity wave area versus time.

In the winter months (Nov/Dec), a diurnal variation in thunderstorm activity is evident for days with both high and low thunderstorm activity, although the total thunderstorm area for low activity days is much lower. We have multiplied the low-activity curve by 2 in this case to more easily observe the diurnal pattern. Thunderstorm activity generally peaks in the local afternoon, between about 18 – 20 UTC (14-16 LT). During the winter months (June/July), there is no diurnal pattern to the thunderstorm activity, as expected (dashed red curve, top panel).

The acoustic wave activity during summer months peaks strongly in the post-sunset time (between 21 – 0 LT), and the magnitude of the peak is the same for high and low thunderstorm activity days (solid blue and red lines, middle panel). Because the diurnal variation does not agree with the thunderstorm diurnal variation, and because the magnitude of the peak is not dependent on thunderstorm activity, we conclude that thunderstorms are not a primary driver of acoustic waves in the low-latitude ionosphere. However, winter months (June/July), have no diurnal pattern in acoustic wave activity. This indicates there is a different driving process occurring in winter than in summer, but it is not necessarily thunderstorm activity. However, thunderstorm activity may be important in seeding post-sunset instability in the ionosphere that appears as acoustic wave activity in GPS TEC data.

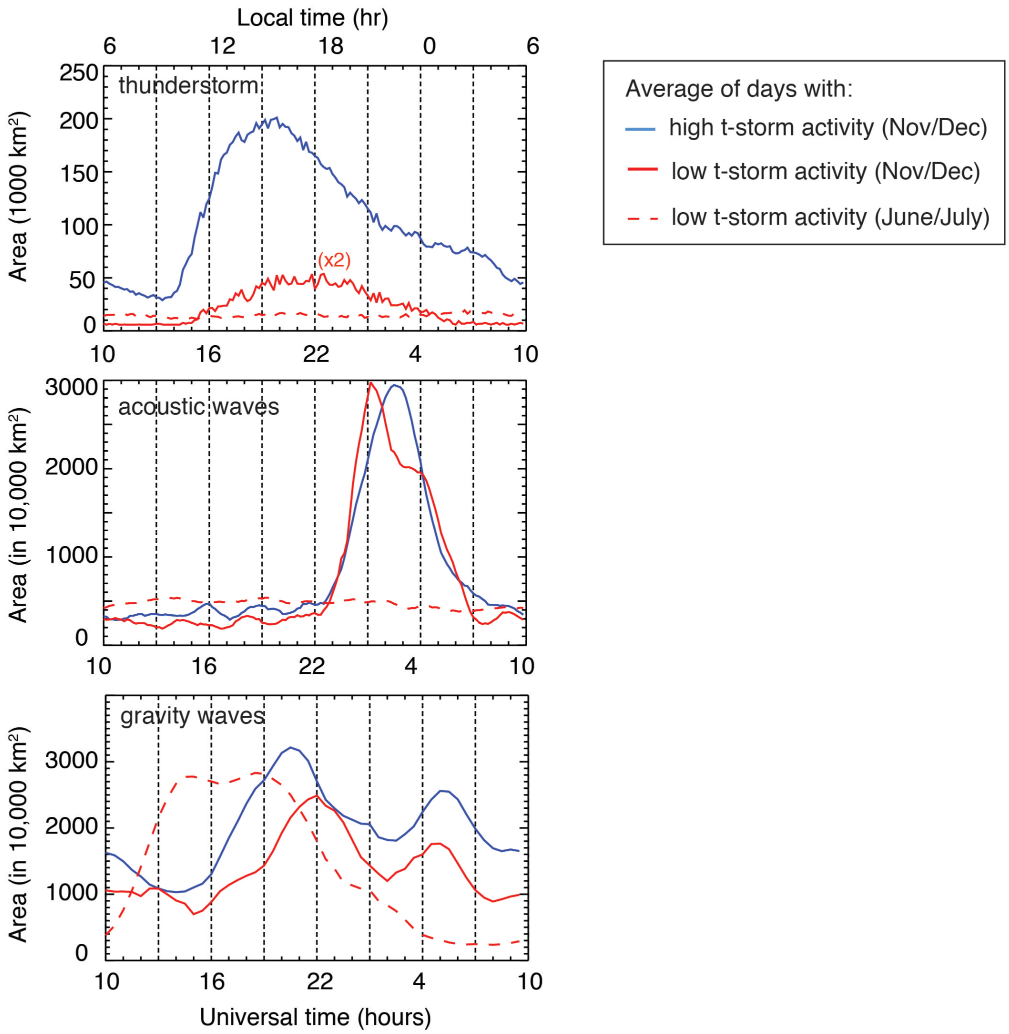

Figure 2. Diurnal averages of thunderstorm area (top), ionospheric acoustic wave area (middle), and ionospheric gravity wave area (bottom). Solid blue curve averages high thunderstorm activity days for Nov/Dec. Solid red curve averages low t-storm activity days for Nov/Dec, and red dashed average all days in June/July.

The diurnal behavior of gravity waves is shown in the bottom panel of Figure 2. Gravity wave activity during winter (solid curves) show a diurnal pattern with two peaks, the first between about 16-18 LT, the second just after 0 LT. The magnitude of the IGW area is higher on days with high thunderstorm activity days (blue solid) compared to low thunderstorm activity days (red solid). This suggests that the amount of gravity wave activity in low latitudes is somewhat driven by local thunderstorms. The gravity wave activity during winter peaks between 9-15 LT. Since there is no thunderstorm activity during this time, the driver for this gravity wave activity must be due to some other process.

Discussion/Conclusions

Diurnal activity of ionospheric acoustic waves (IAW) and ionospheric gravity waves (IGW) was studied versus thunderstorm activity in winter (June/July) and summer (Nov/Dec) of 2013. IAWs show a strong diurnal pattern in summer, peaking in the pre-midnight time period. However, the peak magnitude does not correspond to thunderstorm area, and the peak time is significantly after the peak in thunderstorm activity. This suggests thunderstorm activity is not primarily responsible for the IAW, although it could be related to seeding post-sunset irregularities [Tsunoda, 2007; 2010]. In the winter, no diurnal variation was noted in the IAWs.

Diurnal activity of ionospheric gravity waves (IGW) in the summer was found to have a double-peaked structure. The magnitude of this structure increased with increasing thunderstorm activity. The first peak of the structure occurs just slightly after the peak thunderstorm activity in time. These two findings indicate that thunderstorms have an observable, but most likely not dominant effect on the low-latitude ionosphere. Wintertime IGW activity has an observable diurnal pattern unrelated to thunderstorm activity.

These findings confirm that low-latitude ionospheric dynamics are more complicated than mid-latitude ionospheric dynamics. This is most likely due to many competing sources. However, thunderstorms do seem to have an observable effect on gravity wave activity at low-latitudes, and could be influential in acoustic wave activity.

References

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