

Atmospheric wave energy of the 2020 August 4 explosion in Beirut, Lebanon, from ionospheric disturbances

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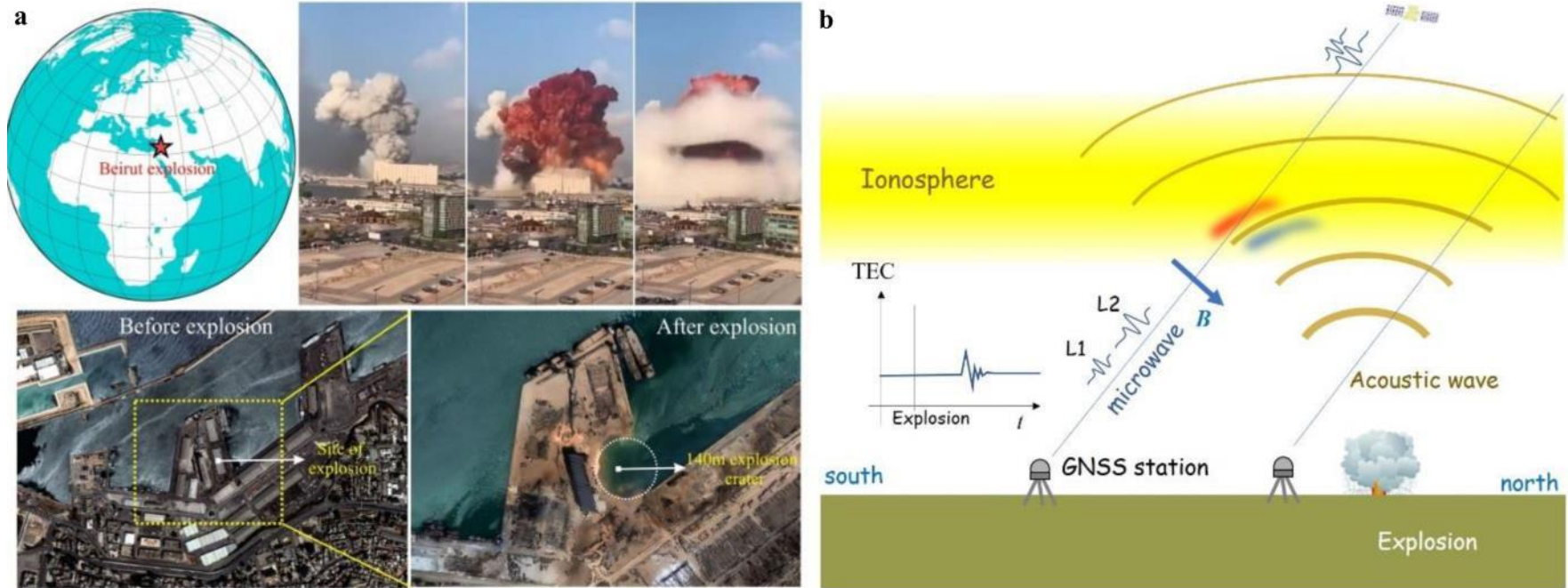
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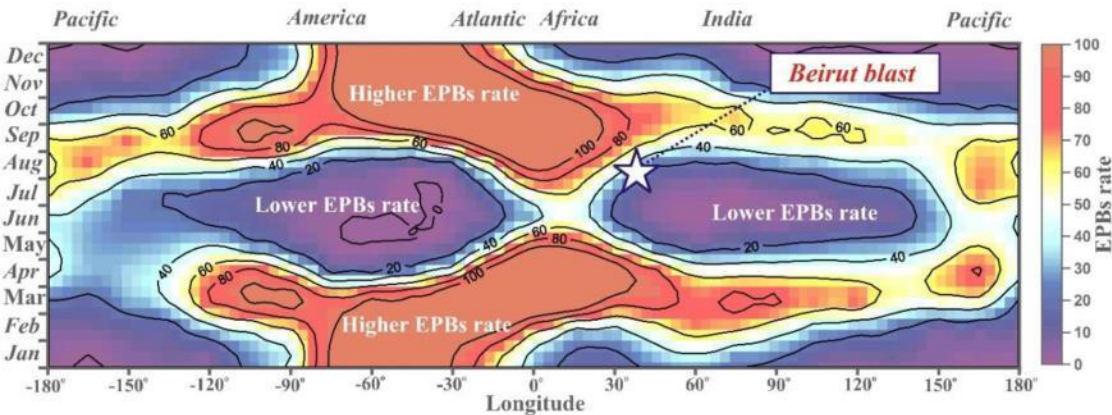


2020 Beirut explosion and ionospheric disturbance



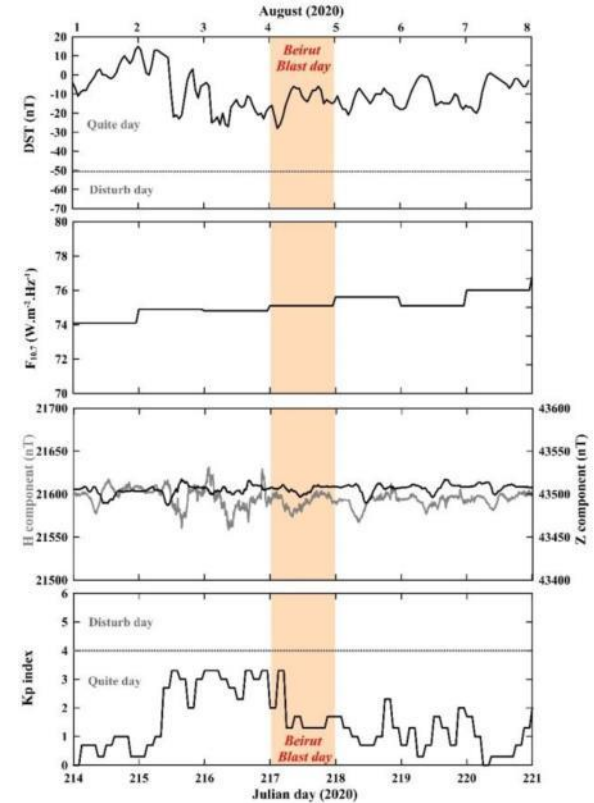
(a) Location of August 4, 2020 Beirut explosion point marked by a red star in the globe. Sequence of the ash cloud captured during the explosion (snaps archived at <https://nigma.global>). **(b)** Illustration of ionospheric disturbance caused by an explosion can be detected by differential ionospheric delays of microwave signals of two carrier frequencies from GNSS satellites. The disturbances in ionosphere are observed 10-12 minutes after the explosion, the time necessary for the acoustic wave to reach the ionospheric F region. The wave makes electron density anomalies (a pair of positive and negative anomalies shown with red and blue) on the southern side of the explosion

Space weather around the Beirut explosion day



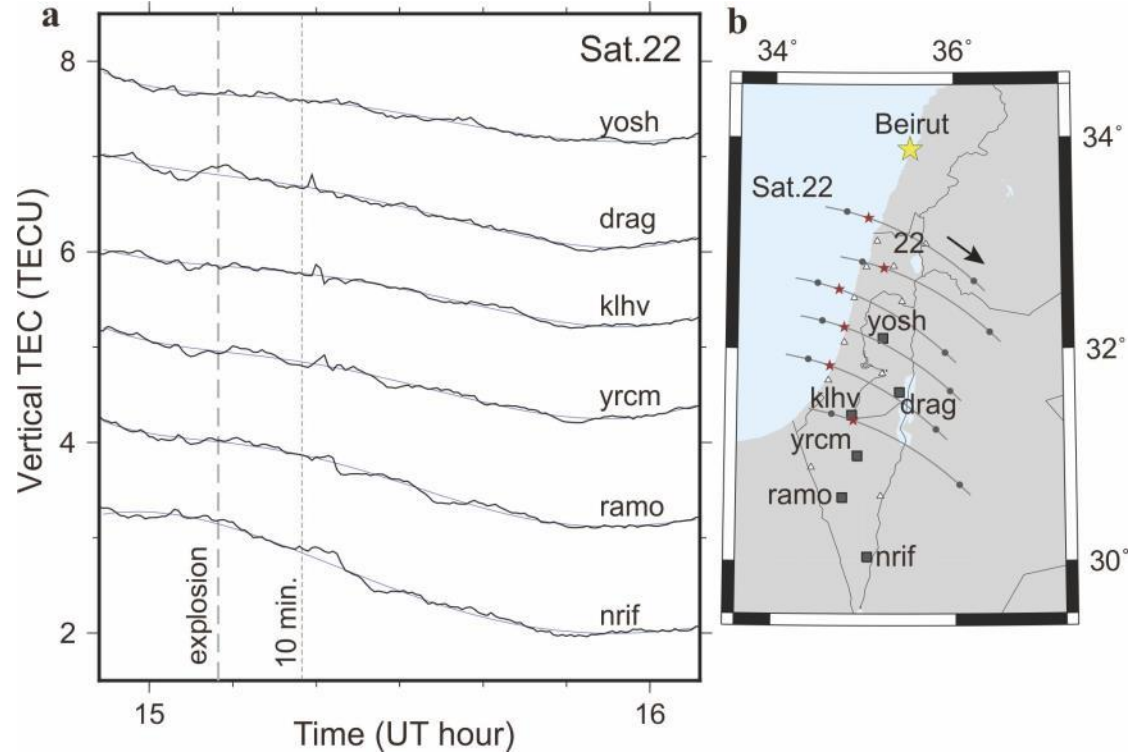
Equatorial Plasma Bubbles rate as a function of time and longitude

- The EPB production rate is not high at the longitude of Beirut in early August.
- The Kp index is about 1.7, which indicates a quite geomagnetic activity around the time of the Beirut explosion



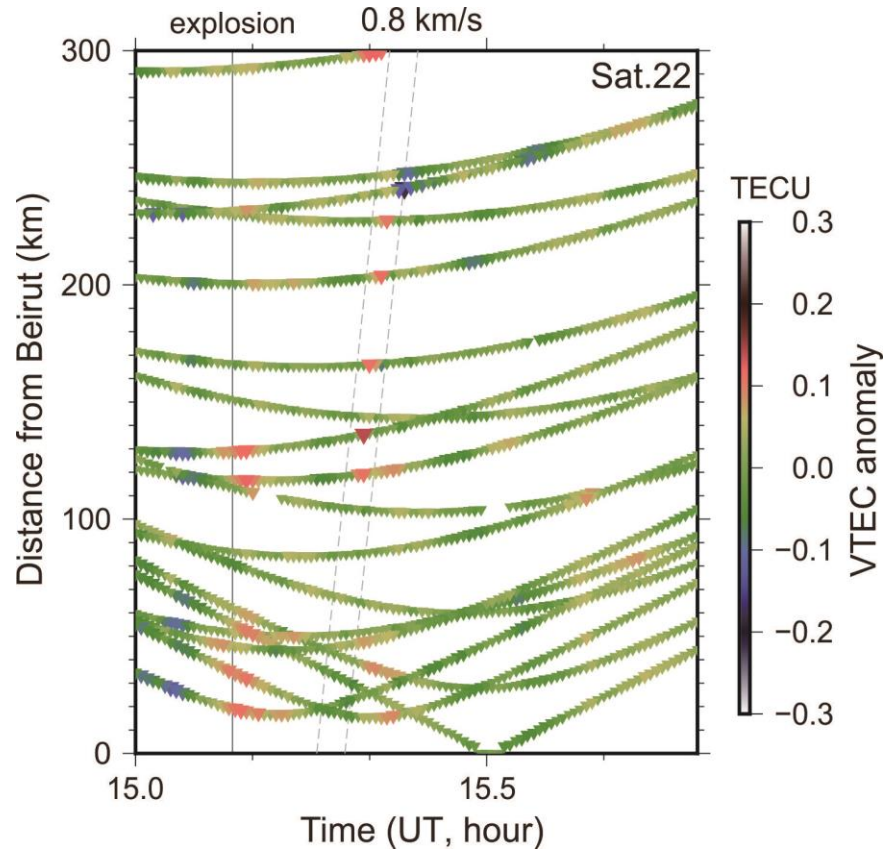
The geomagnetic activity indices, F10.7 solar radiation intensity, and geomagnetic field from 1 to 8 August (214 to 221 Julian day) 2020

Time series of vertical TEC changes



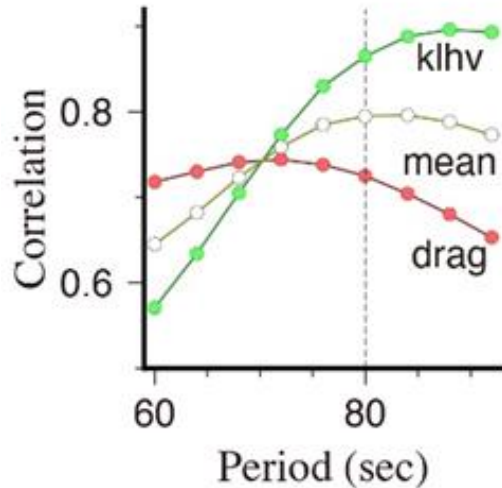
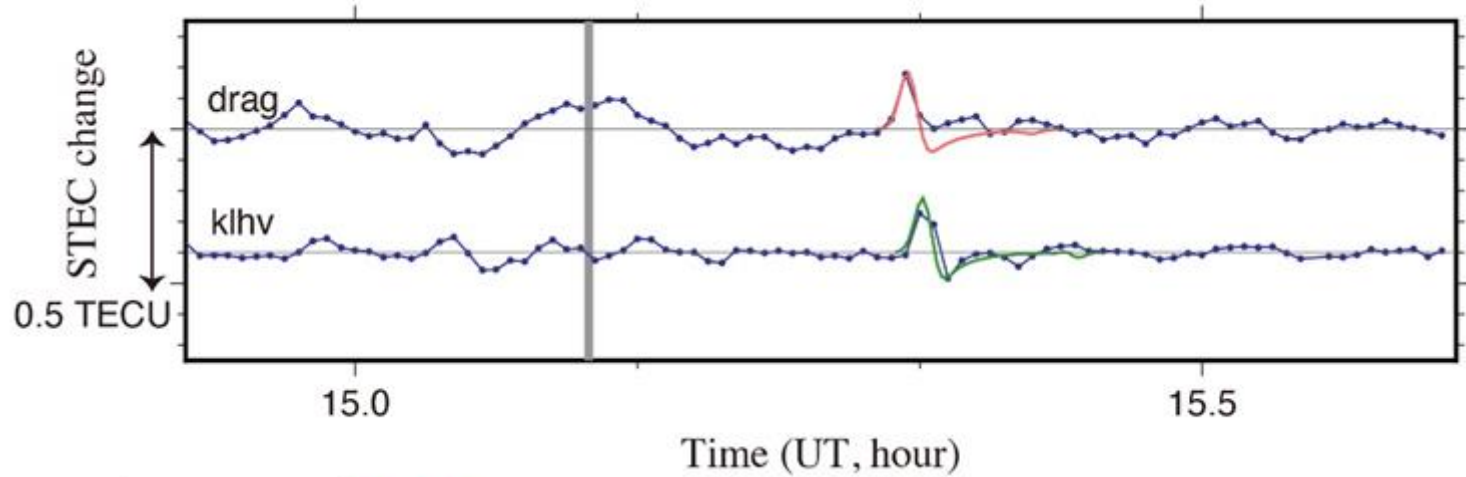
(a) The VTEC change from GPS satellite 22 at stations drag, klhv, yrcm, ramo and nrif (squares in **b**) over 14:54–16:06 UT on August 04, 2020. The dashed vertical line represents the explosion time (15:08:18 UT). Ionospheric disturbances are seen shortly after the dotted line indicating 10 min after the explosion as the departure from the smoothed reference curves (best fit degree-5 polynomials, thin gray curves). (b) The trajectory of sub-ionospheric points (SIPs) calculated assuming the thin ionosphere at altitude 300 km, marked with solid circles (hourly time mark) and red stars (explosion time).

VTEC anomalies in the travel time diagram



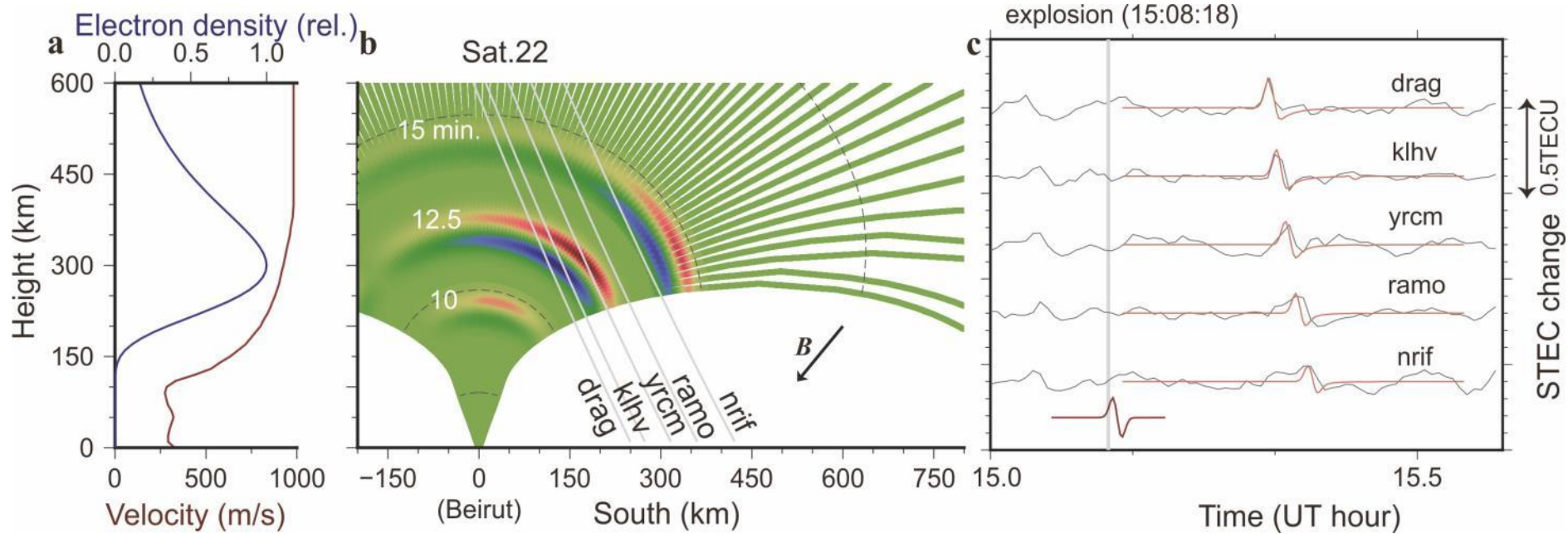
- The anomaly propagated southward at an apparent speed ~ 0.8 km/s

Modeling of GNSS-TEC time series



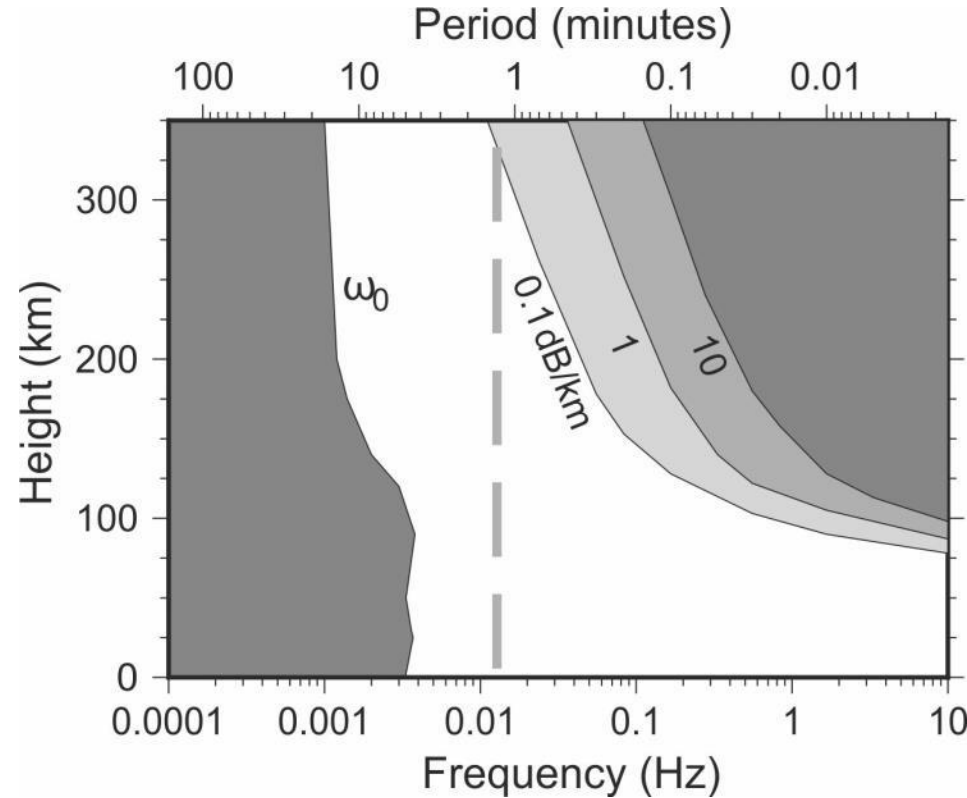
- $f(t) = -(at) \exp \frac{-t^2}{2\sigma^2}$ (maximum at $t = -\sigma$ and minimum at $t = \sigma$)
- we found that 80 seconds maximizes the correlation between the observed and synthesized curves of the two stations.

Numerical simulation of the observed TEC changes



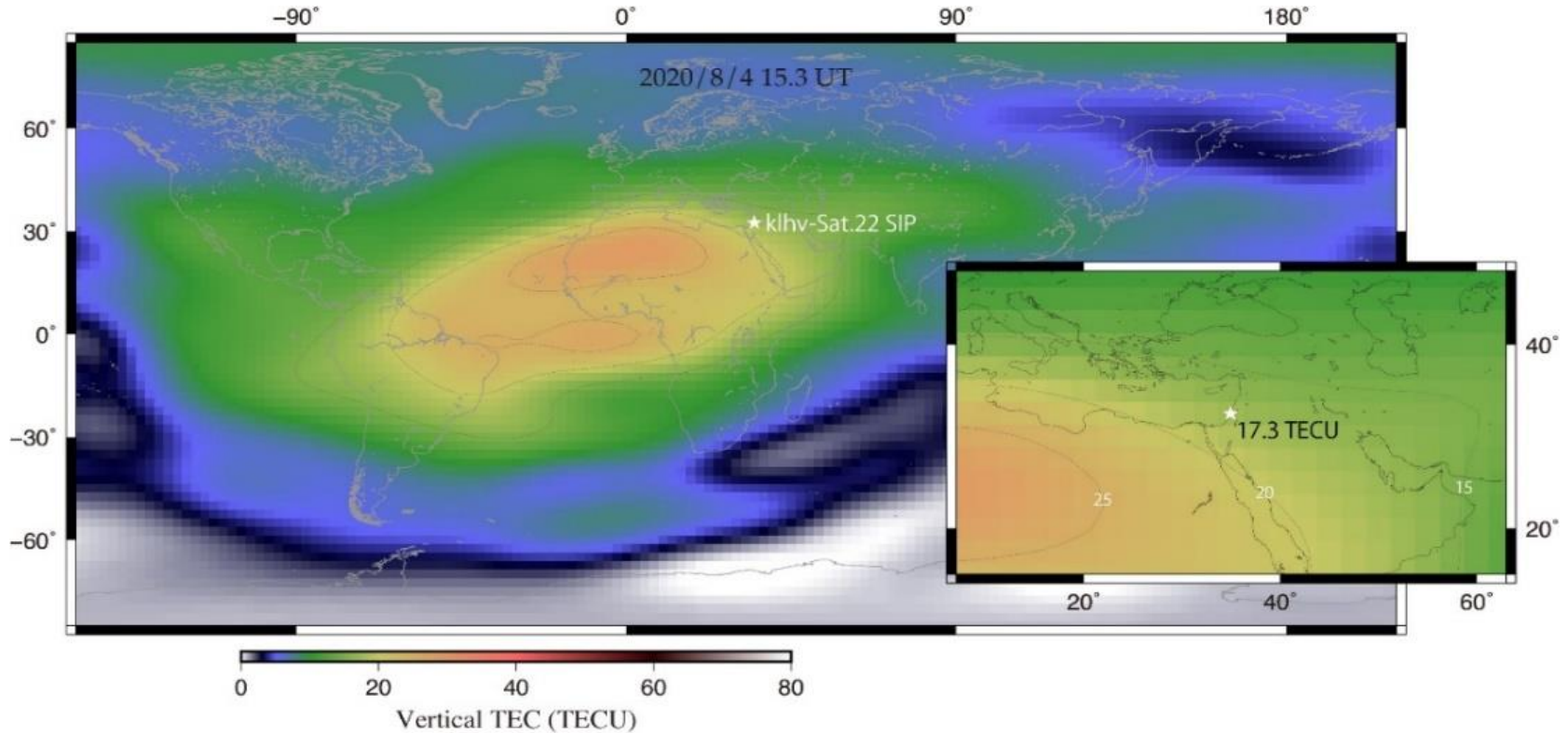
(a) Relative electron density (dark blue) and velocity of acoustic wave (dark red, U.S. Standard Atmosphere 1976) plotted as functions of height. **(b)** Ray tracing of an N-shaped acoustic wave for zenith angles 0–22 degrees performed assuming the velocity profile shown in **(a)**. The black dashed curves indicate equal-time contours for 5, 10, 15, and 20 min after the explosion. Colors shown along the ray paths indicate the position of the N-shaped pulse at 10.0, 12.5, and 15.0 min after the explosion. Gray lines are the LOSs 12.5 min after explosion connecting the satellite 22 and five GNSS stations **(c)** The observed (dark gray, residuals from the best-fit degree-7 polynomials) and synthesized (red, based on the ray tracing) STEC time series of the five GNSS stations for GPS satellite 22. Note that the observed arrival times, waveforms and relative amplitudes are consistent with the synthesized curves.

Attenuation of airwaves in the Earth's atmosphere



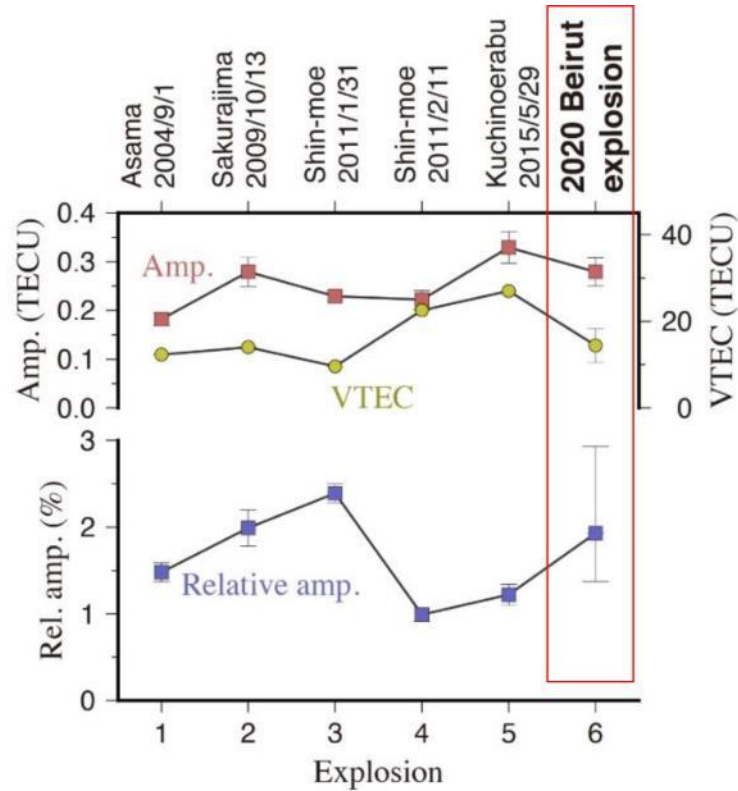
The frequency (~ 12.8 mHz) and period (~ 1.3 minutes) of the observed TEC oscillations by the Beirut explosion (vertical dashed line) and the altitude-dependent attenuation of acoustic waves in the Earth's atmosphere, modified from Blanc. The observed frequency corresponds to the high end of the atmospheric band pass filter

VTEC distribution from Global Ionospheric Map



- The background vertical TEC of the Beirut explosion is ~ 13.4 TECU according to the Global Ionospheric Map.

Slant TEC and its comparison with volcanic explosions in Japan



- The peak-to-peak amplitude of the disturbance reached $\sim 2\%$ of the background electrons, comparable to recently recorded volcanic explosions in the Japanese Islands

Key observations

- The ionospheric disturbances caused by the explosion was 0.28 ± 0.03 TECU. in peak-to-peak amplitude of slant TEC
- The disturbances in ionosphere are observed 10–12 min after the explosion.
- An N-shaped pulse has reported with period ~ 1.3 minutes propagating southward at ~ 0.8 km/s.
- The peak-to-peak amplitude of the disturbance reached $\sim 2\%$ of the background electrons, comparable to recently recorded volcanic explosions in the Japanese Islands.

References

- Gentile, I. C., Burke, W. C. & Rich, F. J. A global climatology for equatorial plasma bubbles in topside ionosphere. *Ann. Geophys.* **24**, 163-172 (2006).
- Blanc, E. Observations in the upper atmosphere of infrasonic waves from natural or artificial sources: A summary. *Ann. Geophys.* **3(6)**, 673–688 (1985).
- Mannucci, A. J., Wilson, B. D., Yuan, D. N., Ho, C. H., Lindqwister, U. J. & Runge, T. F. A global mapping technique for GPS-derived ionospheric total electron content measurements. *Radio Sci.* 33, 565–582, (1998).
- Cahyadi, M. N., Handoko, E. Y., Rahayu, R. W. & Heki, K. A new index for the volcanic explosion scales using impulsive ionospheric disturbances. *Adv. Space Res.* under review (2020).
- Heki, K. Chapter 5-3: Ionospheric disturbances related to earthquakes in *Advances in Ionospheric Research: Current Understanding and Challenges. Space Physics and Aeronomy, Vol. 3*, edited by C. Huang and G. Lu, pp.320, Wiley/American Geophysical Union, ISBN:978-1-119-50755-0 (2020).
- Cahyadi, M. N. & Heki, K. Coseismic ionospheric disturbance of the large strike-slip earthquakes in North Sumatra in 2012: Mw dependence of the disturbance amplitudes. *Geophys. J. Int.* **200**, 116-129 (2015).
- Heki, K. & Ping, J. Directivity and apparent velocity of coseismic ionospheric disturbances observed with a dense GPS array. *Earth Planet. Sci. Lett.* 236, 845– 855 (2005).