Volcanic Disruption of the Equatorial Ionosphere: ICON Observations of the Tonga Eruption

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\section*{Ionospheric Impacts of Volcanic Eruptions}

The Hunga Tonga-Hunga Ha'apai (hereafter called 'Tonga') volcano erupted at \textasciitilde4:15UT on 15/1/22, driving atmospheric pressure waves around the globe [1,2] (Fig 1). These waves propagated into space, producing traveling ionospheric disturbances (TIDs) [3,4,5] which persisted for several days after the eruption [6]. While direct modification of the ionosphere has been associated with the passage of atmospheric waves originating in the lower atmosphere [7], the potentially larger electrodynamic effects on the plasma have only recently been considered [8]. Here we show immediate, global-scale dynamo effects of the eruption using observations from NASA's Ionospheric Connection Explorer (ICON).

\section*{Data and Methods}

The ICON mission explores energy and momentum transfer from solar and atmospheric sources into the ionosphere [9], so is apt to study Tonga's ionospheric effects. ICON’s Ion Velocity Meter (IVM) measures in situ plasma densities and drifts [10], MIGHTI remote-senses neutral wind profiles [11], and the Far Ultra-Violet (FUV) Imager remote-senses plasma density profiles [12] (Fig 2). For the relevant scale sizes \textasciitilde1s, \textasciitilde10km), IVM measurements can be extrapolated along the field lines, providing remote sampling of the electric field. To distinguish from quiet-time variability, we find the solar local time-dependent ion drift climatology for Jan 8-13, 2022 (gray in Fig 4c), when magnetic conditions were quiet (Fig 3). We omit the day before the eruption due to a geomagnetic storm. As noted by Harding et al. (2022) [8], there is little evidence of penetration electric fields due to the storm, so it is unlikely to confound our analysis.

\section*{Observations: ICON’s First Glimpse of the Eruption}

We report extreme zonal and vertical ExB ion drifts (6.9s and 8.8s w.r.t. to the climatology, respectively) \textasciitilde4000 km away from Tonga within an hour of the eruption, well before the arrival of any atmospheric wave (Fig 4).

\section*{Theory: Disruptions to the E-Region Dynamo}

With a spherically expanding neutral wind model (Fig 4b), the IVM south footpoint encounters first a westward, then eastward, then eastward, then westward wind (Fig 5). We use a simplified slab model following Kelley 2009 [13] to determine the resulting electric fields and ion drifts, considering currents in only the Hall region (\textasciitilde100-120km) and neglecting Pedersen currents. In this model, a polarization electric field is created to balance the wind-driven current and find the resulting ExB drifts, which agree well with our observations.

\section*{Discussion and Conclusions}

The region with extreme ion drifts was magnetically connected to the E-region just 400km from Tonga, suggesting that the wavefront expanding from Tonga created strong electric potentials which were then transmitted along the magnetic field (i.e., via AlfVén waves). A simple theoretical model (Fig 5) reveals the observed drift signatures are consistent with an expanding wave with a large (>200m/s) neutral wind amplitude. These observations are the first direct detection in space of the near-immediate dynamo effects of a volcanic eruption and will prove essential for constraining ionospheric models of impulsive lower atmospheric events.

\section*{Ongoing Work: ICON’s Later Tonga Encounters}

This work examined Tonga’s immediate dynamo effects, studying ICON’s first orbit post-eruption, when only the IVM sampled the region affected by the volcano. Ongoing work will examine ICON’s later orbits, incorporating neutral wind and density profile data to get a more complete picture of how the eruption’s ionospheric dynamo modification evolves.