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Ionospheric effects of volcanic eruptions

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RESUMEN

Se han realizado numerosos estudios sobre los efectos ionosféricos de la erupción volcánica del Monte Pinatubo de junio de 1991. Basados en intervalos de 1 minuto de sondaje realizado en estaciones ubicadas al norte del volcán, se han detectado perturbaciones ionosféricas caracterizadas por trenes de onda cuasi-periódicas. Las ondas ionosféricas fueron atribuidas a ondas gravitatorias generadas por la fuerte erupción volcánica del Monte Pinatubo y sus características fueron determinadas. En el presente trabajo se busca detectar perturbaciones ionosféricas causadas por erupciones volcánicas en América, basados en datos horarios de la frecuencia crítica de la capa F2 (foF2) y la altura virtual de la capa F (h'F). El estudio fue realizado para periodos de nivel de actividad magnética tranquila. Ninguna de las erupciones aquí analizadas alcanza la intensidad del Pinatubo. Sin embargo, un decrecimiento de foF2 y de su amplitud de variación y un aumento de h'F en relación con sus valores durante el día previo y el posterior al de la erupción fueron detectados en algunos casos. En otros, la perturbación fue detectada solamente en uno de los parámetros analizados. La ausencia de perturbaciones en registros horarios podría deberse a la falta de coincidencia de los máximos apartamientos de los valores respecto a una situación de normalidad con el momento del registro de los parámetros ionosféricos. La observación de los efectos está directamente relacionada con la intensidad de la erupción.

PALABRAS CLAVE: Erupción volcánica, ionosfera, frecuencia crítica de F2, altura virtual de la capa F.

ABSTRACT

Ionospheric effects of Mount Pinatubo volcanic eruption in June 1991 were recorded on 1-minute interval soundings made by stations north of the volcano. Disturbances characterized by quasi-periodic wavelike trains were detected. They were attributed to gravity waves generated by the eruption, and its characteristics were determined. We search for similar ionospheric disturbances caused by volcanic eruptions in North and South America, based on hourly F2 critical frequency (foF2) and F layer virtual height (h'F) data. The study was carried out for quiet magnetic activity levels. All eruptions reached the Pinatubo intensity. A decrease of foF2 and of its amplitude of variation, and an increase of h'F in relation to their values during the day before and after the eruption were detected in some cases. In other cases the disturbance was detected for only one parameter, or for none. The absence of disturbances in the hourly records could be due to the lack of coincidence between the maximum departures of the parameters from the normal situation, and the recording time of the parameter. The observed disturbances are correlated with the eruption intensity.

KEY WORDS: Volcanic eruption, ionosphere, F2 critical frequency, F layer virtual height.

INTRODUCTION

Volcanic eruptions (Cheng and Huang, 1992; Igarashi *et al.*, 1994), strong earthquakes (Leonard and Barnes, 1965 Davies and Baker, 1965) and nuclear blasts (Kanellakos, 1967) can trigger acoustic-gravity waves which propagate in the atmosphere and produce different effects depending on the altitude.

The sudden injection of energy and momentum into the atmosphere during volcanic eruptions generates atmospheric disturbances which can cause pressure fluctuations in the troposphere, as well as disturbances in the F2 critical frequency, foF2 (that is, in electron densities), in the virtual height of the F layer, h'F, and in the total electron content, TEC, in the ionosphere.

Cheng and Huang (1992) and Igarashi *et al*. (1994) found that the pressure waves on the Earth surface and the ionospheric waves detected during the Mount Pinatubo eruption (15.1ºN, 120.3ºE) in June 1991 (magnitude 6 in a scale from 0 to 8) were caused by the eruption. Cheng and Huang (1992) studied 1-minute interval ionospheric soundings from a station chain north of the volcano. The period of the ionospheric waves was determined to be around 16 to 30 minutes, the wavelength between 160 and 435 km, and the velocity between 131 and 259 m/s. Ionograms over Chung Li showed severe alterations which in some cases prevented a measurements of the ionospheric parameters.

Ionospheric databases generally supply hourly values. We use hourly data to detect ionospheric effects of volcanic eruptions. The effects of Mount Pinatubo eruption were investigated for hourly foF2 and h'F data from Manila (14.6ºN, 121.1ºE). Disturbances were noticed in both parameters, although with much less detail than in 1-minute interval data. The influence of volcanic eruptions on the ionosphere was analyzed for the American continent.

Most of the eruptions are of intensity 2 and 3, and all present explosions. Only cases with quiet magnetic activity (Ap < 30) were studied, in order to assure that the variations observed were not caused by geomagnetic effects.

DATA

Ionospheric data coincident with several eruptions were looked for those listed in Table 1 were selected for this study according to quiet magnetic activity, and completeness and quality of data.

Volcanic databases supply systematic information after 1970, but in a few cases only the exact time of the erup-

Table 1

Volcanic eruptions, their location, date and magnitude, Ap values, ionospheric stations and available parameters

Volcano	Geogr. Coord.	Date of eruption	Mag.	Ap	Station	Parameters
Lascar	23.4ºS – 67.7º W	March 28, 1960	3	17	Tucumán	fo F2 and h' F
Tupungatito	33.3ºS – 69.8ºW	October 16, 1959	2	4	Concepción	fo F2 and h' F
		May 5, 1961	2	20	Concepción	fo F2 and h' F
					Tucumán	fo F2 and h' F
		August 3, 1964	2	5	Concepción	fo F2 and h' F
		January 19, 1980	2	3	Tucumán	fo F2 and h' F
Planchón	32.5ºS-70.6ºW	November 6, 1959	2	23	Tucumán	fo F2 and h' F
					Concepción	fo F2 and h' F
		July 10, 1960	2	3	Tucumán	fo F2 and h' F
					Concepción	fo F2 and h' F
San Pedro	21.9ºS-68.4ºW	December 2, 1960	2	26	Concepción	fo F2 and h' F
Calbuco	41.3ºS-72.6ºW	January 25, 1961	2	18	Tucumán	fo F2 and h' F
					Concepción	fo F2 and h' F
Villarrica	39.4ºS-71.9ºW	March 3, 1964	2	7	Concepción	fo F2
		October 29, 1971	3	27	Tucumán	fo F2 and h' F
					Concepción	fo F2 and h' F
Chillán	36.9ºS-71.4ºW	March 3, 1974	2	20	Concepción	fo F2 and h' F
St. Helen	46.2ºN-122.2ºW	May 18, 1980	5	4	Boulder	fo F2
					Pt. Arguello	fo F2

tion is given. For dates previous to 1970, the information is even more scarce.

The ionospheric foF2 and h'F parameters used were extracted from the NOAA data center (retrievable from www.ngdc.noaa.gov), and correspond to Concepción (36.6ºS, 73ºW), Tucumán (26.9ºS, 65.4ºW), Boulder (40.0ºN, 105.3ºW) and Pt. Argüello (34.6ºN, 120.6°W). Not always both parameters were available in all the cases.

Figure 1 shows the effects of Mount Pinatubo eruption that began at 2155 UT on June 14, 1991, over Manila. Few hours after the beginning of the eruption, foF2 decrease and then between 09 and 15 UT there is no measured hourly data. At the same time there is not h'F hourly data between 07 and 09 UT. The first h'F data recorded (10 UT) is a very high value, equal to 645 km. A solar flare occurred at 0815 UT would be the cause off the missing data. However, ionograms from 0720 to 0810 UT (that is previous to the flare) shown by Cheng and Huang (1992) every 1 minute already show the anomaly produced by the eruptions which prevented the ionospheric parameters measurement. Cheng and Huang (1992) show the effect of the flare over h'F at fixed frequencies, from where it is deduced that during around 20 minutes, measurements could not be made. Afterwards, continuity of the disturbance, with similar characteristics to that of the moment previous to the solar flare occurrence, is observed. For this reason it is assumed that the high h'F value may be due to the eruption. The missing foF2 and h´F data may be due to the altered ionograms after the eruption and to the solar flare effect during a brief moment interval impeding any measurements.

Hourly values of foF2 and h'F of three days (the day of the eruption, and the previous and following day) were plotted.

Figure 2 shows the effects of Lascar eruption, which begins on March 28, 1960. This volcano has explosions on the first day and two more on the following day. On the second day (March 29) a strong increase in h'F can be noticed in relation to the previous and the following days. foF2 does not present significant variations, except for spread F lasting several hours.

Figure 3 shows the effects of Tupungatito eruption (May 5, 1961). An h'F increase and spread F can be noticed over Tucumán. Concepción data present gaps which prevented any analysis.

Figure 4 for the Planchon eruption of November 6, 1959, shows an increase in h'F and spread F during 5 hours over Tucumán. Over Concepción, h'F present a similar be-

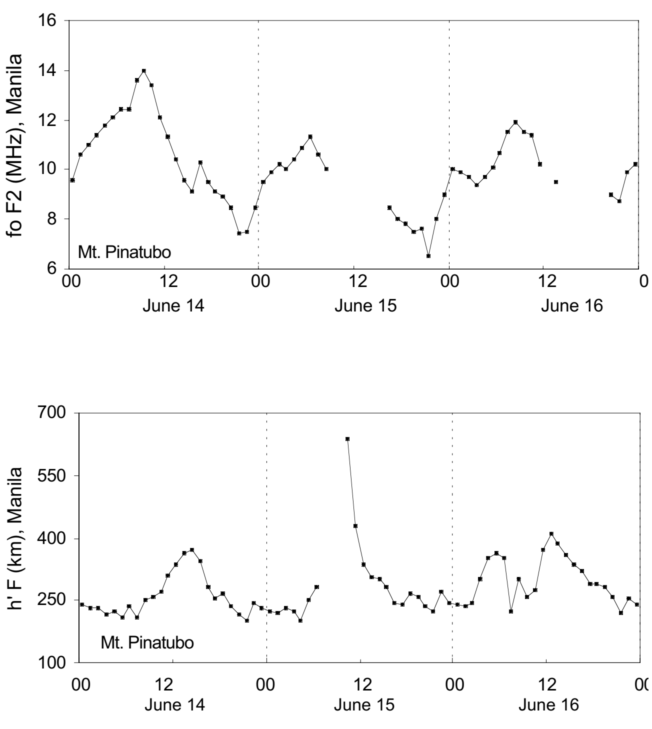

Fig. 1. Hourly foF2 and h'F of Manila from 0 UT of the day previous to the volcanic eruption of Mount Pinatubo on June 15, 1991, until 23 UT of the day after the eruption.

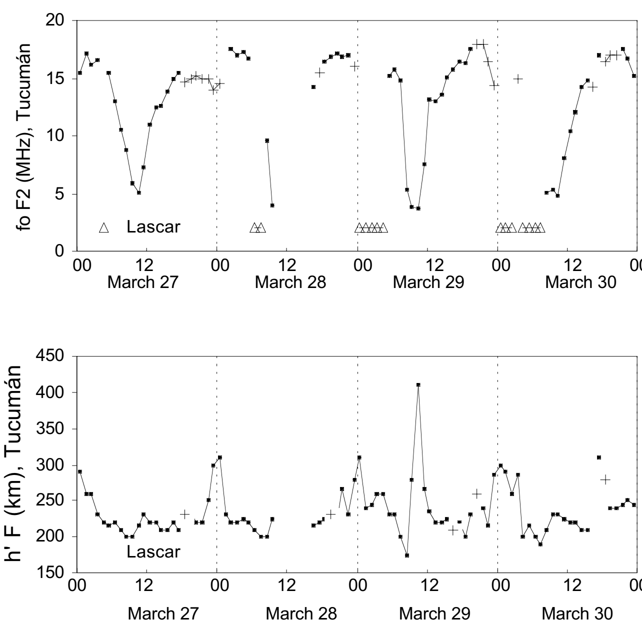

Fig. 2. Hourly foF2 and h'F of Tucumán, from 0 UT of the day previous to the volcanic eruptions of Lascar on March 28 and 29, 1960, until 23 UT of the day after the eruption. The triangle indicates spread-F. The cross indicates greater than true values for foF2 and less than true values for h'F.

havior to that of Tucumán, and there is also a decreased in foF2 amplitude of variation.

Figure 5 shows ionospheric data during the Planchón eruption of July 10, 1960. A decrease in foF2 and in its amplitude of variation, and a slight increase in h’F can be noticed over Tucumán. In Concepción only the decrease in foF2 amplitude of variation was observed.

Figure 6 show Concepción data during the eruption of Villarrica in October 29, 1971. A decrease in foF2 amplitude of variation and a slight increase in h’F is observed. Over Tucumán, foF2 and h’F seems to have a similar behavior, but any accurate analysis can be made due to the scarce data.

Figure 7 shows the effects of Mount St. Helen eruption on May 18, 1980, over Boulder and Pt. Arguello. In both places, a decrease in foF2 and its amplitude of variation as important as in the case of Mount Pinatubo over Manila can be noticed. The uncertain h’F values of Boulder and the missing h’F data for Pt. Arguello prevented the study of the effects on this parameter.

The rest of the eruptions analyzed have no significant effects over foF2 and h’F, at least on an hourly basis, or, in some cases, the effects could not be accurately defined due to incomplete data sets.

Comparatively, the ionospheric effect is greater for stronger volcanic eruptions.

If the period of the ionospheric waves produced by the eruption are of the order deduced by Cheng and Huang (1992), between 16 and 30 minutes, the observation of foF2 and h´F effects based on hourly records is subject to the coincidence between the maximum departures of the ionospheric parameters from their mean behavior, and the time of record.

CONCLUSIONS

A possible mechanism for ionospheric effects of volcanic eruption would be the upwelling of molecular rich thermospheric gas from lower altitudes impulsed by the eruption. As the photoionization rate is proportional to atomic oxygen concentration, and the loss rate to molecular nytrogen

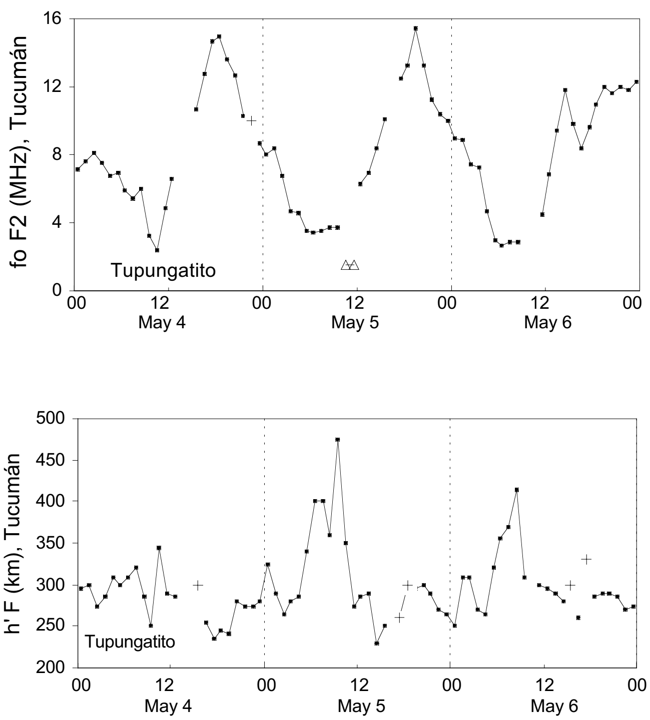

Fig. 3. Hourly foF2 and h’F of Tucumán, from 0 UT of the day previous to the volcanic eruption of Tupungatito on May 5, 1961, until 23 UT the day after the eruption. The triangle indicates spread-F. The cross indicates greater than true values for foF2 and less than true values for h’F.

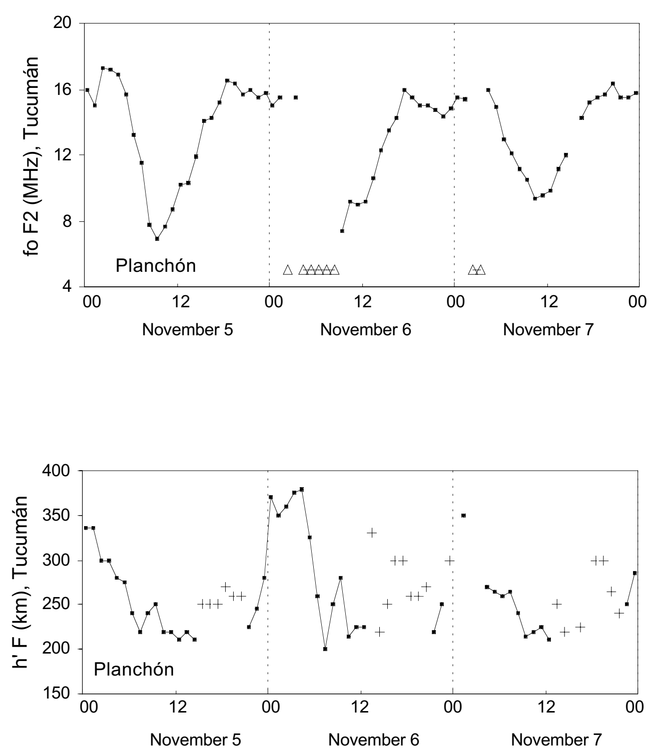

Fig. 4. Hourly foF2 and h’F of Tucumán, from 0 UT of the day previous to the volcanic eruption of Planchón on November 6, 1959, until 23 UT the day after the eruption. The triangle indicates spread-F. The cross indicates less than true values for h’F.

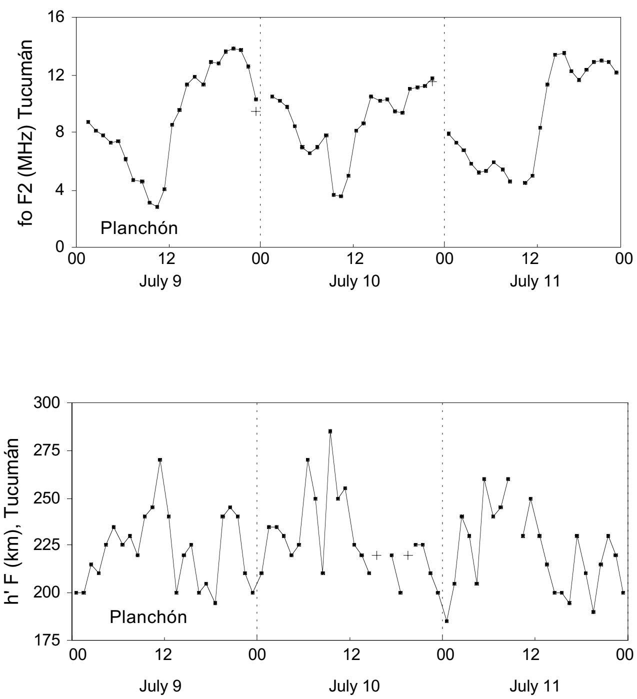

Fig. 5. Hourly foF2 and h'F of Tucumán, from 0 UT of the day previous to the volcanic eruption of Planchón on July 10, 1960, until 23 UT the day after the eruption. The cross indicates greater than true values for foF2 and less than true values for h'F.

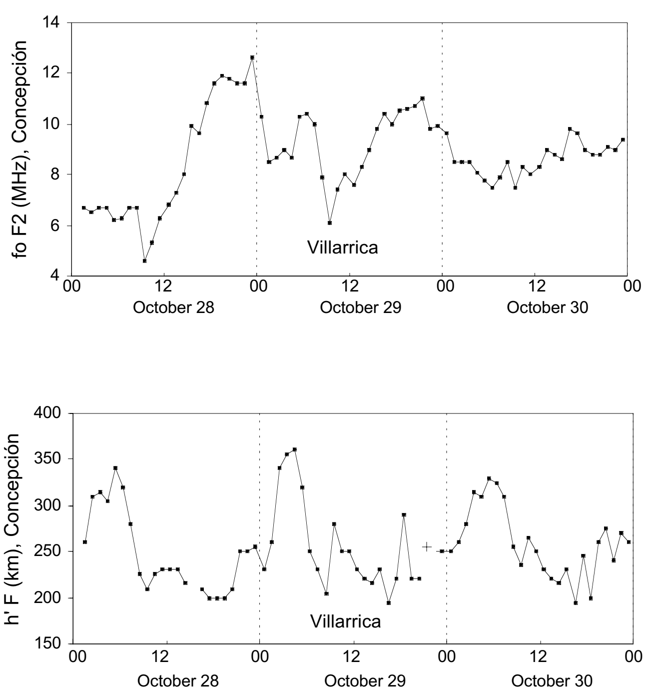

Fig. 6. Hourly fo F2 and h' F of Concepción, from 0 UT of the day previous to the volcanic eruption of Villarrica on October 29, 1971, until 23 UT the day after the eruption. The cross indicates less than true values for h'F.

and molecular oxygen concentration, an increase of the mean molecular mass due to the mentioned upwelling, would lead, in addition to an uplift of the layer, to a decrease in NmF2, that is foF2. However, this mechanism would not explain the decrease in foF2 amplitude of variation.

Kazimirovsky and Kokourov (1995) argue that internal-wave energy dissipation, coming in our case from volcanic eruptions, may lead to variations in the turbopause height. Turbopause height variability should influence thermospheric composition and temperature distribution, which in turn should lead to an ionospheric response at F2 layer altitudes.

From our results it is concluded that:

- The effects of volcanic eruption over the F region are a decrease of foF2 amplitude of variation and/or an increase in h'F in 60% of the cases here analyzed. The effect over both parameters at the same time is observed in 70% of these cases.

- Comparing the ionospheric effects of the different eruptions, it is inferred that their detection is strongly dependent on the volcanic intensity.

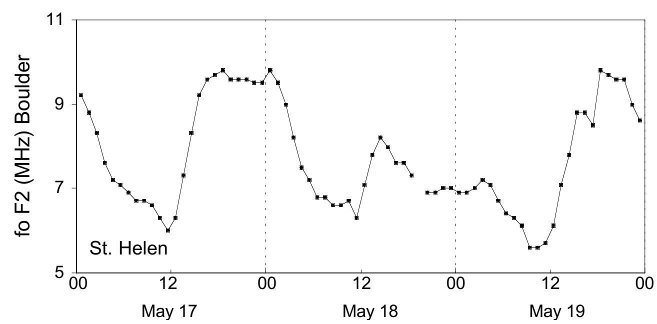

Fig. 7a. Hourly fo F2 of Boulder, from 0 UT of the day previous to the volcanic eruption of St. Helen on May 18, 1980, until 23 UT the day after the eruption.

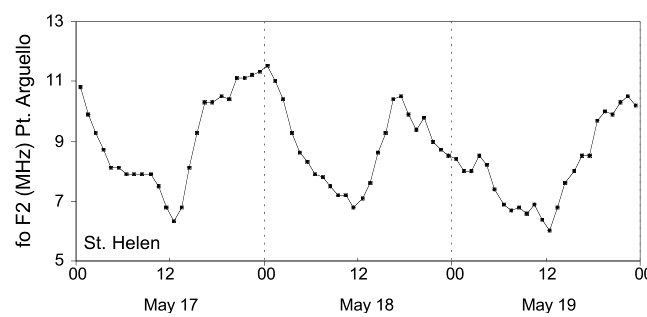

Fig. 7b. Hourly foF2 of Pt. Arguello, from 0 UT of the day previous to the volcanic eruption of St. Helen on May 18, 1980, until 23 UT the day after the eruption.

• Based on hourly records, the detection of ionospheric disturbances is subject to the coincidence of the data time of record and the maximum departures of foF2 and h'F from their mean behavior produced by the eruption.

The statistics of this work will be enlarged in order to generalize our results. In addition, the purpose of future research is to study the influence of neutral winds, magnetic activity, and the equatorial ionization anomaly upon the ionospheric effects of volcanic eruptions.

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