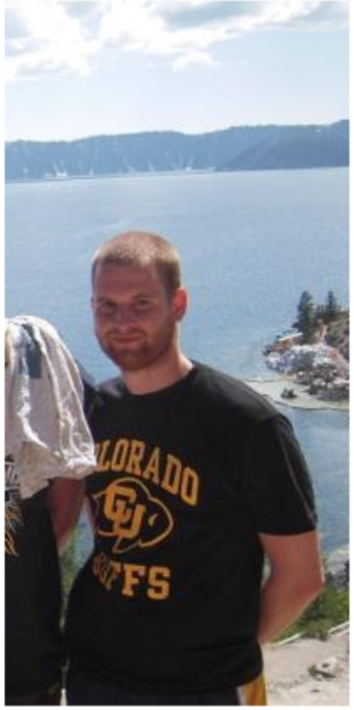
Ionospheric Electron Density Response to Solar Flares

Ryan Handzo and Jeff Forbes
Department of Aerospace Engineering Sciences, University of Colorado, Boulder, CO

Bodo Reinisch
Lowell Digisonde International LLC, Lowell, MA

How does the ionosphere evolve in height and time in response to a solar flare?

1. Previous studies of ionosphere flare response
2. Characteristics of flares considered in this study
3. Methodology for identifying flare response
4. Interpretation of flare response at Millstone Hill
5. Comparison between flare responses for different flare integrated energies and mid-latitude vs. magnetic equator
6. Conclusions



Ryan's Ph.D. research concerns the potential use of signals of opportunity (e.g., TV signals) for satellite navigation beyond GPS effectiveness.

Previous Studies of Solar flare Response Relevant to the Current Work

Modeling

TIE-GCM modeling by Qian et al. [2010, 2011] : dependence on flare location on solar disk; importance of integrated flare energy vs. peak energy; possible effects of transport

Time-Dependent Ionospheric Model (TDIM) by Smithtro et al. [2006]: anomalous decrease of NmF2

TDIM modeling by Sojka et al. [2013] : dependence of E, F1, F2-region responses to aspects of the solar UV/EUV spectrum

Observations

Mendillo and Evans [1974] : ISR measurments of height vs. time ionospheric response to 7 Aug 1972 flare

Thome and Wagner [1971]: ISR measurements of height vs. time ionospheric response to 2 flares

Smithtro et al. [2006]: Ionograms for an M1-class flare

Qian et al. [2010, 2011] : TEC measurements for a few X-class flares

Le et al. [2013] : Statistical analysis of TEC response to many flares

Li et al. [2012] : Ionogram f_{min}, foF2 responses for a few flares

The Present Work in Context

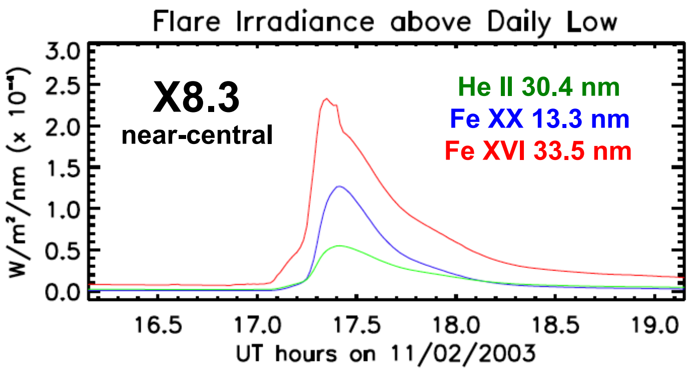
Analyses of foF2, foE, TEC do not provide the full picture of the ionospheric response to a solar flare; this will be especially evident at the end of this talk.

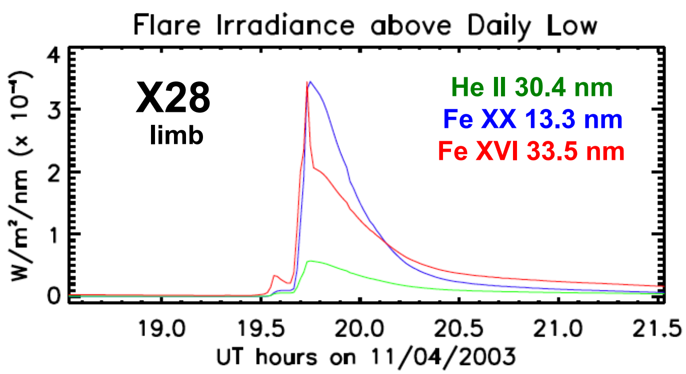
Incoherent Scatter Radars (ISRs) are the obvious preferred choice to observe the ionospheric response (Ne, Te, Ti, etc.) to a solar flare. However, they are sparsely distributed around the globe and operate on low duty cycles; the chances of catching a flare are low, and opportunities to compare response characteristics as a function of latitude for a given flare and between different solar flares at a given site are even lower.

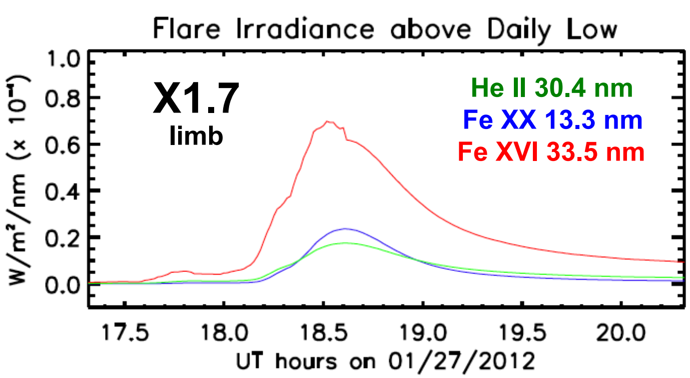
Depictions of the height vs. time response to a flare by an ISR are rare: Thome and Wagner [1971], Mendillo and Evans [1974]

In this paper we demonstrate the ability of the global digisonde network to characterize the height vs. time ionospheric response to solar flares at many locations over the globe and note the limitations involved.

EUV Flare Irradiances Based on the Flare Irradiance Spectral Model (FISM) [Chamberlain et al., 2008]



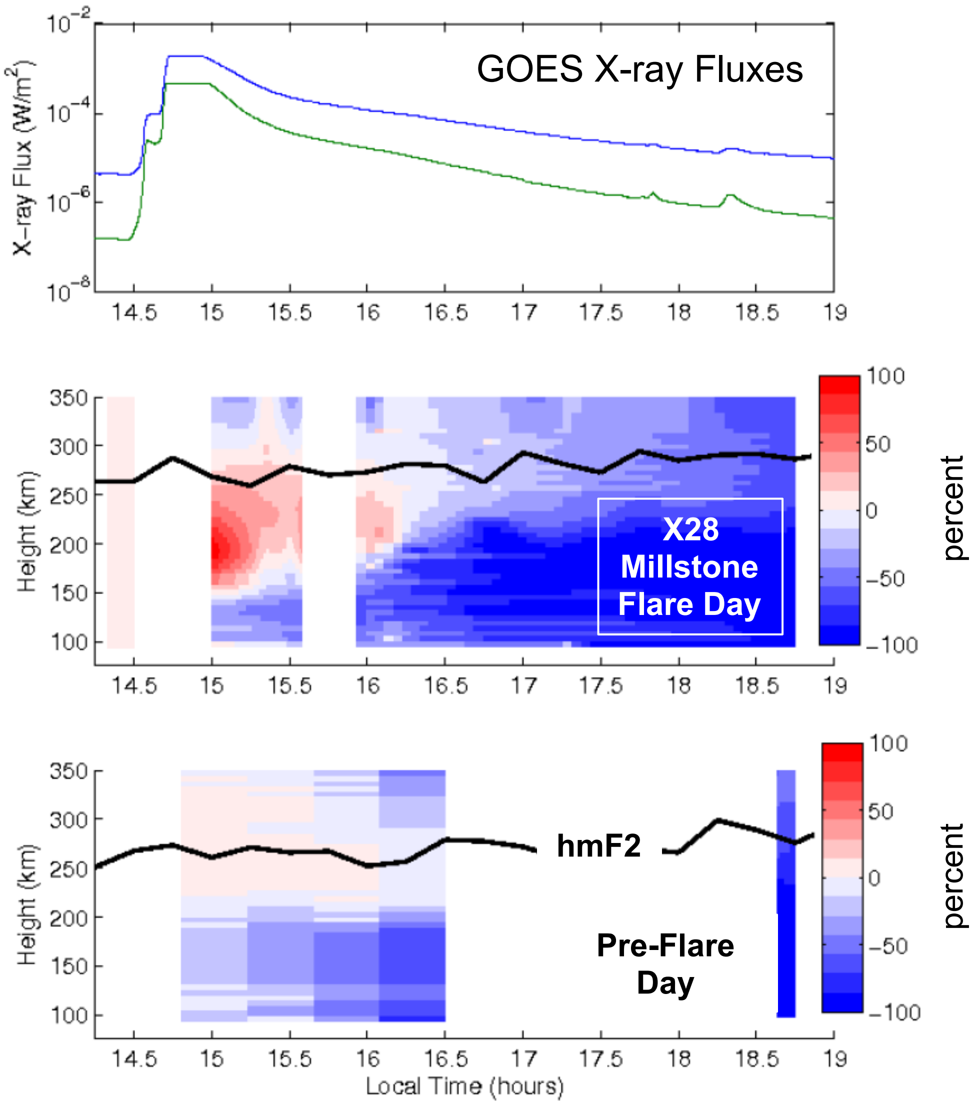




Integrated energies at 30.4 nm and 33.5 nm

$$\frac{X8.3}{X28} \approx 1.2 \qquad \frac{X1.7}{X28} \approx 0.5$$

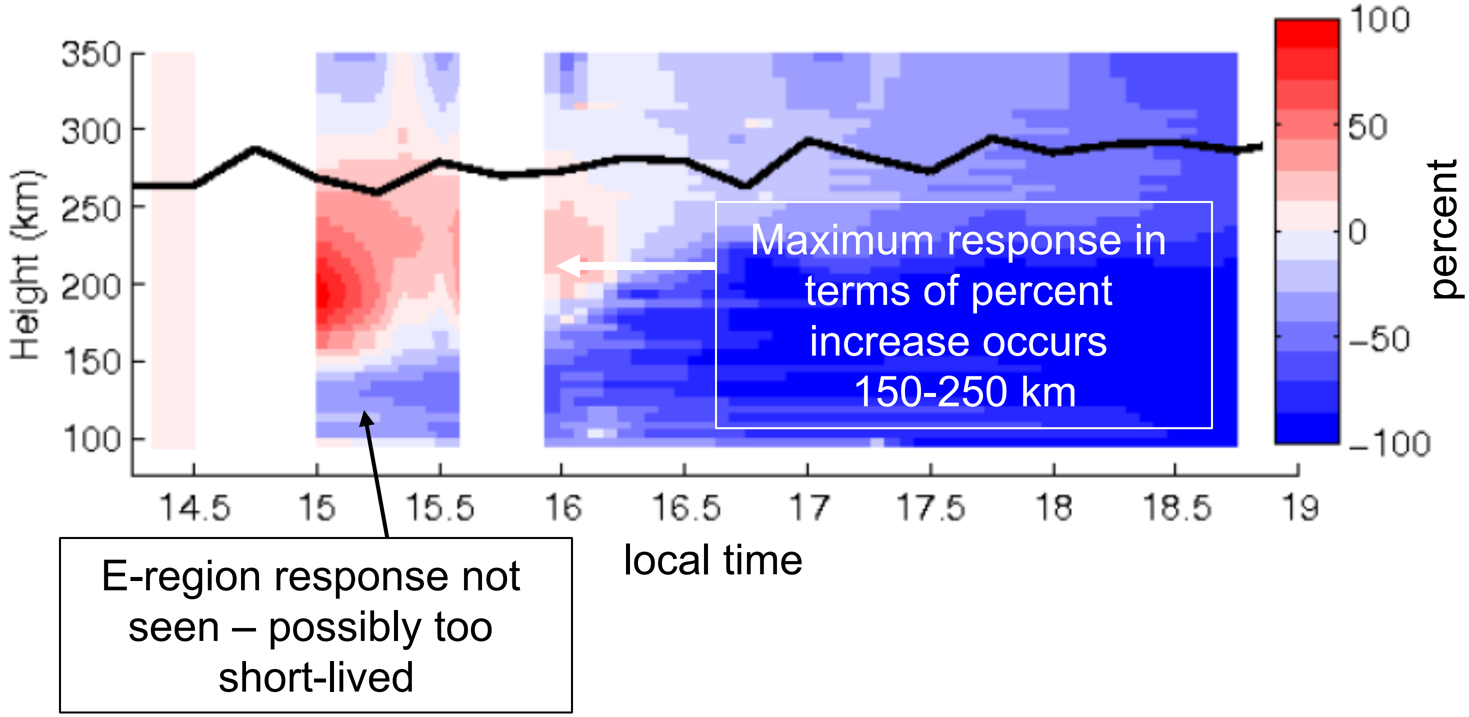
Flare Response Methodology



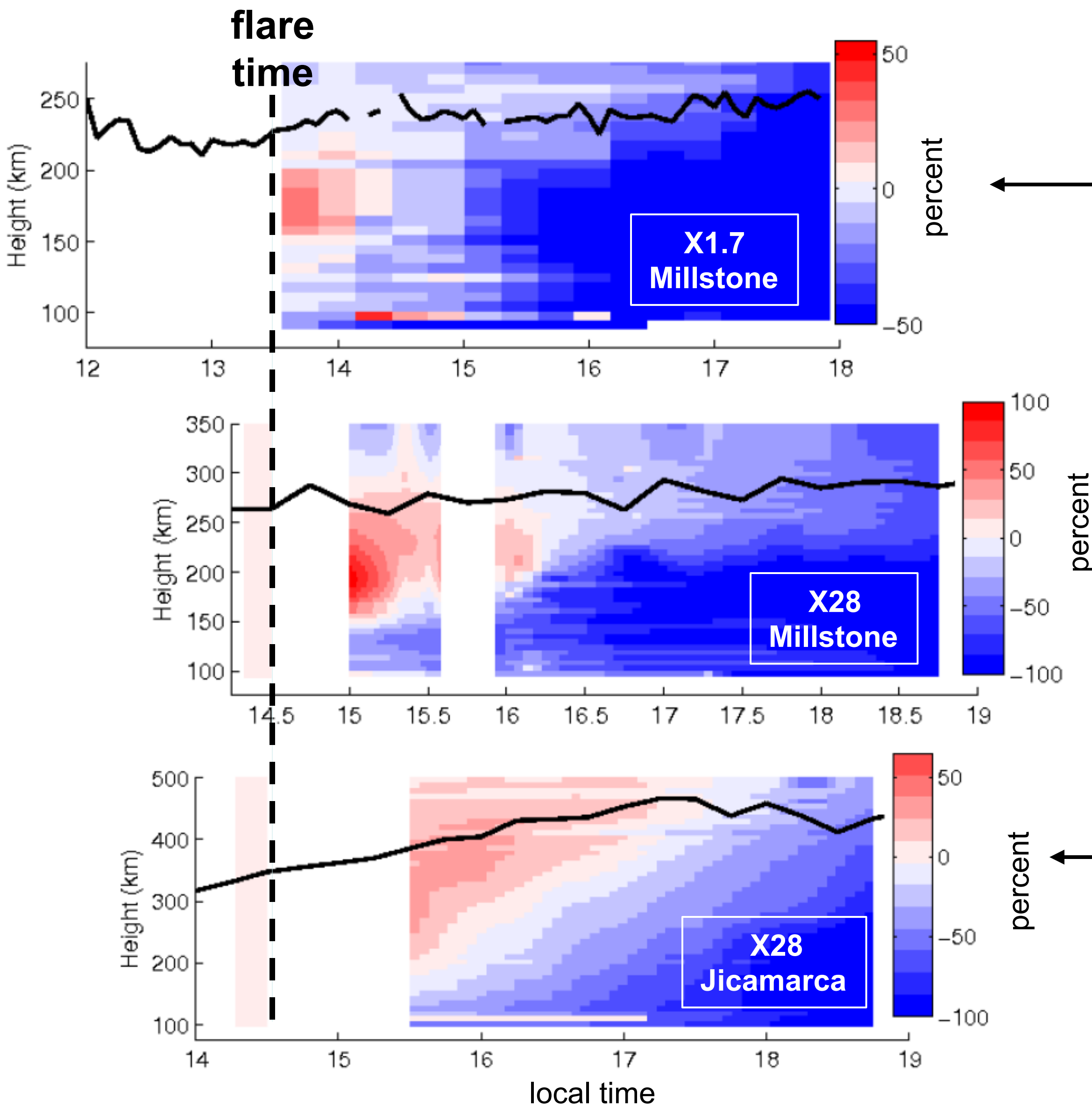
- Post-noon flare responses identified in terms of percent change with respect to pre-flare 1-hour average
- Flare response corroborated through comparison with day before
- Data drop-outs near flare time due to enhanced D-region absorption produced by X-rays

X28 Flare Response Analysis - Millstone

- NmF2 response relatively weak, but other studies report positive TEC flare response at mid-latitudes [Smithtro et al., 2006; Mendillo and Evans, 1974]
- Possible upward diffusion of plasma into topside – enhanced plasma scale height may result from heating by fast vertical transport of photoelectrons produced in the F1 region
- Limb darkening of EUV emissions + enhanced chemical loss due to heated neutral atmosphere



Comparison Between Limb Flare Responses



Integrated energies at 30.4 nm and 33.5 nm

$$\frac{X1.7}{X28} \approx 0.5$$

upward drifts at Jicamarca apparently carry ionization produced at lower levels into the topside F-region

Conclusion

Digisondes are capable of revealing the height vs. time response of the ionosphere to X-class solar flares between about 150 km and the F-layer peak, and beyond 15 minutes after the flare peak.

These data are capable of validating many aspects of simulated solar flare responses.

The ability of digisondes to serve a similar role for smaller flares remains to be determined.

SDO/EVE high-cadence measurements of solar EUV emissions	+	First-principles models (photochemistry, energetics, dynamics, electrodynamics)	+	digisonde data	→	advanced understanding needed for developing a predictive capability

Flare Information and Context

Flare Date	Flare Rating	Flare Time (UTC)	Digisonde Station	Station Latitude (deg)	Station Longitude (deg)	Active Region	Origin Hemisphere	Disk Location
November 2, 2003	X8.3	17:03	Millstone Hill	42.60	288.50	10486	Southern	Off-Center/SW
November 4, 2003	X28	19:29	Millstone Hill	42.60	288.50	10486	Southern	Limb
November 4, 2003	X28	19:29	Jicamarca	-12.00	283.20	10486	Southern	Limb
January 27, 2012	X1.7	18:37	Millstone Hill	42.60	288.50	11402	Northern	Limb

mm/dd/yyyy	Wavelength	Flare Peak Value	Integrated Energy
	(nm)	(10^{-4} W/m^2/nm)	(J/m^2/nm)
11/02/2003	13.3	1.26	0.198115
11/02/2003	33.5	0.55	0.120000
11/02/2003	30.4	2.33	0.458530
11/04/2003	13.3	3.45	0.415682
11/04/2003	33.5	0.57	0.098182
11/04/2003	30.4	3.45	0.385747
01/27/2012	13.3	0.23	0.053921
01/27/2012	33.5	0.18	0.052271
01/27/2012	30.4	0.69	0.198983

11/01/2003	210	5o	5-	4o	3-	3o	*3+	3+	4o
11/02/2003	190	3+	4-	3+	3o	3-	*3+	4+	3-
11/03/2003	167	3+	3o	3-	3-	2o	2+	*3-	3+
11/04/2003	168	3o	3o	6+	7o	3-	2o	*3+	3-
01/26/2012	128	2+	0+	2o	2+	2-	3-	*2o	1+
01/27/2012	142	2-	2-	3o	2o	2+	2-	*1+	0+

X8.3 at Millstone & X28 at Jicamarca