Ionosonde observations of ionospheric disturbances due to the 15 February 2013 Chelyabinsk meteor explosion

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Abstract

We report the results of our investigations on ionospheric effects potentially caused by the 15 February 2013 Chelyabinsk meteor explosion. We used the observation data from a number of digisonde stations located in Europe and Russia to detect the traveling ionospheric disturbances (TIDs) likely to have been caused by the meteor explosion. We found that certain characteristic signatures of the TIDs can be identified in individual ionogram records, mostly in the form of Y-forking/splitting of the ionogram traces. Based on the arrival times of the disturbances, we have inferred the overall propagation speed of the TIDs from Chelyabinsk to be 171 ± 14 m/s. In addition to the natural fulfillment of scientific endeavors, this work also highlights the importance of maintaining the mastery of ionosondes as ionospheric diagnostic instruments (in terms of operation, data analysis, representation, and interpretation) for many generations of space researchers to come.

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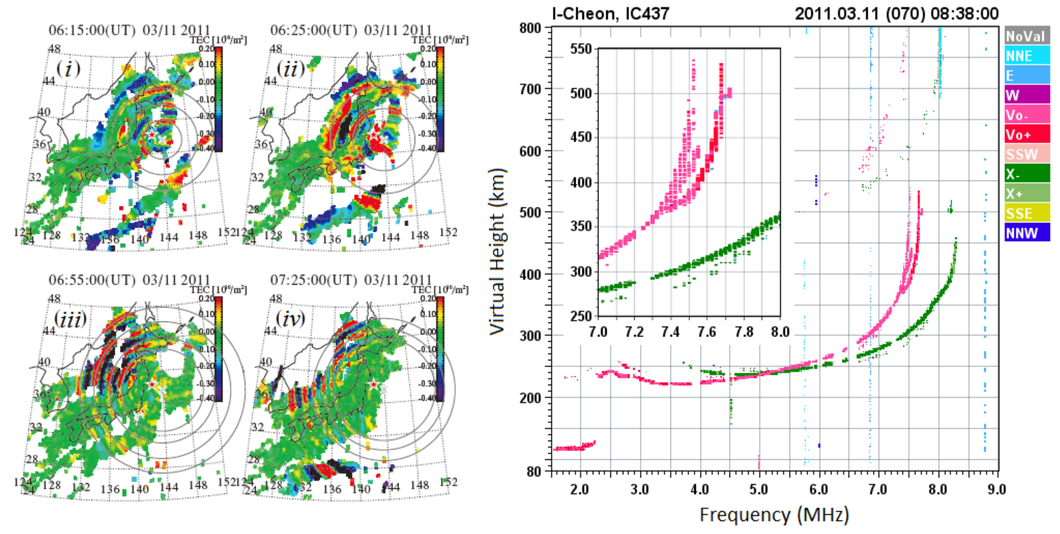
Situational Overview

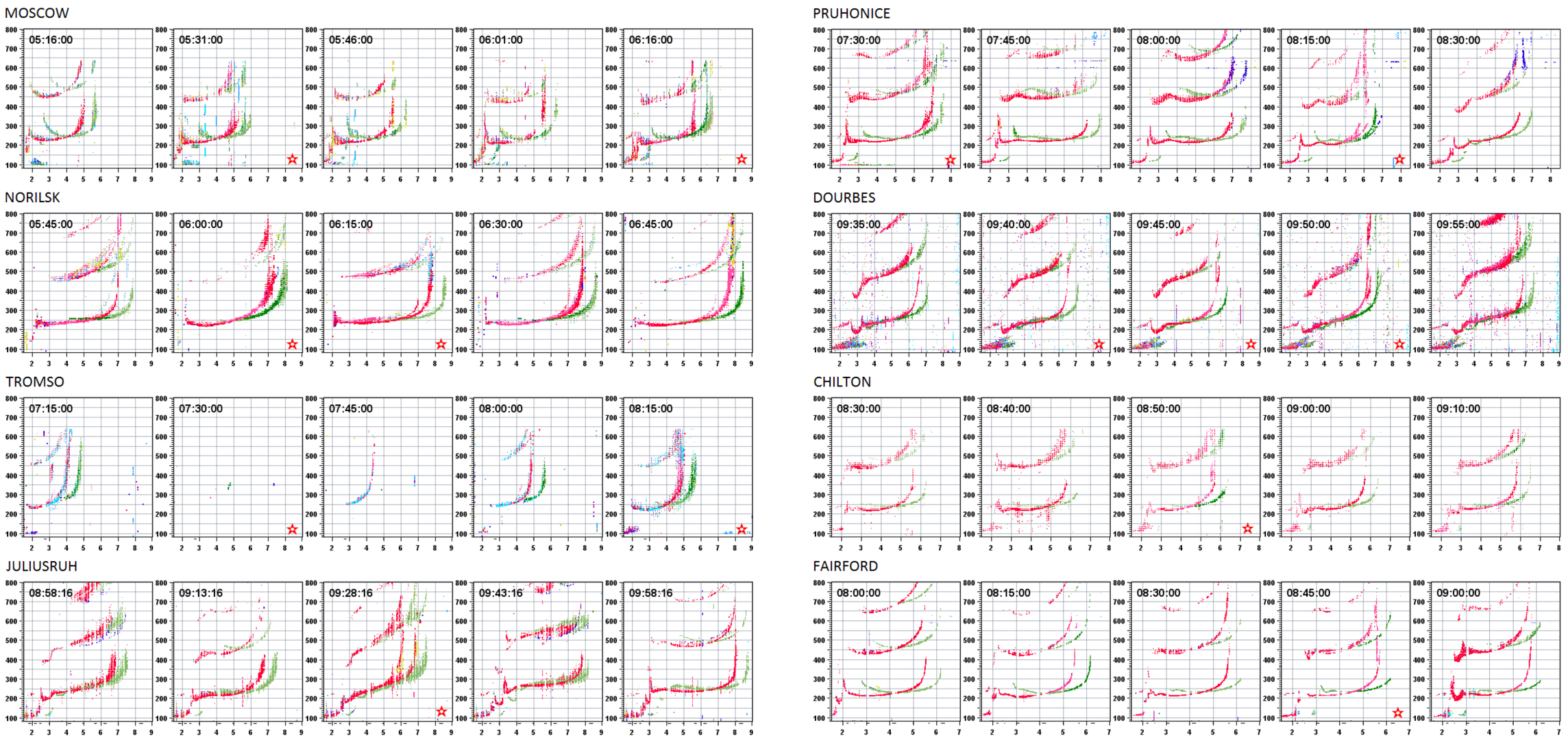
A large meteor explosion happened on 15 February 2013 at approximately 03:20 UTC. The map shows great circle arcs from Chelyabinsk (the meteor explosion site) toward several ionosonde stations located in Europe and Russia.

The Basics: Characteristic Signatures of TIDs in Ionograms



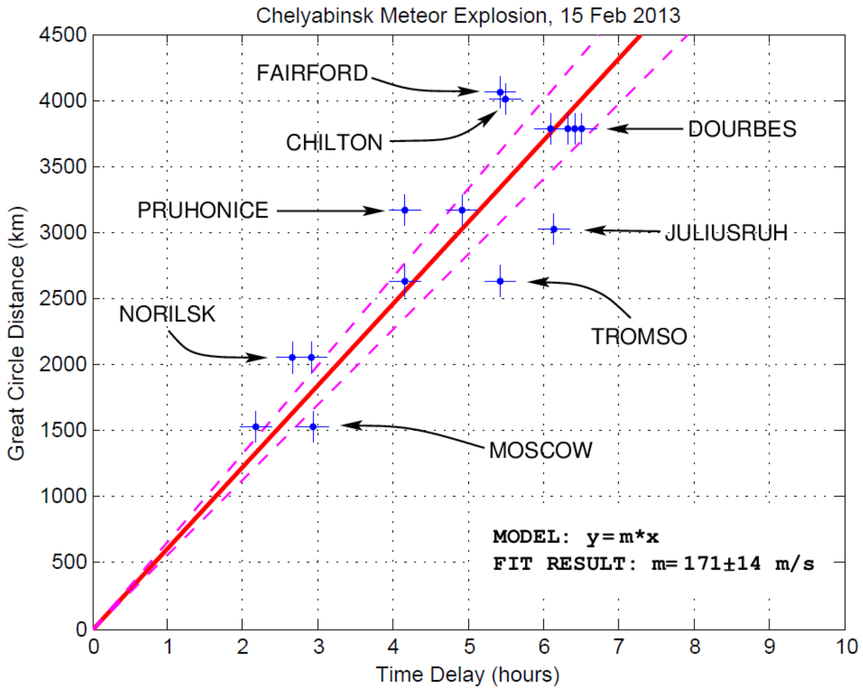
Left: Pattern of concentric TID wavefronts mapped using GPS TEC data recorded over Japan shortly after the 11 March 2011 Tohoku earthquake, reproduced from *Tsugawa et al.* [2011]. Right: Ionosonde data from I-Cheon, Korea, taken a few hours after the earthquake also show some characteristic signatures of these TIDs, in the form of a Y-forking of the ionogram trace.

Ionogram Records: Arrivals of TIDs from the Chelyabinsk Meteor Explosion



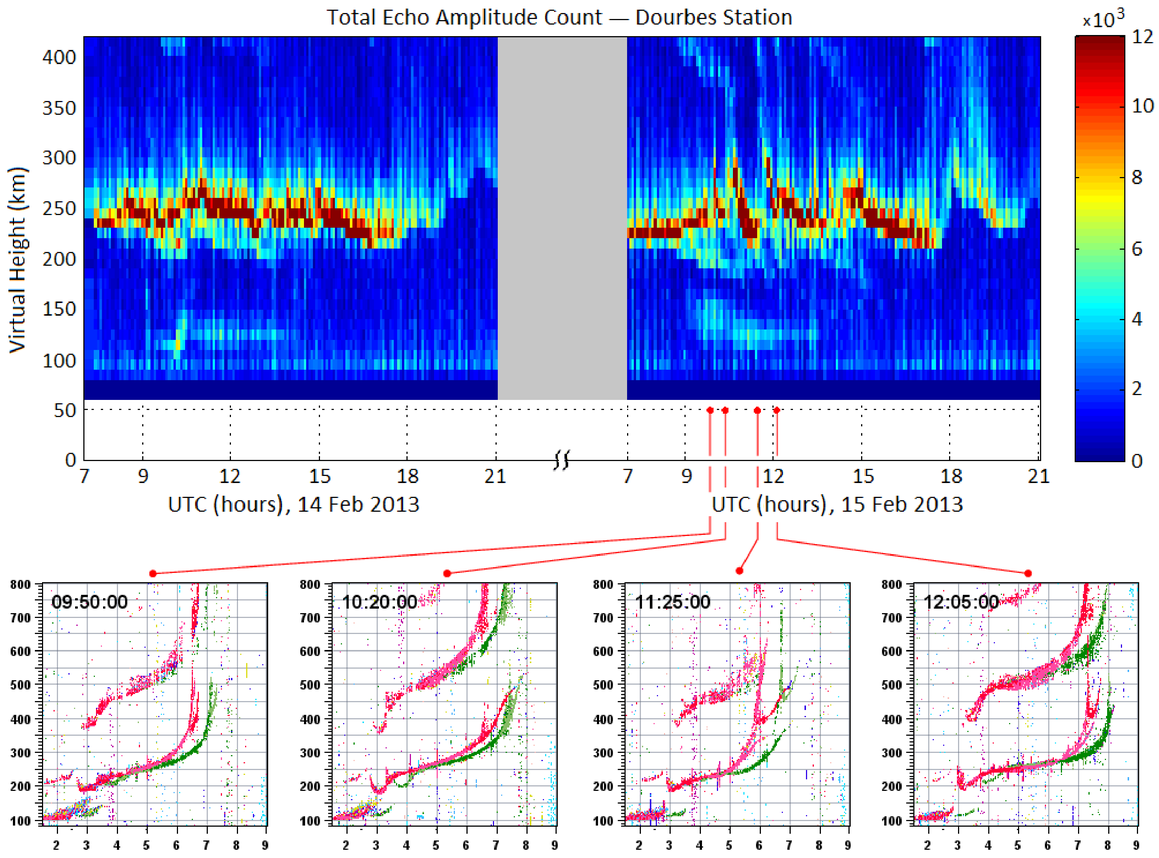
A survey of ionogram data taken on 15 February 2013 (from Moscow, Norilsk, Tromso, Juliusruh, Pruhonice, Dourbes, Chilton, and Fairford stations) showing the early/first arrival of ionospheric disturbances over these stations following the meteor explosion. Each respective row depicts a set of sequential ionograms around the times when the suspected TID signatures were observed. The ionograms exhibiting the characteristic TID signatures are marked accordingly with a red star at the bottom right corner. In all of the above ionograms, the x-axis is the sounding frequency (MHz), and the y-axis is the virtual height (km). The ionogram traces in red color are those of O-mode polarization, and the traces in green color are those of X-mode polarization. Note that the meteor explosion itself occurred on 15 February 2013 at approximately 03:20 UTC.

Estimating the TID Propagation Velocity



A plot of the great circle distance from Chelyabinsk to each ionosonde stations versus the corresponding time delay for the traveling ionospheric disturbances to arrive. The result of a linear fit to the data points is also overlaid on the graph (solid red line), revealing a propagation speed of roughly 171 m/s. The dashed magenta lines indicate the 95% confidence interval bounds.

Closer Look at the TID Signatures



An RTI-style plot of ionogram data from the Dourbes station, covering a representative time window 07:00-21:00 UTC on 14 and 15 February 2013. The colormap indicates the level of the total echo amplitude count at any given virtual height and time, summed over all sounding frequencies. Shown also are samples of individual ionogram at four specific times during the passage of traveling ionospheric disturbances over this station after the Chelyabinsk meteor explosion several hours earlier.