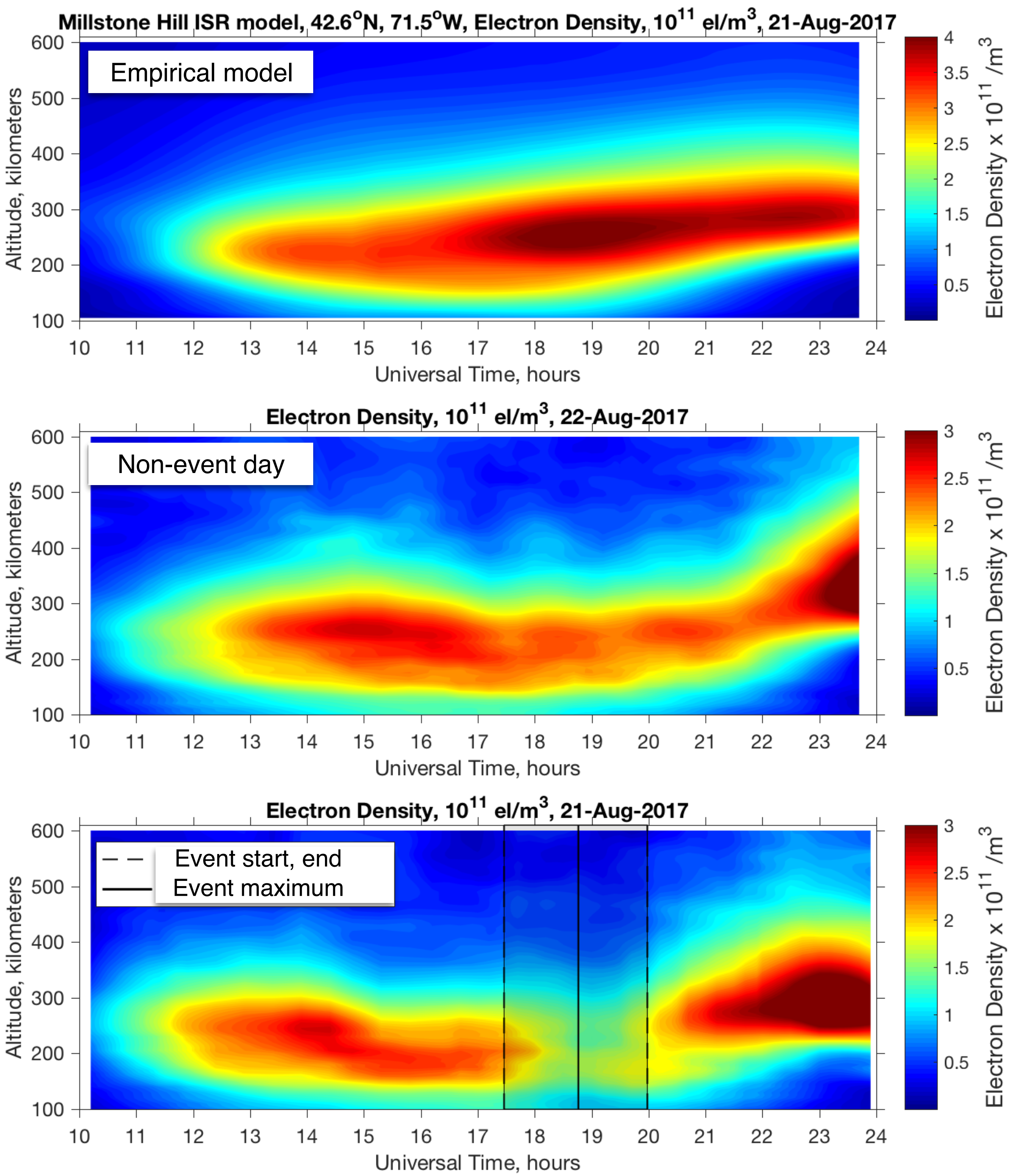
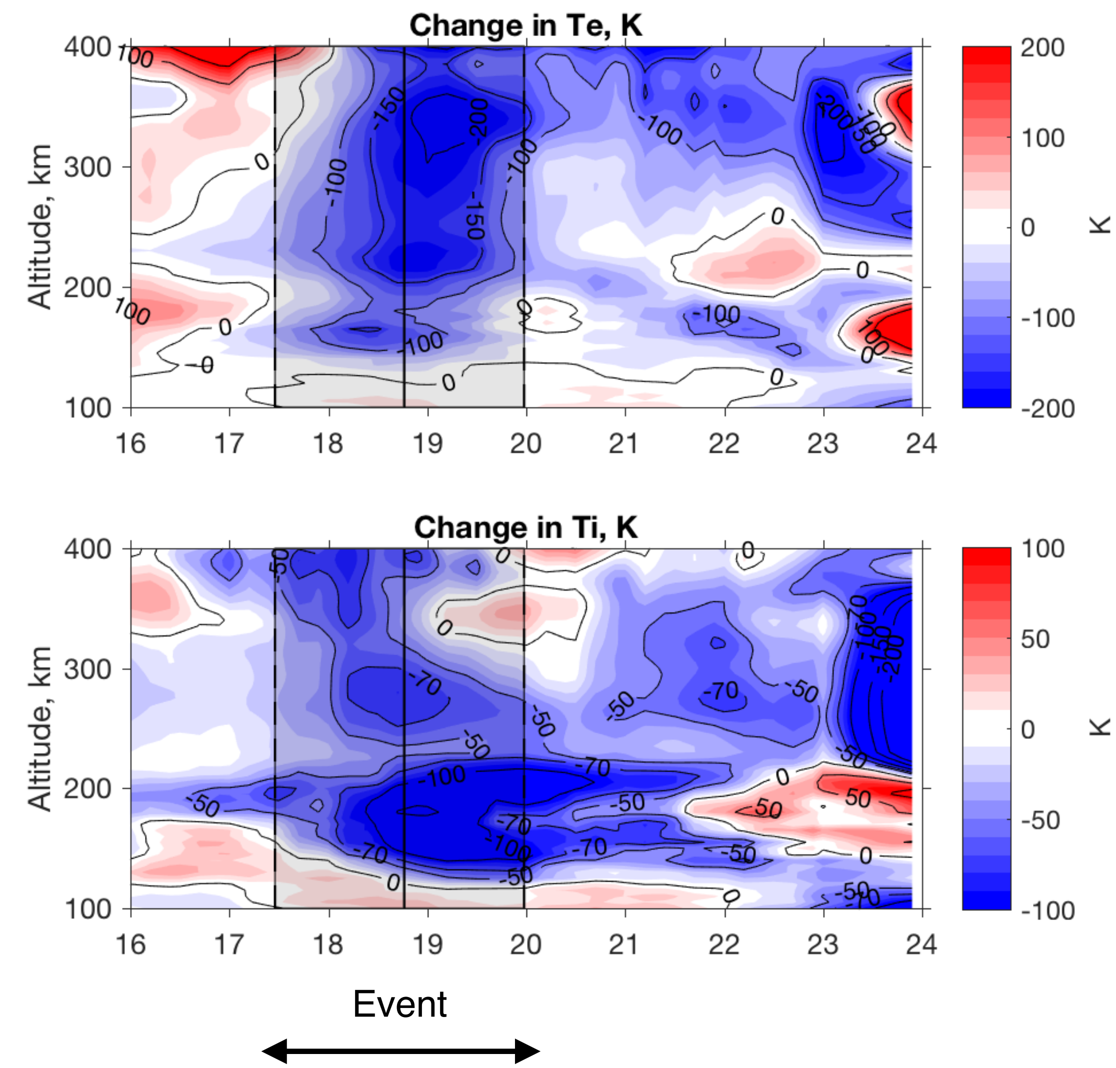
GROUP 1



Millstone Hill ISR model, 42.6°N, 71.5°W, Electron Density, 10^11 el/m^3, 21-Aug-2017
Empirical model
Electron Density, 10^11 el/m^3, 22-Aug-2017
Non-event day
Electron Density, 10^11 el/m^3, 21-Aug-2017
Event start, end
Event maximum
Altitude, kilometers
Universal Time, hours
Electron Density x 10^11 /m^3



Change in Te, K
Change in Ti, K
Altitude, km
K
Event

Geophysical Research Letters

RESEARCH LETTER
10.1029/2018GL077334

Special Section:
New Understanding of the Solar Eclipse Effects on Geospace: The 21 August 2017 Solar Eclipse

Key Points:
- Observations of ionospheric changes due to the solar eclipse are presented
- Electron density is decreased by 30–40%, electron temperature by 100–220 K, and ion temperature by 50–140 K
- Large 20– to 40–m/s vertical plasma drift seen in the topside ionosphere during recovery from eclipse is expected to affect plasmasphere

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Ionospheric Response to the Solar Eclipse of 21 August 2017 in Millstone Hill (42N) Observations

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Abstract This study examines the ionospheric changes associated with the solar eclipse of 21 August 2017. The effects associated with the passage of the eclipse shadow were observed more than 1,000 km away from the totality at midlatitudes using the Millstone Hill incoherent scatter radar and digisonde. There was a 30–40% decrease in electron density, a 100- to 220-K decrease in electron temperature, and a 50- to 140-K decrease in ion temperature. Surprisingly, the greatest decrease in electron density occurred above 200 km. The most unexpected effect was a large 20- to 40-m/s upward vertical drift observed in the topside ionosphere right after the local maximum obscuration. We suggest that this drift led to a posteclipse increase in the topside electron density.

Plain Language Summary During the solar eclipse of 21 August 2017, millions of people who watched it from the ground could feel a sudden chill in the air as the Moon's shadow moved across the continental United States. However, it is far less certain what happens during the solar eclipse in the atmosphere at higher altitudes. Here we present ionospheric observations at 100–600 km above the ground and from >1,000 km away from the totality zone. We report up to 100- to 140-K cooling in the ion temperature, which is very close to the temperature of neutral particles, 100- to 220-K cooling in electron temperature, and up to 40% reduction in electron density shortly after the maximum obscuration. We suggest that eclipse-induced ionospheric disturbances include a rapid upward flow of plasma from 200 km to much higher altitudes where the plasma is stored and then returned back to lower altitudes several hours after the end of the eclipse. We expect that such effects are stronger closer to the totality zone.

1. Introduction

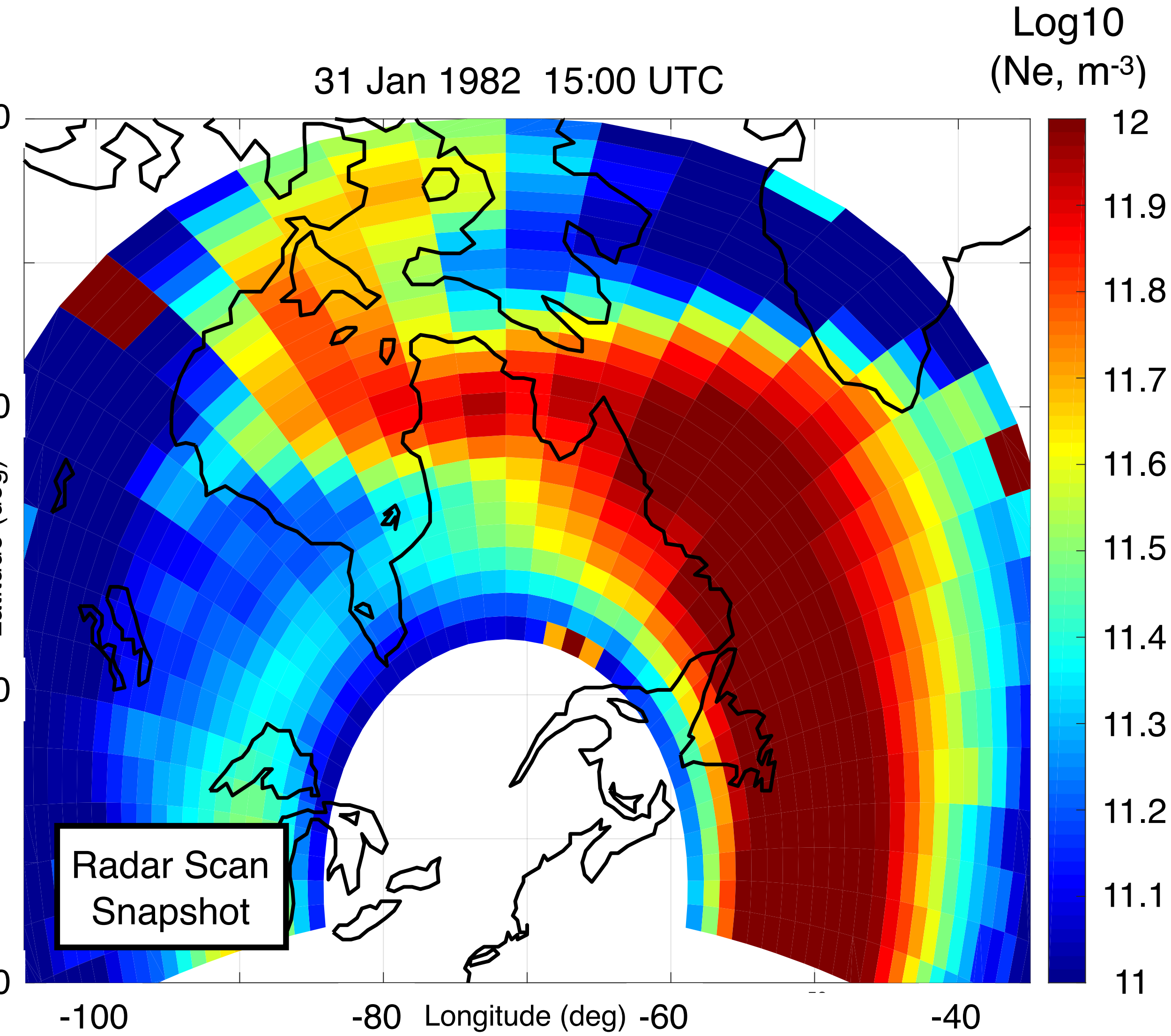
Observations of ionospheric parameters during solar eclipses present a rare opportunity to examine our state of knowledge about fundamental processes responsible for ionospheric behavior. It is well known that the whole ionosphere, from the *E*, *F1*, and *F2* regions through the topside ionosphere, undergoes dramatic variations at eclipse times due to large changes in solar irradiation. Earlier studies of ionospheric response to solar eclipses consistently show a large decrease in electron density (50–60%) in the *E* and *F1* regions (Cherniak & Lysenko, 2013; Salah et al., 1986). Changes in *NmE* and *NmF1* are directly proportional to the area of the Sun covered by the Moon (Le et al., 2008), as decreases in solar radiation lead to a decrease in electron production rates. However, *F2* region ionospheric behavior can be much more complicated, resulting in either a decrease or even a small increase (Muller-Wodarg et al., 1998) in electron density depending on background conditions and onset timing.

While observations of changes in electron density or total electron content during solar eclipses are more widely available in the modern era from networks of ionosondes and Global Navigation Satellite System (GNSS) receivers, direct observations of eclipse-induced variations in plasma temperatures and dynamics remain relatively rare. Incoherent scatter radars (ISRs) produce such direct observations due to the radar scattering dependence on plasma temperature, but only a handful of case studies have previously been available due to observational spatial coverage limitations. Evans (1965) reported that in observations with the Millstone Hill ISR during the afternoon eclipse of 20 July 1963, the electron temperature (*Te*) decreased by ∼1000 K, while the ion temperature (*Ti*) decreased by 100 K at 350 km and 300 K at 650 km, closely following

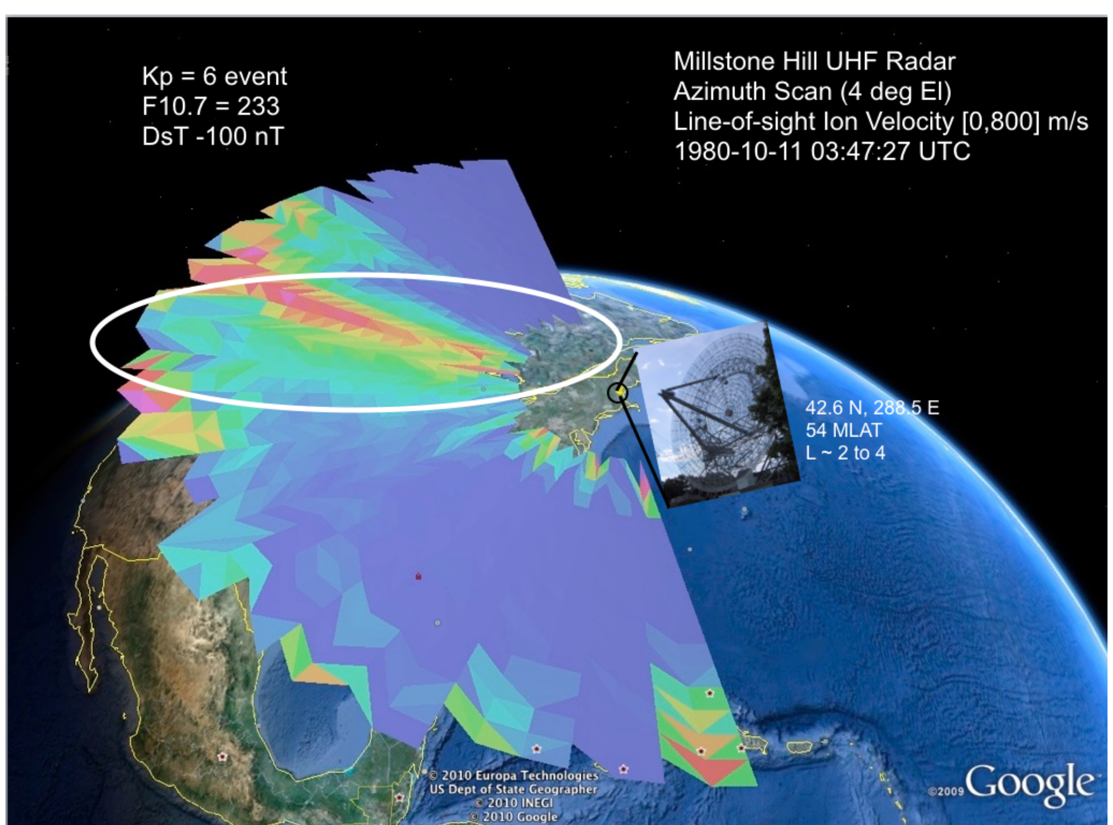
Others:
- Zhang, S.-R., P. J. Erickson, L. P. Goncharenko, A. J. Coster, W. Rideout, and J. Vierinen (2017), Ionospheric bow waves and perturbations induced by the 21 August 2017 solar eclipse, Geophys. Res. Lett., 44. doi: 10.1002/2017GL076054.
- Coster, A. J., L. P. Goncharenko, S.-R. Zhang, P. J. Erickson, W. Rideout, and J. Vierinen (2017), GNSS observations of ionospheric variations during the 21 August 2017 solar eclipse, Geophys. Res. Lett., 44. doi: 10.1002/2017GL075774.

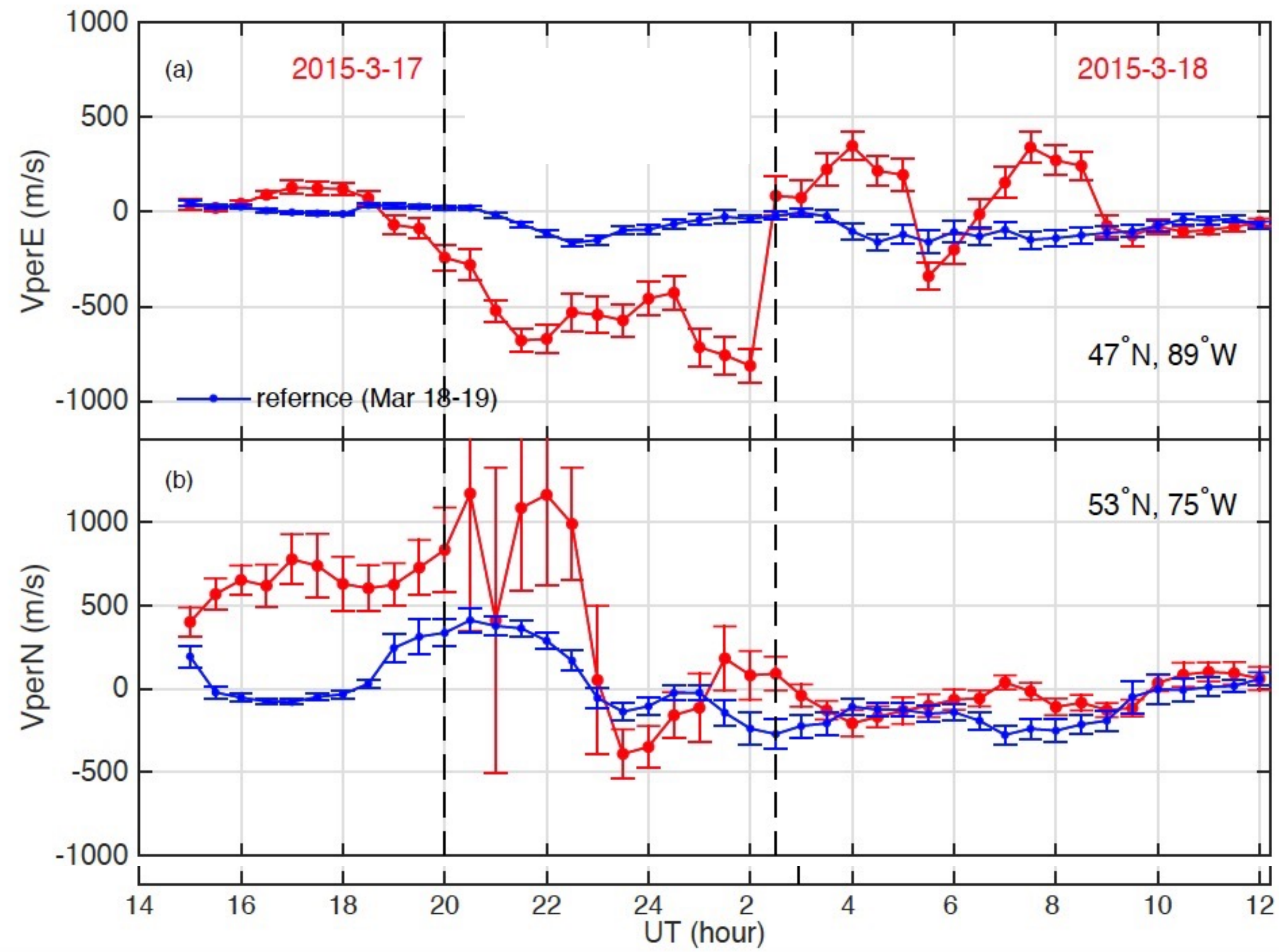
GROUP 2

A


31 Jan 1982 15:00 UTC
Log10
(Ne, m-3)
12
11.9
11.8
11.7
11.6
11.5
11.4
11.3
11.2
11.1
11
70
60
50
40
Latitude (deg)
-100
-80
Longitude (deg)
-60
-40
Radar Scan
Snapshot

E


Kp = 6 event
F10.7 = 233
DsT -100 nT
Millstone Hill UHF Radar
Azimuth Scan (4 deg El)
Line-of-sight Ion Velocity [0,800] m/s
1980-10-11 03:47:27 UTC
42.6 N, 288.5 E
54 MLAT
L ~ 2 to 4
Google


(a)
2015-3-17
2015-3-18
VperE (m/s)
1000
500
0
-500
-1000
47°N, 89°W
refernce (Mar 18-19)
(b)
53°N, 75°W
VperN (m/s)
14
16
18
20
22
24
2
4
6
8
10
12
UT (hour)

GEOPHYSICAL RESEARCH LETTERS, VOL. 29, NO. 13, 1623, 10.1029/2002GL015067, 2002

Ionospheric signatures of plasmaspheric tails

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MIT Haystack Observatory, Westford, Massachusetts, USA

A. J. Coster
MIT Lincoln Laboratory, Lexington, Massachusetts, USA

J. Goldstein
Rice University, Houston, Texas, USA

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Air Force Research Laboratory, Hanscom AFB, Massachusetts, USA

Received 7 March 2002; revised 5 April 2002; accepted 9 April 2002; published 2 July 2002.

[1] We make direct comparisons between GPS maps of total electron content (TEC) over the North American continent, Millstone Hill radar observations of storm enhanced density, and low and high-altitude satellite measurements of the perturbation of the outer plasmasphere during the March 31, 2001 geomagnetic storm. We find that storm enhanced density (SED) and plumes of greatly-elevated TEC are associated with the erosion of the outer plasmasphere by strong sub-auroral polarization electric fields. The SED/TEC plumes identified at low altitude map closely onto the magnetospheric determination of the boundaries of the plasmapause and plasmaspheric tail determined by EUV imaging from the IMAGE spacecraft. Characteristics of the SED/TEC plumes/tails for the March 31, 2001 event are: TEC ~ 100 TECu; *F*-region sunward velocity ~1000 m/s; sunward flux $\sim 5*10^{24}$ ions s^{-1}; total transport to dayside magnetopause/merging region (3-hr event) $\sim 5*10^{28}$ ions. *INDEX TERMS:* 2768 Magnetospheric Physics: Plasmasphere; 2435 Ionosphere: Ionospheric disturbances; 2463 Ionosphere: Plasma convection; 2481 Ionosphere: Topside ionosphere

1. Introduction

[2] Severe space weather effects have been observed at mid latitudes over the continental US during the strong magnetic storms of the current solar cycle. Large-scale enhancements of total electron content (TEC), steep spatial gradients in ionospheric plasma parameters and TEC [*Vo and Foster*, 2001], and the occurrence of strong radio scintillation occur in the sub-auroral region which usually is free from such disturbances. This study reports a coordinated investigation of such events using ground-based GPS, incoherent scatter radar, and low and high-altitude satellite observations. We find a direct relationship between sub-auroral ionospheric perturbations and the structuring and dynamics of the overlying plasmasphere.

[3] A number of important magnetospheric boundaries are found near the auroral/sub-auroral transition, nominally near 60° invariant latitude (Λ), and these result in the ionospheric structure and dynamics which characterize the local ionospheric observations made from MIT's Millstone Hill Observatory, located near 54° Λ in eastern Massachusetts. The high-altitude plasmapause [*Carpenter*, 1963] maps down to the region near the equatorward edge of the (mid-latitude) ionospheric trough (e.g. *Foster et al.* [1978]) and is associated with the transition between the co-rotating inner magnetosphere and the convection-driven ionospheric circulation at auroral latitudes. As the level of geomagnetic disturbance increases, the electric fields and particle populations which characterize the auroral region expand equatorward and their effects are felt at sub-auroral latitudes.

1.1. Storm Enhanced Density

[4] The Millstone Hill incoherent scatter radar frequently observes storm enhanced density (SED) in the pre-midnight sub-auroral ionosphere during the early stages of magnetic storms [*Foster*, 1993]. These high-TEC plumes of ionization appear near the equatorward edge of the mid-latitude ionospheric trough, convecting sunward, driven by poleward-directed electric fields.

[5] Figure 1 presents observations of SED during Kp ~6 conditions (after *Foster* [1993]). This MLT/latitude map was built up from Millstone Hill incoherent scatter radar scans taken over a 24-hour period. Storm enhanced density appears in the post-noon sector in the region poleward of the regular diurnal solar enhancement of the topside *F* region. SED was seen continuously by the radar for >8 hours during this event. *Su et al.* [2001] mapped these low-altitude observations to the equatorial plane of the magnetosphere and found that the SED feature mapped into a dayside plume of sunward-streaming plasmaspheric materials observed at geosynchronous orbit (a plasmasphere drainage plume [*Elphic et al.*, 1996]). That study concluded that SED is an ionospheric signature of the erosion of the outer plasmasphere which traces the path of plasmaspheric materials as they are swept to the dayside magnetopause/merging region [*Elphic et al.*, 1997].

1.2. Sub-Auroral Polarization Electric Field

[6] Strong polarization electric fields develop across the sub-auroral ionosphere during disturbed conditions (e.g. *Yeh et al.* [1991]). Field aligned currents driven by hot plasma pressure gradients in the inner magnetosphere close across the sub-auroral ionosphere [e.g. *Liemohn et al.*, 2001]. On

0094-8276/02/2002GL015067

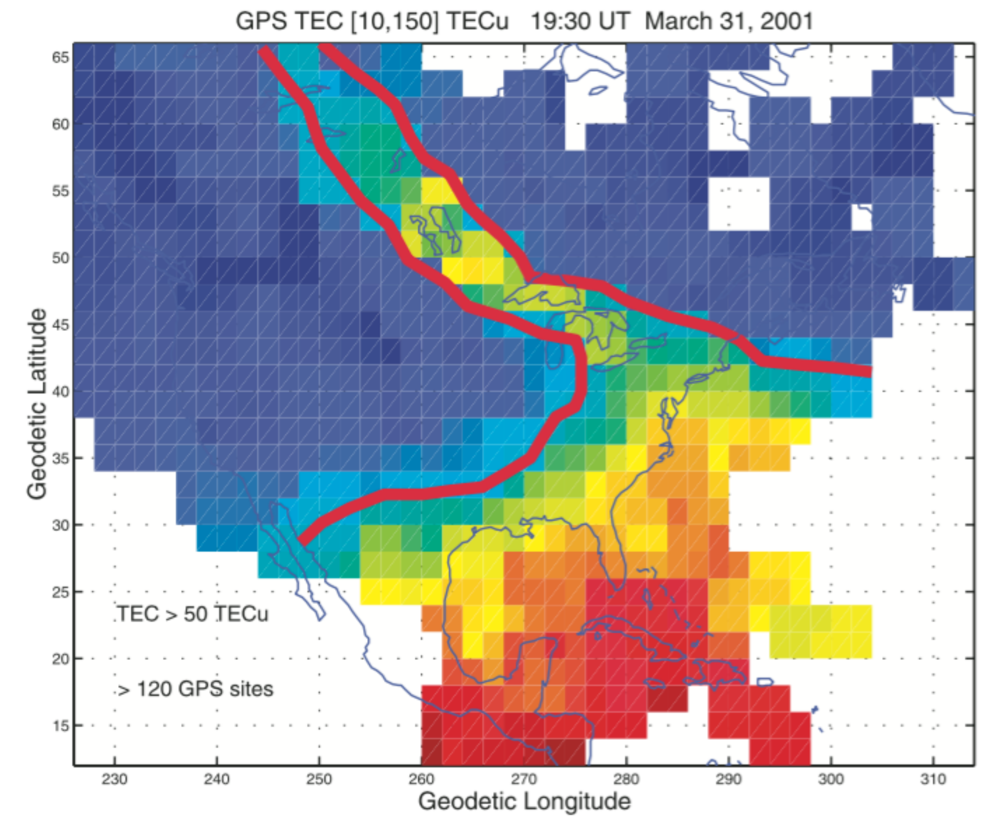


Figure 2. Snapshot of SED plume in the post-noon sector obtained by plotting vertical TEC obtained from >120 GPS receiving sites during a 15-min interval. The 50 TECu contour is outlined in red and defines the instantaneous position of the SED/TEC enhancement.

AGU PUBLICATIONS
JGR
Journal of Geophysical Research: Space Physics

RESEARCH ARTICLE
10.1002/2016JA023307

Special Section:
Geospace system responses to the St. Patrick's Day storms in 2013 and 2015

Key Points:
- Multiple strong ion-neutral coupling effects appeared within a few hours of SAPS during a single intensification of a great magnetic storm
- Strong ion-neutral frictional heating accompanied by large atmospheric upwelling, with ion upwelling as a potential source of ion upflow

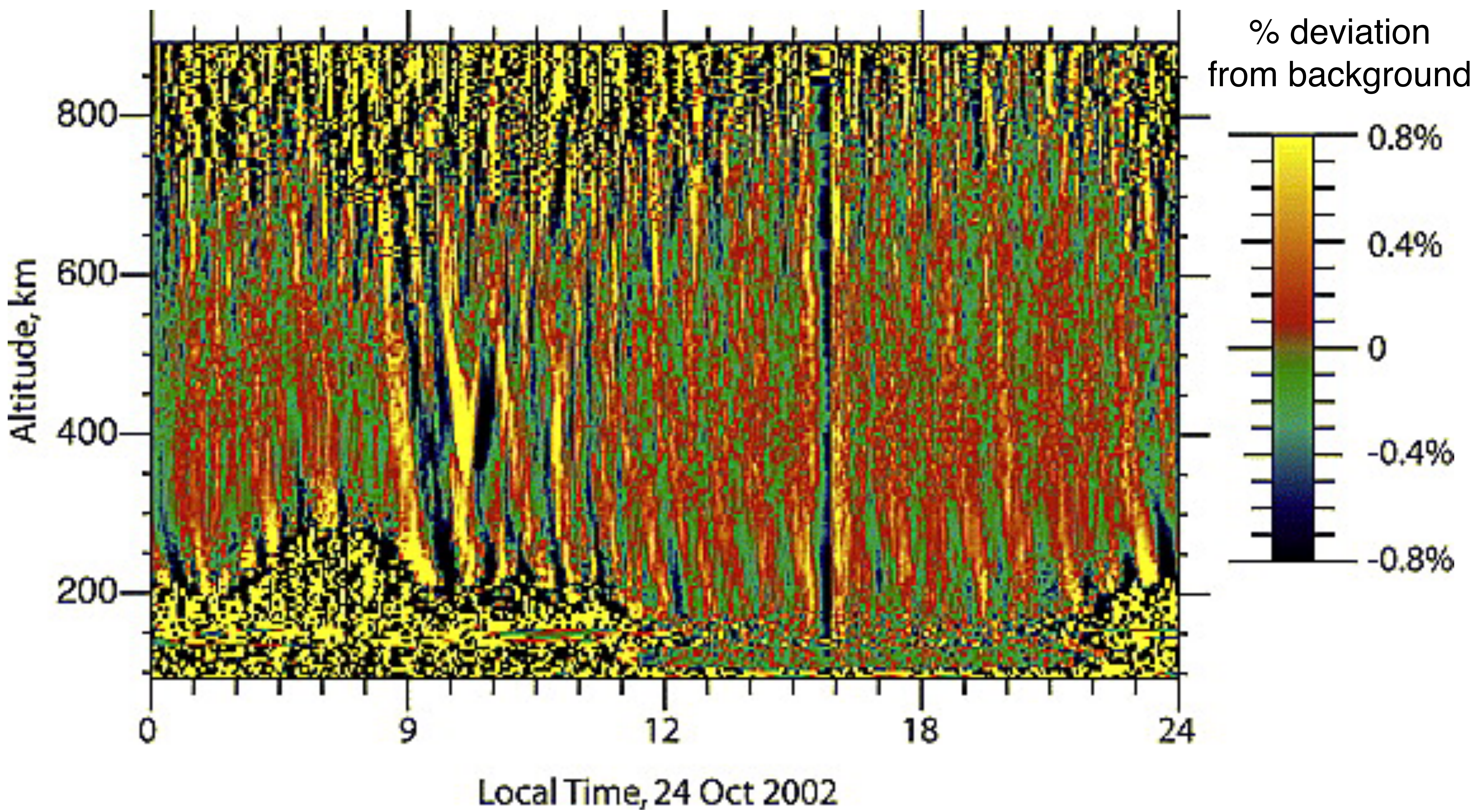
Observations of ion-neutral coupling associated with strong electrodynamic disturbances during the 2015 St. Patrick's Day storm

Shun-Rong Zhang[1], Philip J. Erickson[1], Yongliang Zhang[2], Wenbin Wang[3], Chaosong Huang[4], Anthea J. Coster[1], John M. Holt[1], John F. Foster[1], Michael Sulzer[5], and Robert Kerr[6]

[1]Haystack Observatory, Massachusetts Institute of Technology, Westford, Massachusetts, USA, [2]Applied Physics Laboratory, The Johns Hopkins University, Baltimore, Maryland, USA, [3]High Altitude Observatory, National Center for Atmospheric Research, Boulder, Colorado, USA, [4]Air Force Research Laboratory, Wright-Patterson, Ohio, USA, [5]Arecibo Observatory, SRI International, Menlo Park, California, USA, [6]Computational Physics, Inc., Springfield, Virginia, USA

GROUP 3

Millstone Hill Electron Density, detrended



JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 114, A06303, doi:10.1029/2008JA013999, 2009

Omnipresent vertically coherent fluctuations in the ionosphere with a possible worldwide-midlatitude extent

Dorey J. Livneh,[1] Ilgin Seker,[1] Frank T. Djuth,[2] and John D. Mathews[1]

Received 23 December 2008; revised 4 March 2009; accepted 20 March 2009; published 3 June 2009.

[1] Incoherent Scatter Radar power profile observations at Arecibo, Millstone Hill, and the Poker Flat AMISR have revealed the continuous presence of Coherent Omnipresent Fluctuations in the Ionosphere (COFIs) with periods ranging from roughly 30 to 60 minutes and apparent vertical wavelengths increasing with altitude from tens to hundreds of kilometers. Upon high-pass filtering of the Incoherent Scatter Radar power profile and electron concentration data, the COFIs are seen unambiguously and ubiquitously in Arecibo results from 22–23 March 2004, 5–6 June, 21–25 September, and 17–20 November 2005, as well as Millstone Hill results from 4 October to 4 November 2002. The COFIs are strong throughout the F region, often spanning altitudes of 160 km to above 500 km, and are detected day and night in the F2 layer. In fact, the COFIs are seen at every time and altitude that there is sufficient plasma to detect them. The COFIs are also observed at Poker Flat, although the poor signal-to-noise ratio over segments of the data makes it difficult to determine whether or not they are always present. The consistent detection of the COFIs, along with the longitudinal alignment and large latitudinal spread of the observation sites, suggests that these waves are always present over at least North America. This phenomenon appears to have been reported in Total Electron Concentration (TEC) maps of the ionosphere over much of North America Tsugawa et al. (2007b) as well as in airglow images from Arecibo and many other midlatitude sites around the world. These observations give us insight into the horizontal properties of the waves. While Medium-Scale Ionospheric Disturbances (MSTIDs) are generally associated with aurorally generated acoustic gravity waves, the properties of the COFIs may suggest otherwise. We present other possible source mechanisms, notably a possible link to oscillations in the solar wind and magnetosphere. We have observed consistent fluctuations with periods of about an hour observed in magnetic field measurements taken at geosynchronous altitudes by the Geostationary Operational Environmental Satellites (GOES)-10 and -12 satellites, which may be linked to the COFIs. We give corresponding solar wind results from ACE and discuss possible coupling mechanisms.

Citation: Livneh, D. J., I. Seker, F. T. Djuth, and J. D. Mathews (2009), Omnipresent vertically coherent fluctuations in the ionosphere with a possible worldwide-midlatitude extent, *J. Geophys. Res.*, *114*, A06303, doi:10.1029/2008JA013999.

1. Introduction

[2] *Livneh et al.* [2007] reported continuous quasiperiodic waves with periods of around 1 hour in the F region over Arecibo, Puerto Rico. This document extends those results to Millstone Hill, Massachusetts and Poker Flat, Alaska. This nearly "steady state" phenomenon has been observed over all of the data sets studied to date. To avoid confusion with other reported phenomena, we shall refer to the phenomenon we report in this paper as Coherent Omnipresent Waves (COFIs). The literature abounds with examples of similar but apparently transient phenomena, Traveling Ionospheric Disturbances (TIDs). TIDs are, as their name suggests, moving fluctuations in the ionosphere observed in the plasma concentration, velocity and/or temperature. While TIDs are traditionally thought to be the ionospheric traces of in situ forcing by neutral Acoustic Gravity Waves (AGWs) [e.g., *Francis*, 1975; *Hocke and Schlegel*, 1996], the properties of these COFIs suggest the possibility of a different, electrodynamic mechanism(s) for their existence. We next review the relevant AGW and non-AGW TID related literature and observations.

[3] AGWs may be generated whenever a parcel of air is vertically displaced and the buoyancy force acts to restore it to its original height. If an AGW exists at the height of the ionosphere, it perturbs the plasma via collisional coupling that varies strongly with altitude and may be observed as a TID using radio methods including Incoherent Scatter Radar (ISR). In this paper we report on TIDs observed by three ISRs, one located at Millstone Hill, Massachusetts

[1]Department of Electrical Engineering, Pennsylvania State University, University Park, Pennsylvania, USA.
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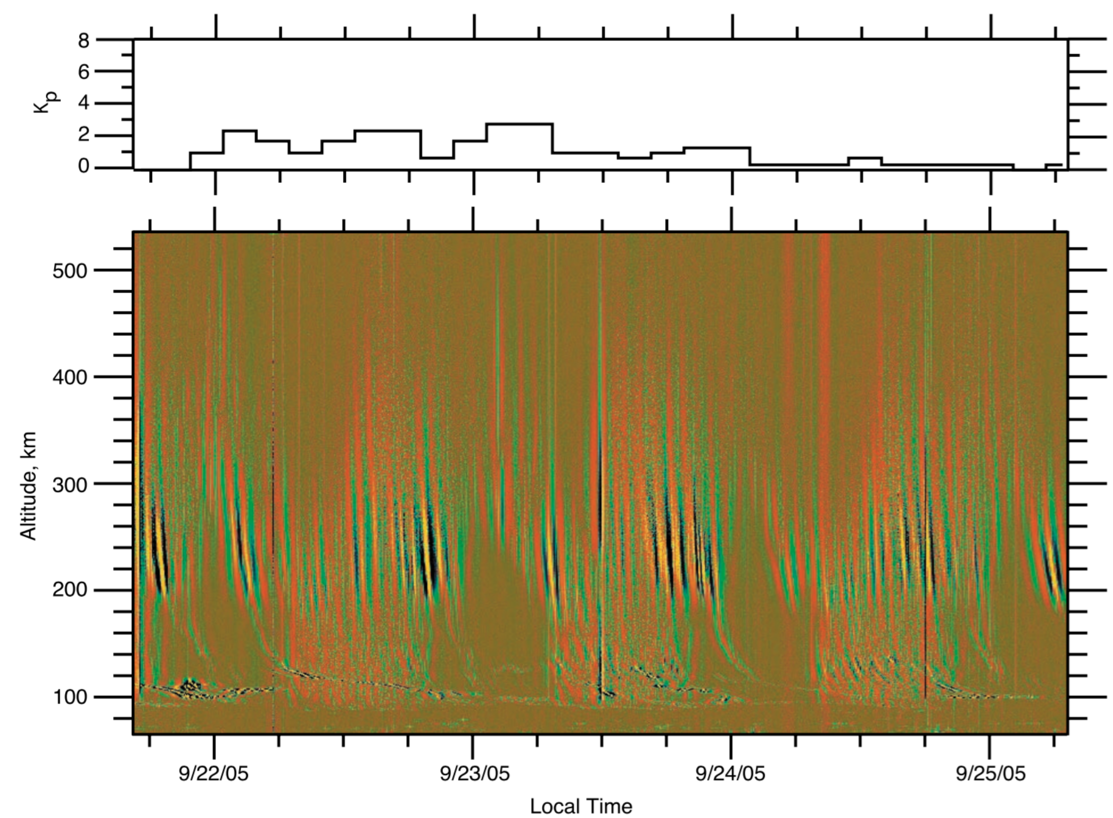
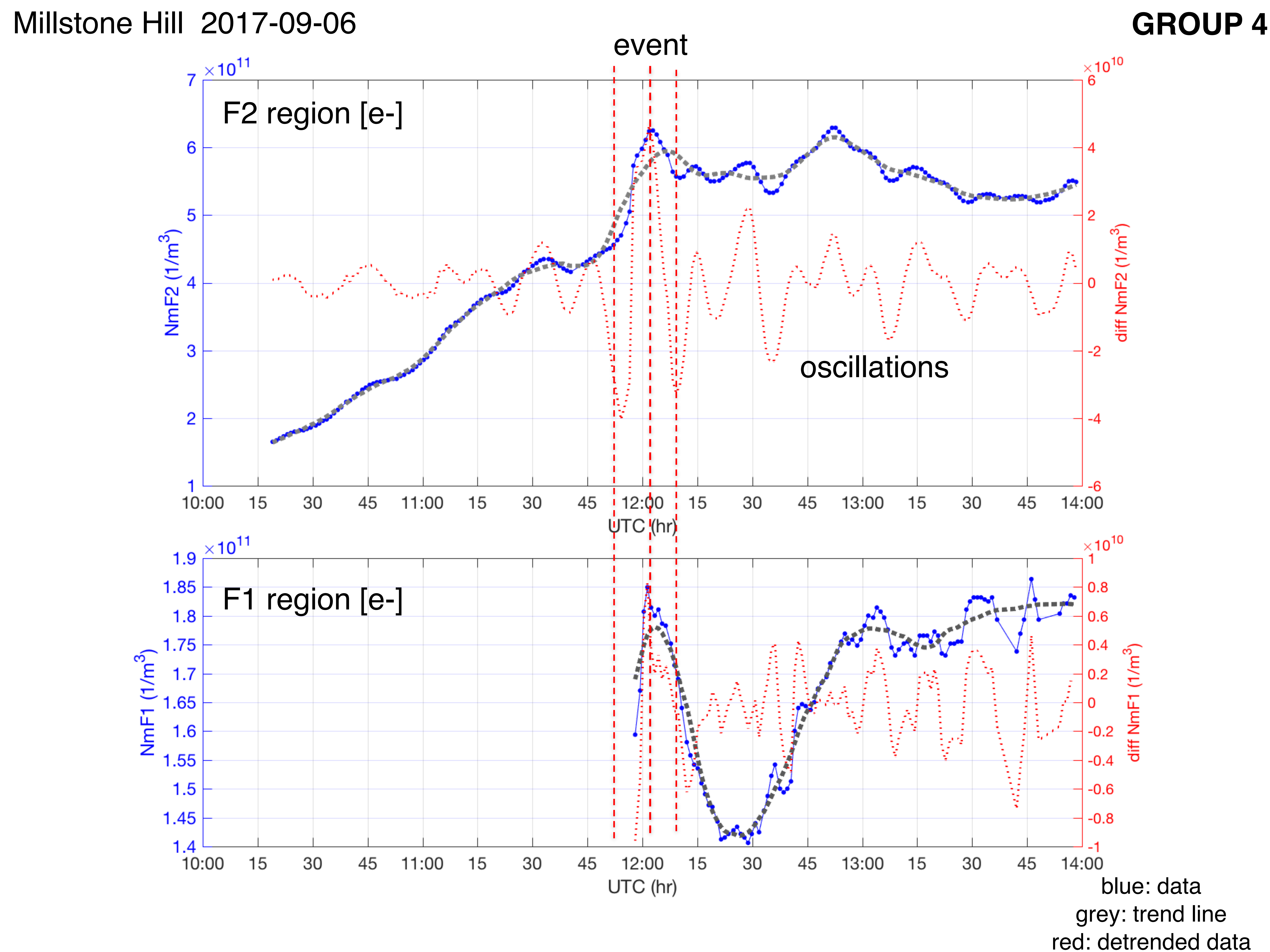
0148-0227/09/2008JA013999



(Arecibo)



Millstone Hill 2017-09-06
GROUP 4
event
F2 region [e-]
oscillations
NmF2 (1/m^3)
diff NmF2 (1/m^3)
UTC (hr)
F1 region [e-]
NmF1 (1/m^3)
diff NmF1 (1/m^3)
UTC (hr)
blue: data
grey: trend line
red: detrended data

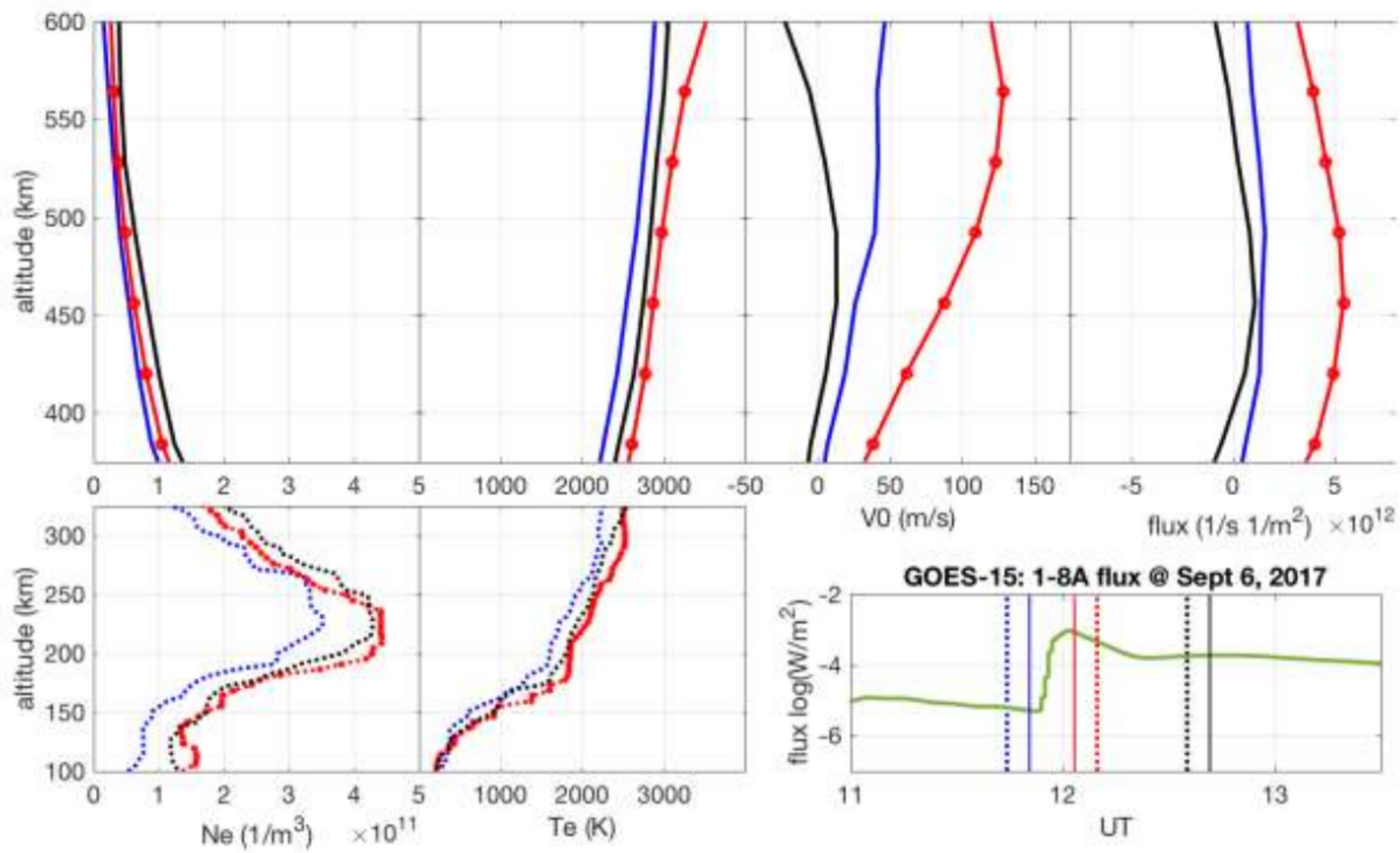


Figure 4. Millstone Hill observations of Earth ionospheric response during the X9 flare event at 11:53 UT on September 6, 2017. Bottom: E and F region measurements of electron density (left) and electron temperature (middle) at 100-350 km. Top: Topside ionosphere measurements of electron density (left), electron temperature (middle left), vertical velocity (middle right), and total ionospheric flux (right) at 350-600 km. For each panel, pre-flare (blue), flare maximum (red), and post-flare (black) curves are given, with dashed lines for E/F region profiles and solid lines for topside region profiles. Bottom right: 1-8 A solar flux as measured by the GOES-15 spacecraft during 9 – 18 UT, with times of the three ionospheric topside profiles marked with corresponding colors and line styles.

Mendillo et al, 2018, Space Weather in press
"Flares at Earth and Mars: An Ionospheric Escape Mechanism?"