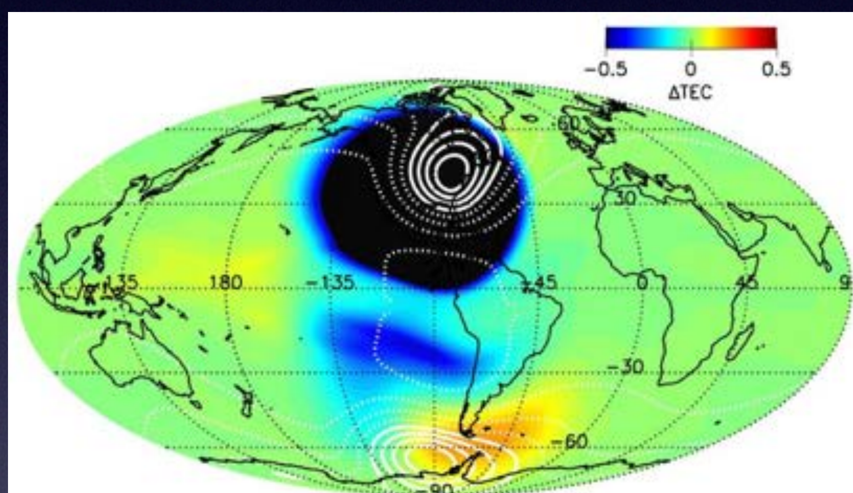
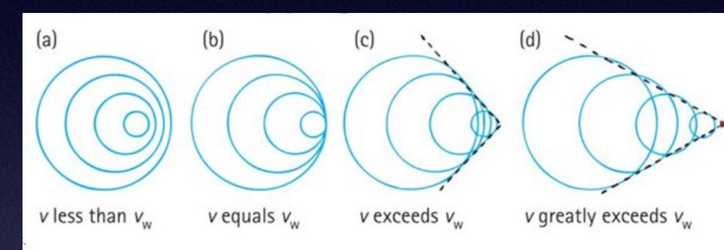
# 2017 Solar Eclipse:
# Studies of Atmospheric and Ionospheric Response

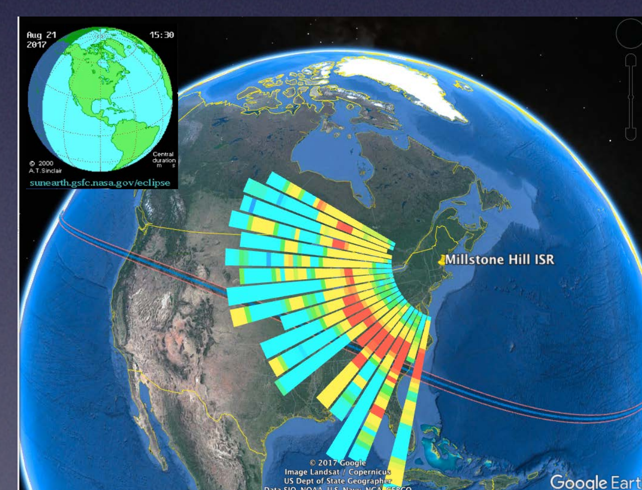
**P. J. Erickson, A. J. Coster, L. P. Goncharenko, S.-R. Zhang**
**MIT Haystack Observatory**

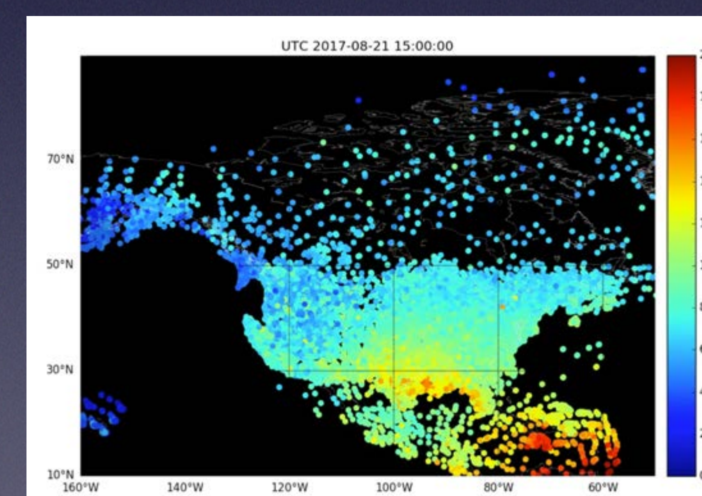



$$dN/dt = E(t)\,q(t) - \alpha N^2$$

$$dN/dt = E(t)\,q(t) - \beta N$$




Support: NSF AGS-1242204, NASA NNX17AH71G

NEROC 2017 Symposium
8 November 2017
Westford, MA

# 2017 Solar Eclipse: Studies of Atmospheric and Ionospheric Response

**P. J. Erickson, A. J. Coster, L. P. Goncharenko, S.-R. Zhang**
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**Outline**

- **Eclipse geometry overview and geophysical conditions**
- **GNSS observations of TEC response**
- **Millstone Hill large aperture high power ionospheric radar: regional and local eclipse ionospheric response**

Support: NSF AGS-1242204, NASA NNX17AH71G

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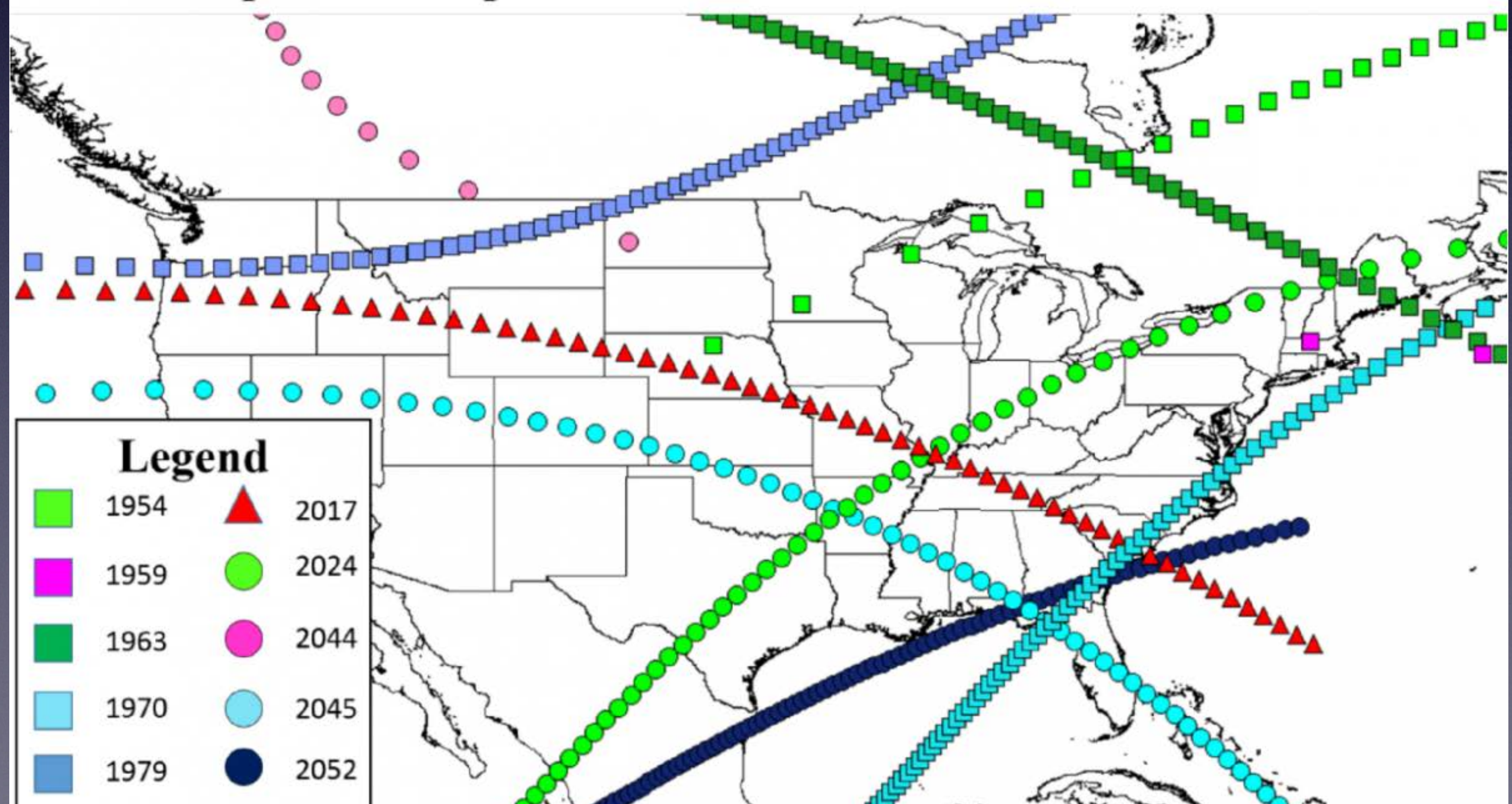
Map of All Eclipses over Continental US From 1950-2052



JOURNAL OF GEOPHYSICAL RESEARCH VOL. 70, NO. 1 JANUARY 1, 1965

# An *F* Region Eclipse

J. V. EVANS

*Lincoln Laboratory, Massachusetts Institute of Technology, Lexington*

*Abstract.* Observations of the electron density, electron temperature, and ion temperature were made over the height range 240–750 km vertically above Millstone Radar Observatory on July 19–21, 1963. The technique employed for these measurements is the incoherent backscatter method. The eclipse occurred on the afternoon of July 20 and caused a large rapid decrease in the electron temperature at all heights and a subsequent recovery. The ion temperature was seen to change at all heights almost equally rapidly, though by a smaller amount. These changes in temperature caused a rapid reduction in the value for the diffusive equilibrium scale height. As a consequence, ionization moved downward and the density at $h_{max}$ increased, though at altitudes above 425 km it decreased. The total electron content of the region under study was about $7 \times 10^{12}$ electrons/cm$^2$ at the commencement of the event but had declined to about $6 \times 10^{12}$ electrons/cm$^2$ by the time point of last contact was reached.

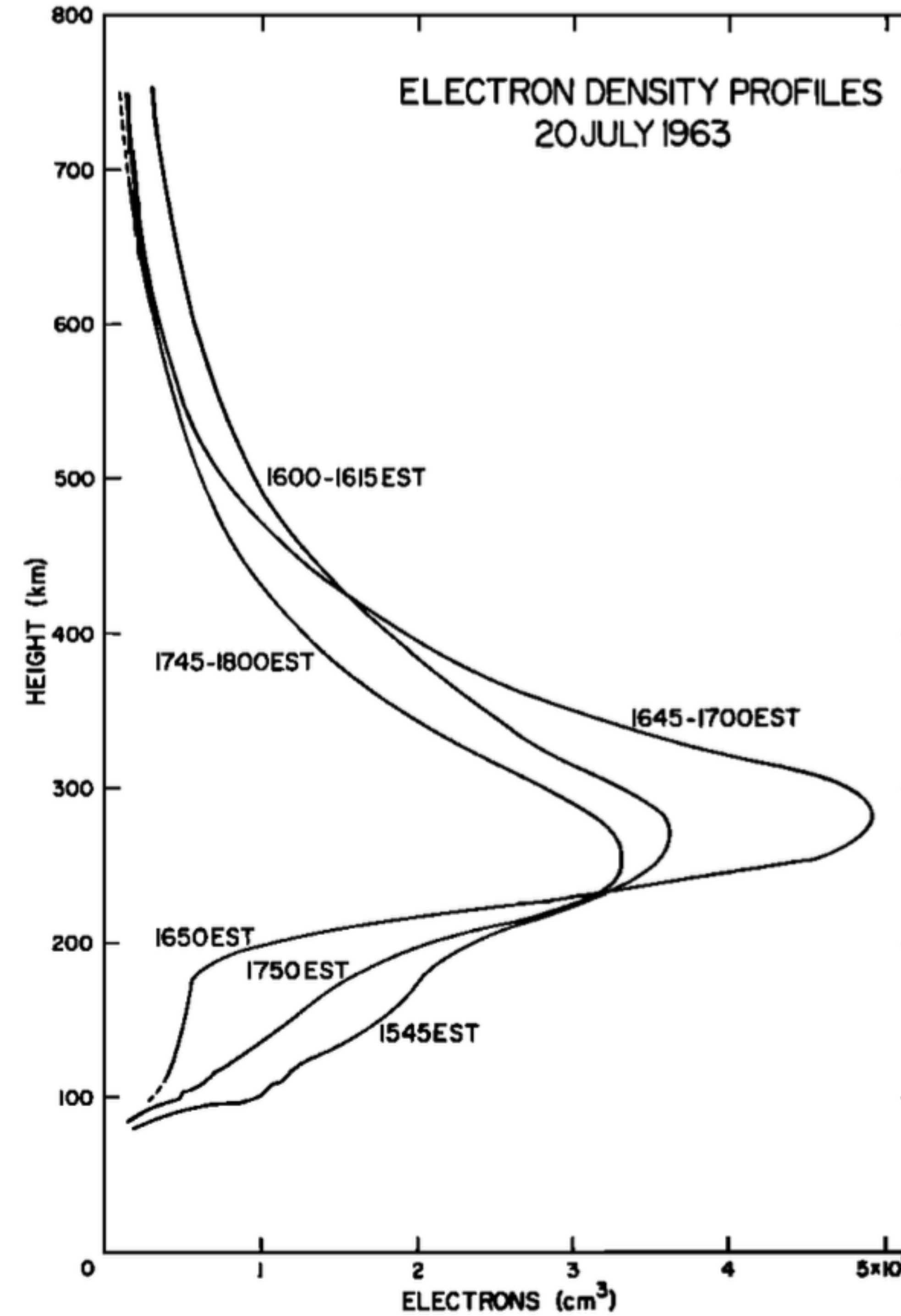



Fig. 4. The electron density profiles at the beginning of the eclipse, at totality, and at the end of the eclipse. In these curves the density distribution obtained from Figure 3 for the region above the peak of the $F_2$ layer has been fitted to true height analyzed ionosonde results for the density below the peak (J. W. Wright, private communication). The height of the backscatter profiles has been adjusted to match $h_{max}$ obtained from the true height analysis.

# Eclipses: A Gigantic, Active Ionospheric Lab Experiment

**SOLAR ECLIPSES AND IONOSPHERIC THEORY**

H. RISHBETH
*S.R.C., Radio and Space Research Station, Ditton Park, Slough, Bucks., England*

(Received 1 March, 1968)

Steady-state continuity equations (NOTE: no transport here - but we know that happens)

$$\mathrm{d}N/\mathrm{d}t = E(t)\,q(t) - \alpha N^2 \quad \text{E layer}$$

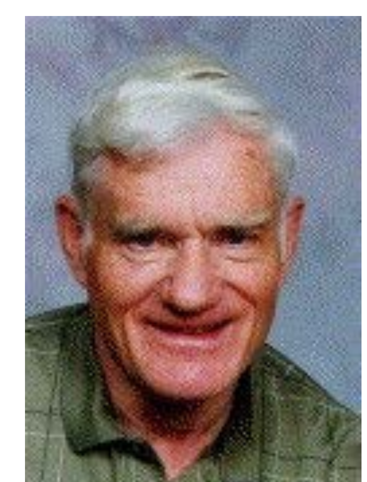
$$\mathrm{d}N/\mathrm{d}t = E(t)\,q(t) - \beta N \quad \text{F2 layer}$$

$E(t)$: Eclipse obscuration function

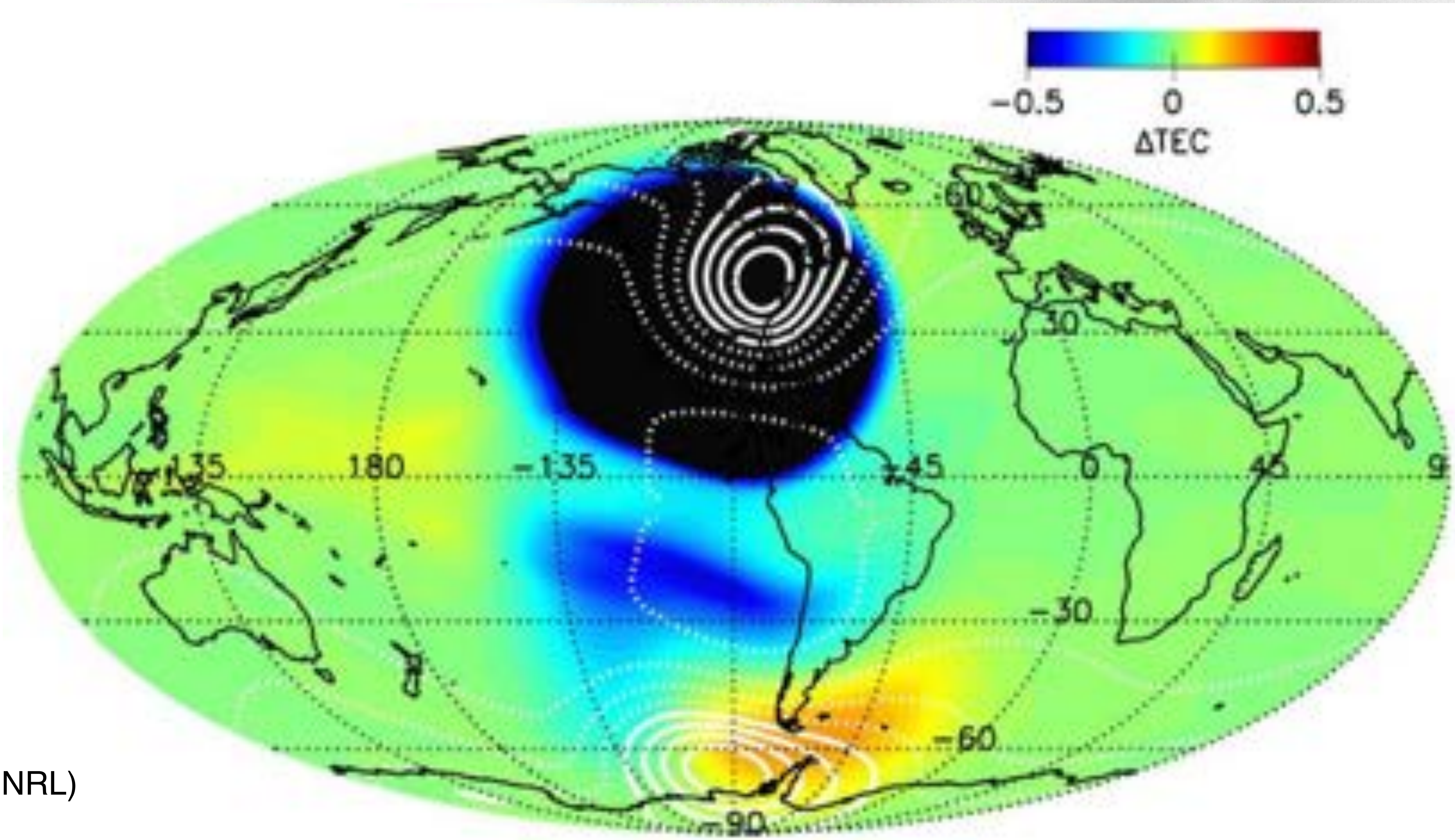
$q(t)$: Normal production function

$$\begin{aligned} q(z) &= [\text{density}]\,[\text{cross-section}]\,[\text{flux at z}] \\ &= n(z)\sigma[F_0 e^{-\tau(z)/\mu_0}], \end{aligned}$$

Observations during an eclipse offer a special opportunity for studying both the solar ionizing radiations and the earth's ionosphere. They are not ideal for this purpose. The ionospheric physicist might wish that the sun could be regarded as a constant, uniform source of ionizing radiation; but investigations of the sun show that it is not. The solar physicist would like to regard the ionosphere as a detector for ionizing radiation. But the ionosphere does not meet the basic requirements of a good detector: straightforward operation, reproduceability, and a linear or other convenient type of response.



# Eclipse Umbra/Penumbra: Ionospheric Effects



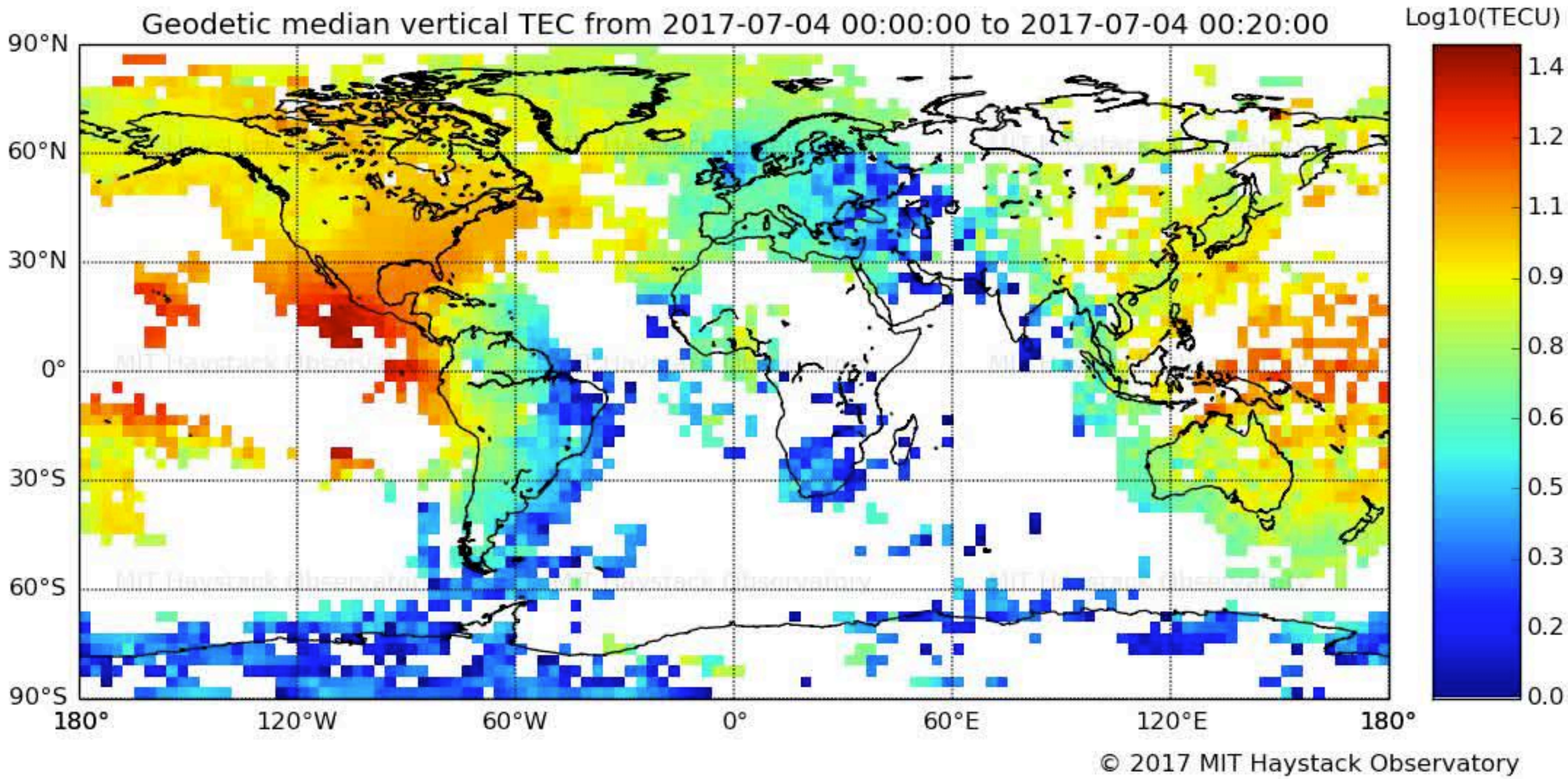

(Joe Huba, NRL)

Modeled effects on electron density

**Both hemispheres affected** (electrical coupling)

# The Ionosphere Is Naturally Complex

(red = more electrons, blue = less)




**Varies in Space, Time: Space Weather**

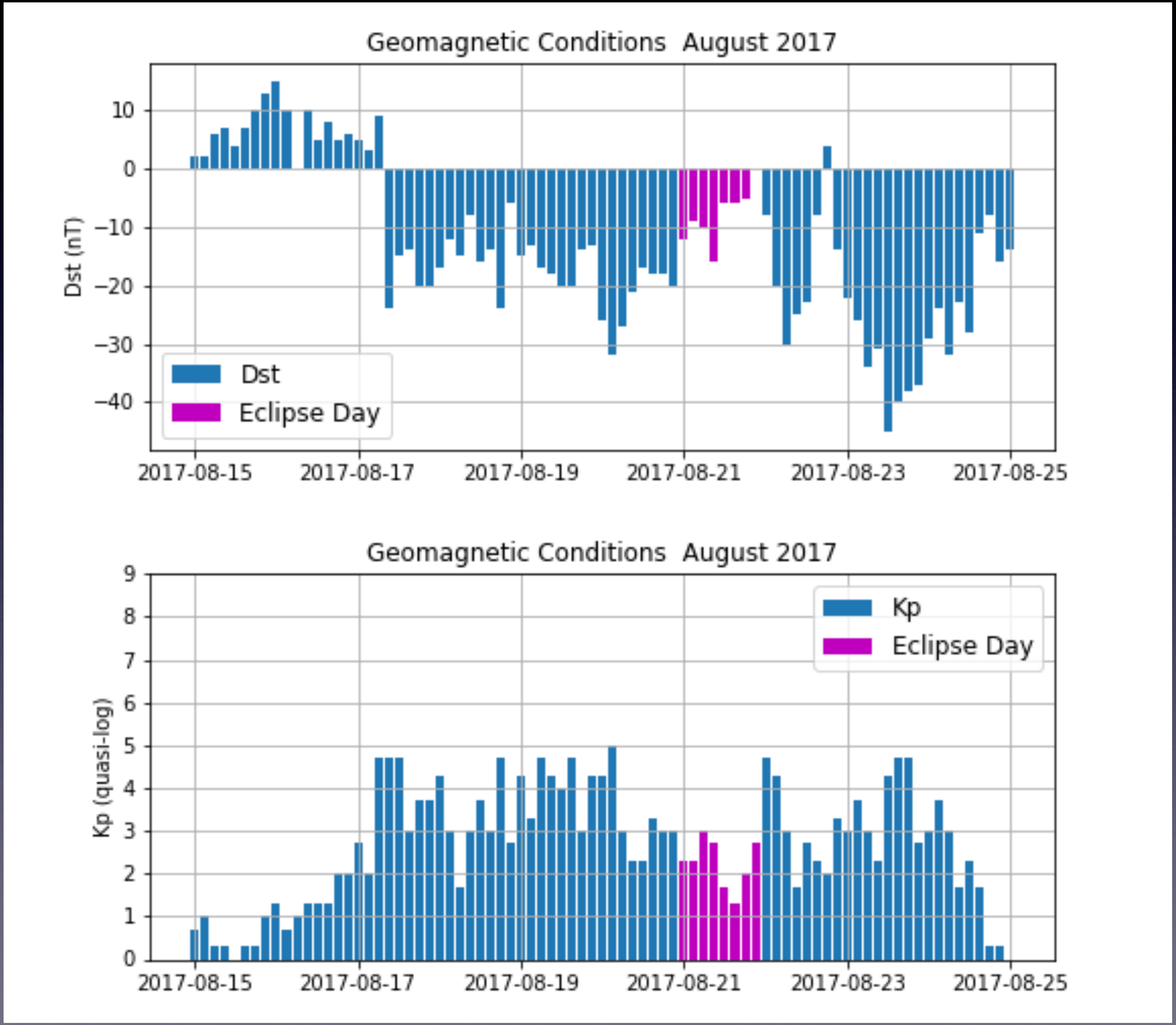
Eclipse 2017

NCAR UCAR | UCARConnect University Corporation for Atmospheric Research

# Geomagnetic / Solar Conditions During the 2017 Eclipse

F10.7 = ~85 SFU

Solar minimum



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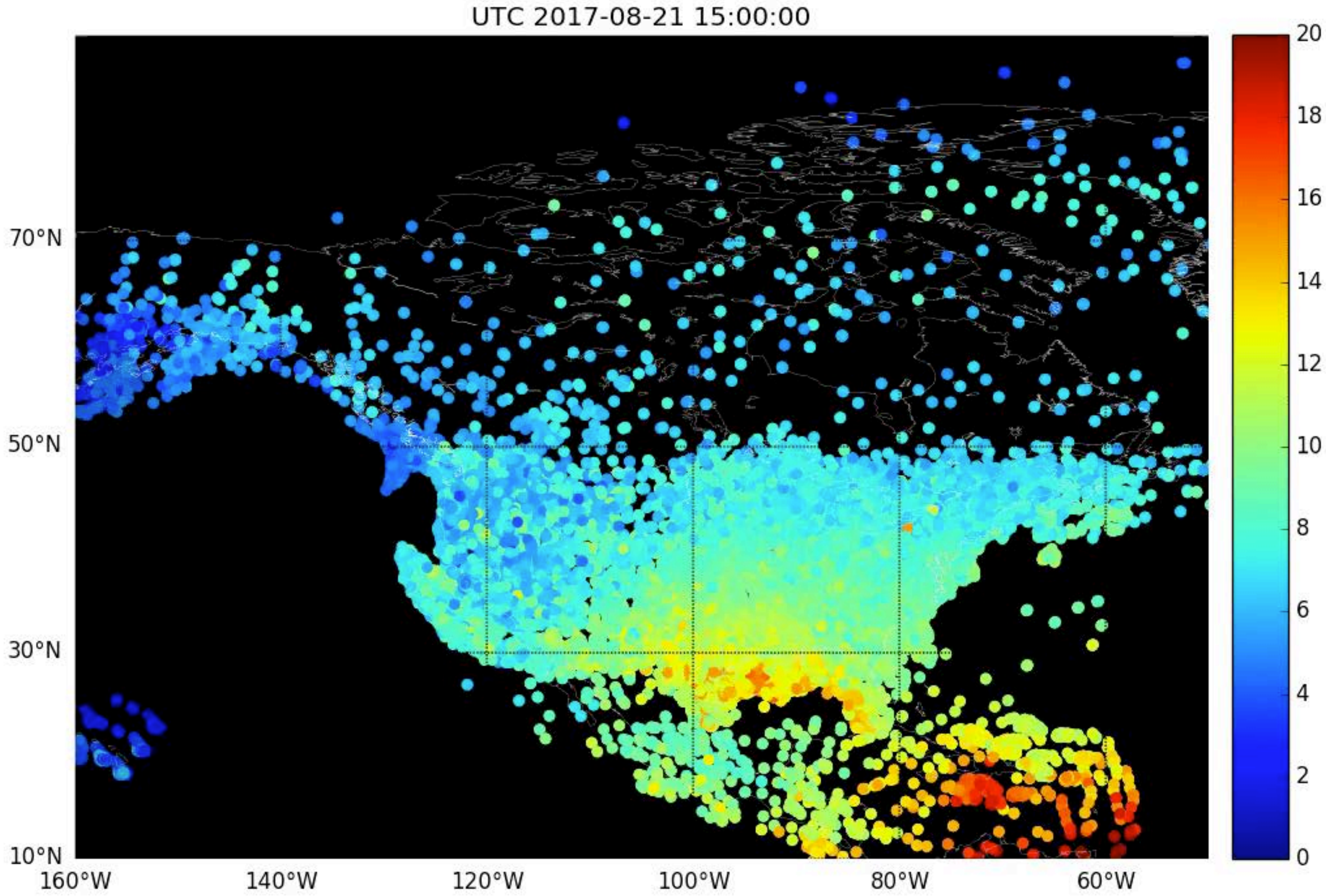
# GNSS TEC: Absolute Electron Density Content Changes




**Eclipse has definite reduction in electron density**

**Model/data comparisons will help improve detailed ion-neutral coupling understanding**

**(1 TEC unit = $10^{16}$ electrons / $m^2$)**

# Solar Eclipse
## GNSS Vertical Total Electron Content

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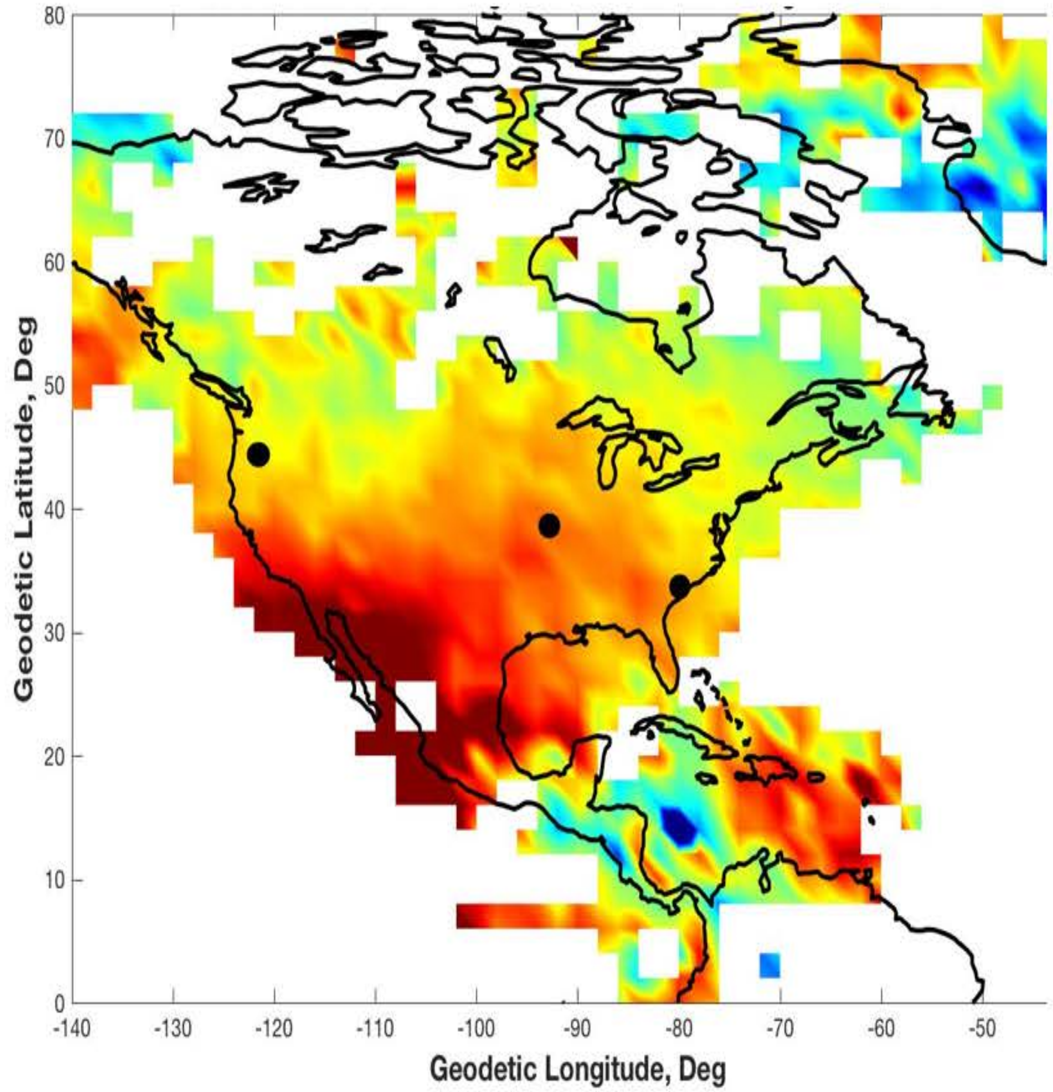
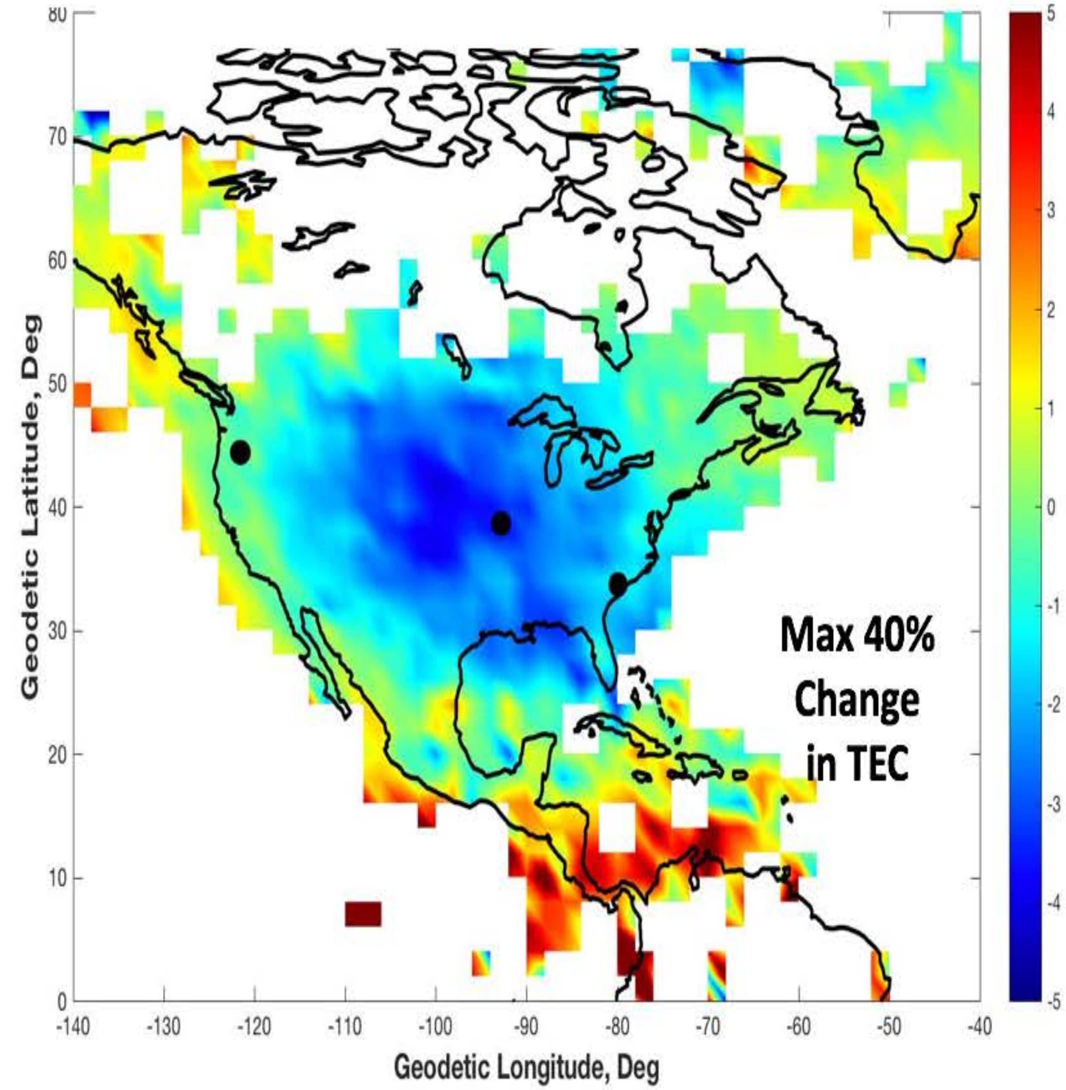
20 August 2017

Difference in TEC at 18:15 UT from 16:45 UT




21 August 2017

Difference in TEC at 18:15 UT from start of solar eclipse at 16:45 UT

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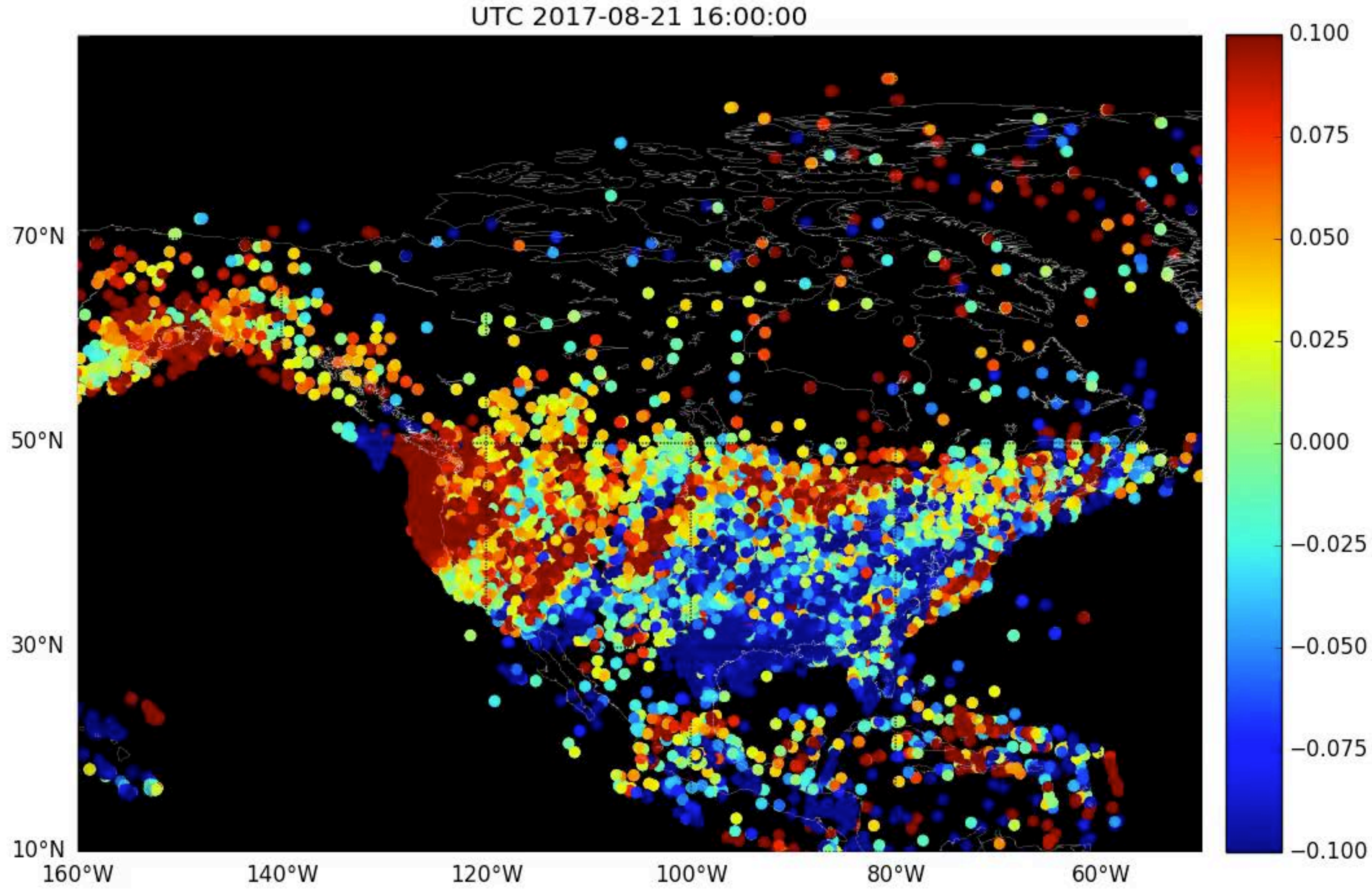
# GNSS TEC:
# Relative Electron Density Content Changes



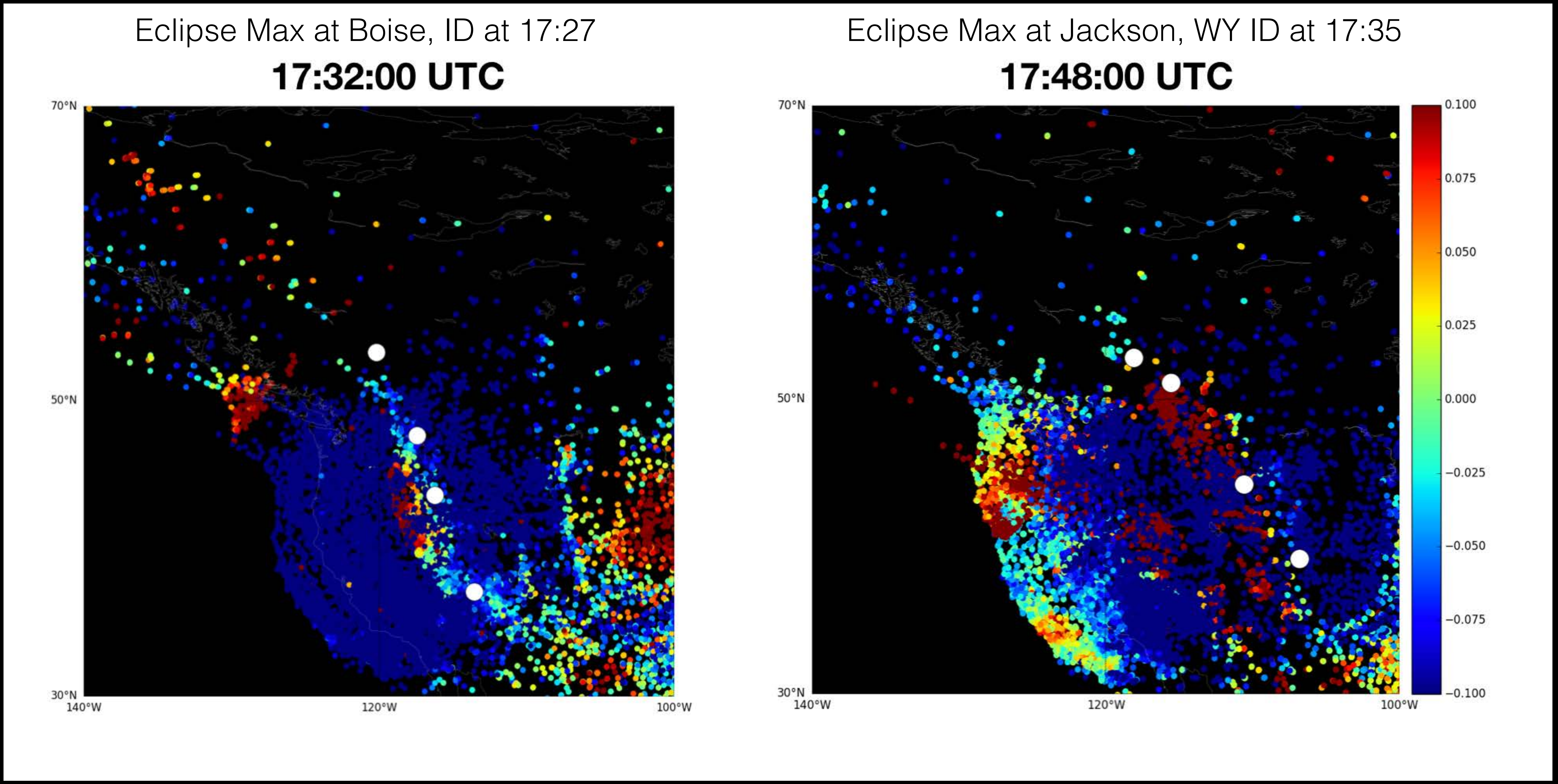

**Eclipse does perturb traveling ionospheric disturbance wave structure post-eclipse**

**Spatio-temporal analysis possible**

**(1 TEC unit = $10^{16}$ electrons / $m^2$)**


©GraphicMaps.com
Arctic Ocean
(Russia)
ASIA
Beaufort Sea
Brooks Range
Alaska Range
Coast
Rocky
Gulf of Alaska
Bering Sea
GREAT
PLAINS
CANADIAN
SHIELD
Hudson Bay
Labrador Sea
N
Great Lakes
Coast Range
Cascades
Mountains
Sierra Nevada
Appalachian Mts.
Pacific Ocean
Atlantic Ocean
600 mi
600 km
COASTAL PLAIN
Gulf of Mexico
Sierra Madres
NORTH AMERICA
CARIBBEAN
Caribbean Sea
CENTRAL AMERICA
worldatlas
Pacific Ocean
SOUTH AMERICA

# Evidence of enhanced TIDs on the western side and eastern side of the Rocky Mountain range.




In the left hand plot, the white dots represent: McBride, CA, Spokane, WA, Boise, ID, and St. George, UT and
in the right hand plot, the white dots represent,: Banff, CA, Jasper, MT, Jackson, WY, and Aspen, CO

Coster et al 2017, submitted

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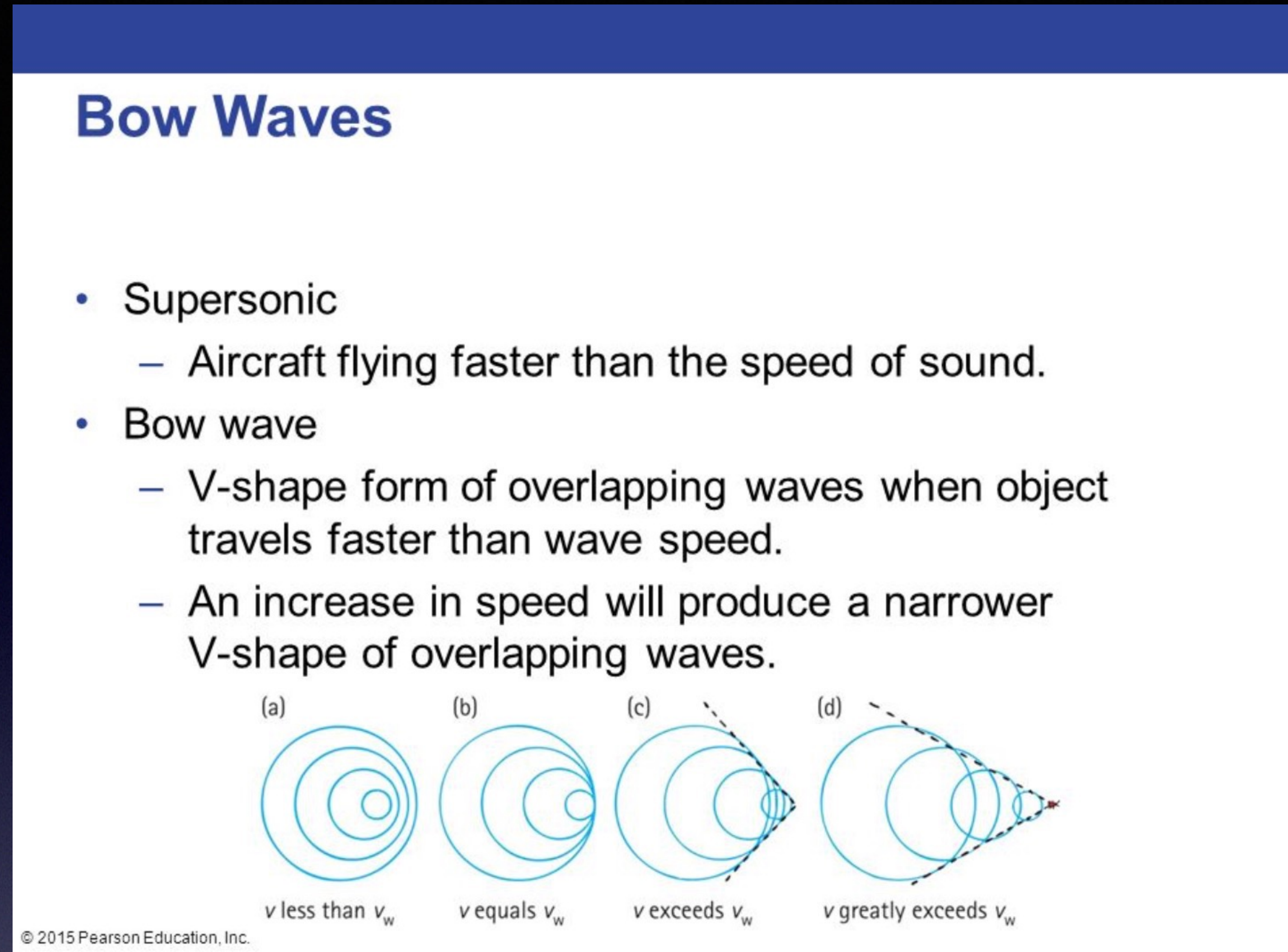
**Eclipse bow waves predicted by many studies (e.g. Chimonas [1970])**




**Did the 2017 Eclipse create bow wave structures?**

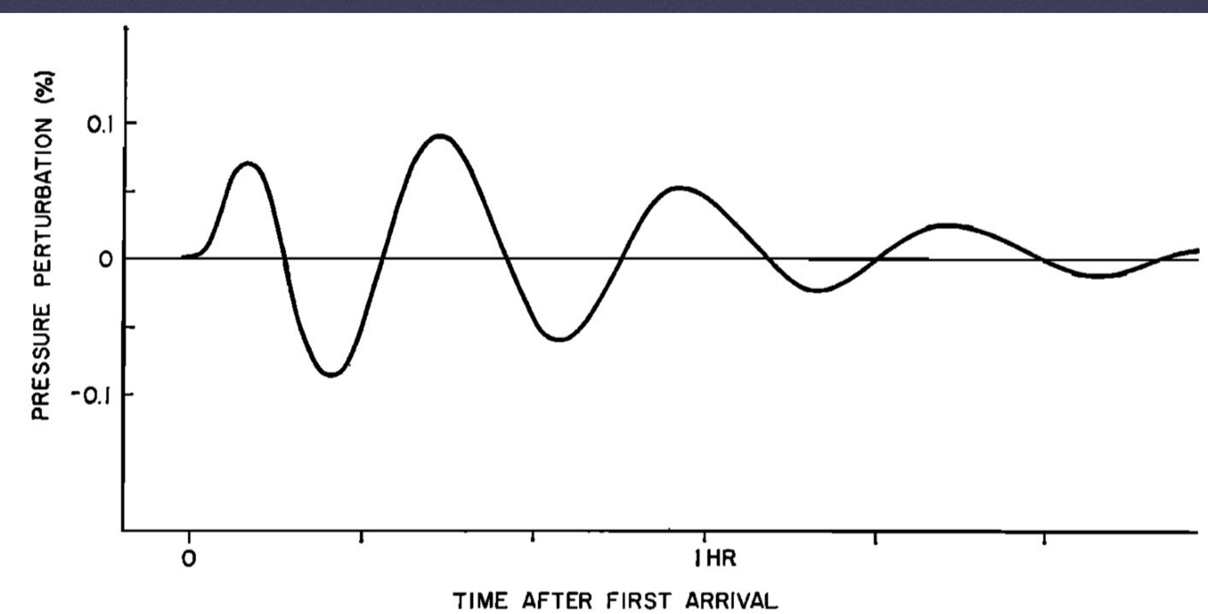



Fig. 2. The pressure perturbation bow wave caused by an eclipse, as computed from the theory of *Chimonas* [1970] for a point 5000 km off the axis of the eclipse path and 300 km above the earth's surface.

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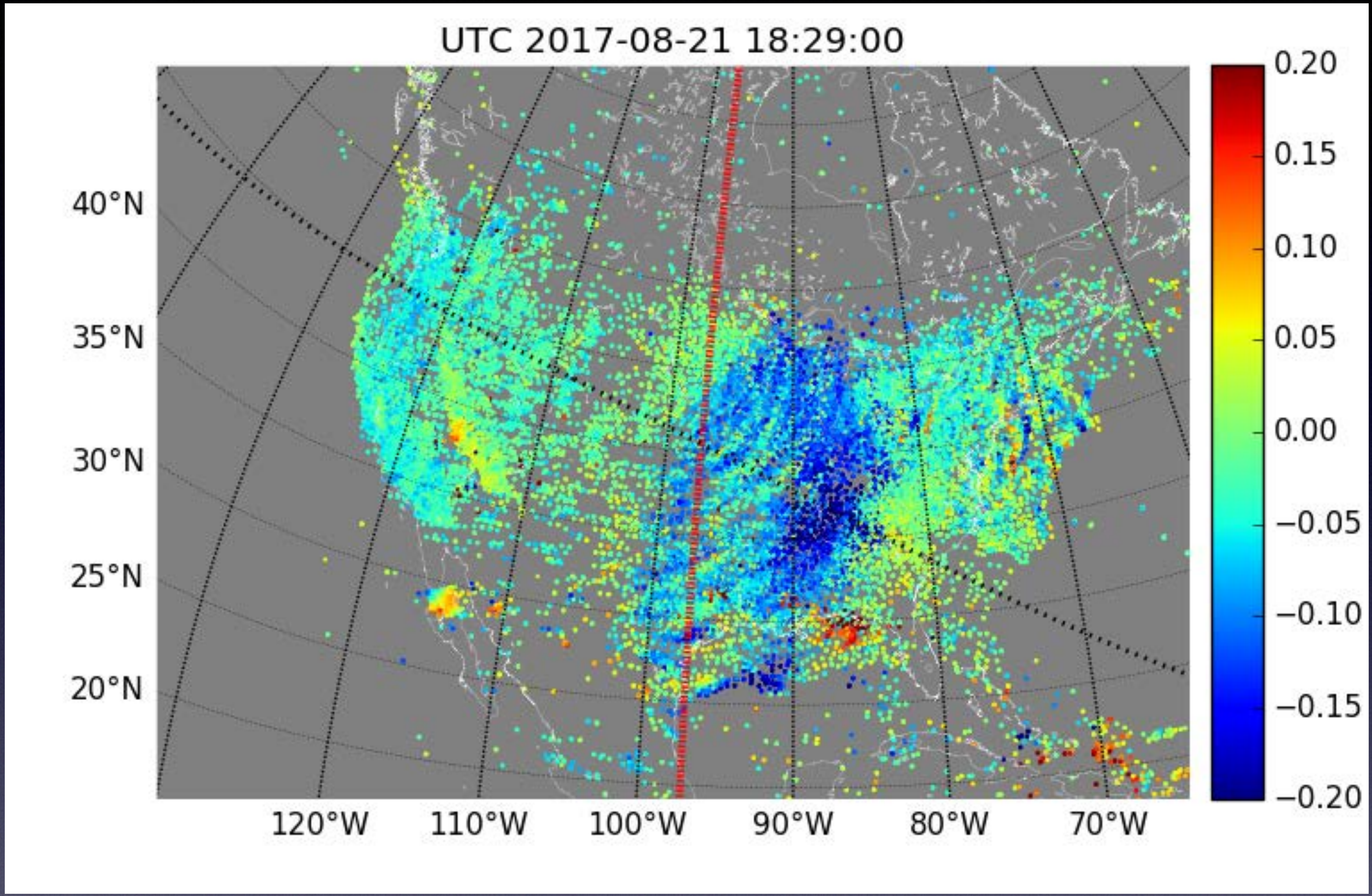
Eclipse bow waves predicted by many studies (e.g. Chimonas [1970])

Did the 2017 Eclipse create bow wave structures?




**Yes!**

**Analysis quantifies meridional, zonal velocity**

**Examine implications for ion-neutral coupling**

Zhang et al 2017, submitted

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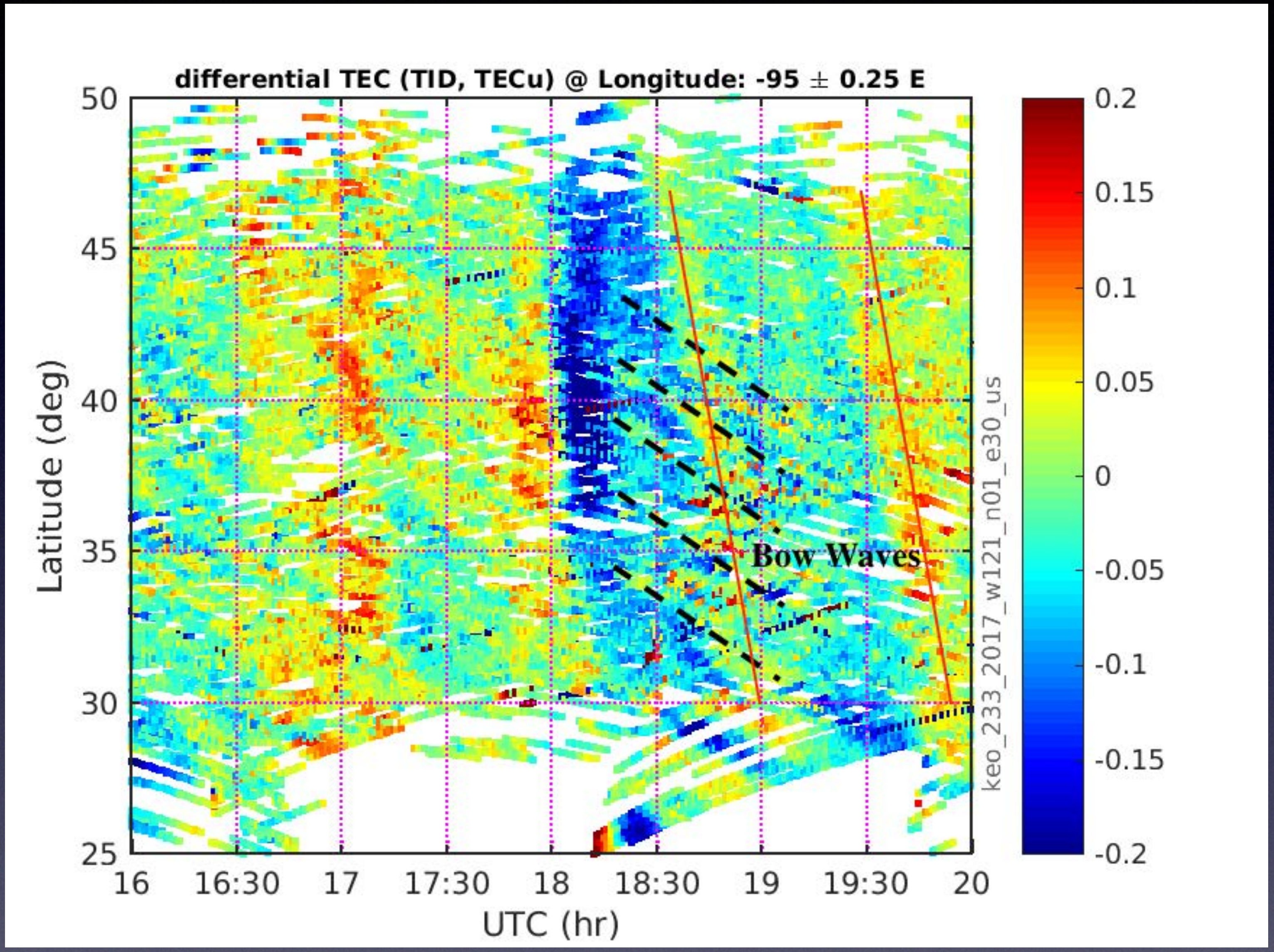
Eclipse bow waves predicted by many studies (e.g. Chimonas [1970])

Did the 2017 Eclipse create bow wave structures?



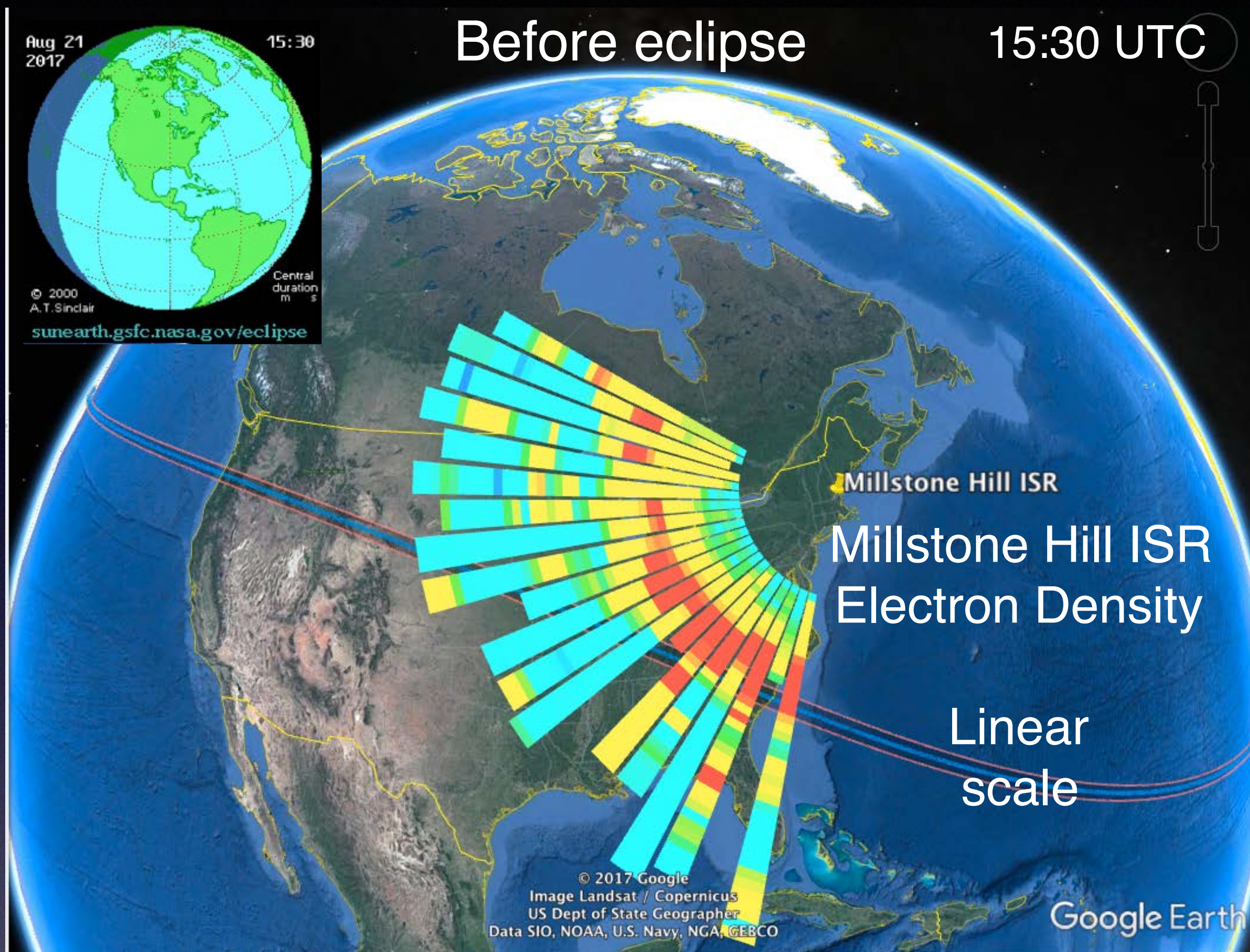

**Example:**
**Bow waves at (2.5 deg/0.5 hr) = 140 m/s in meridional direction**

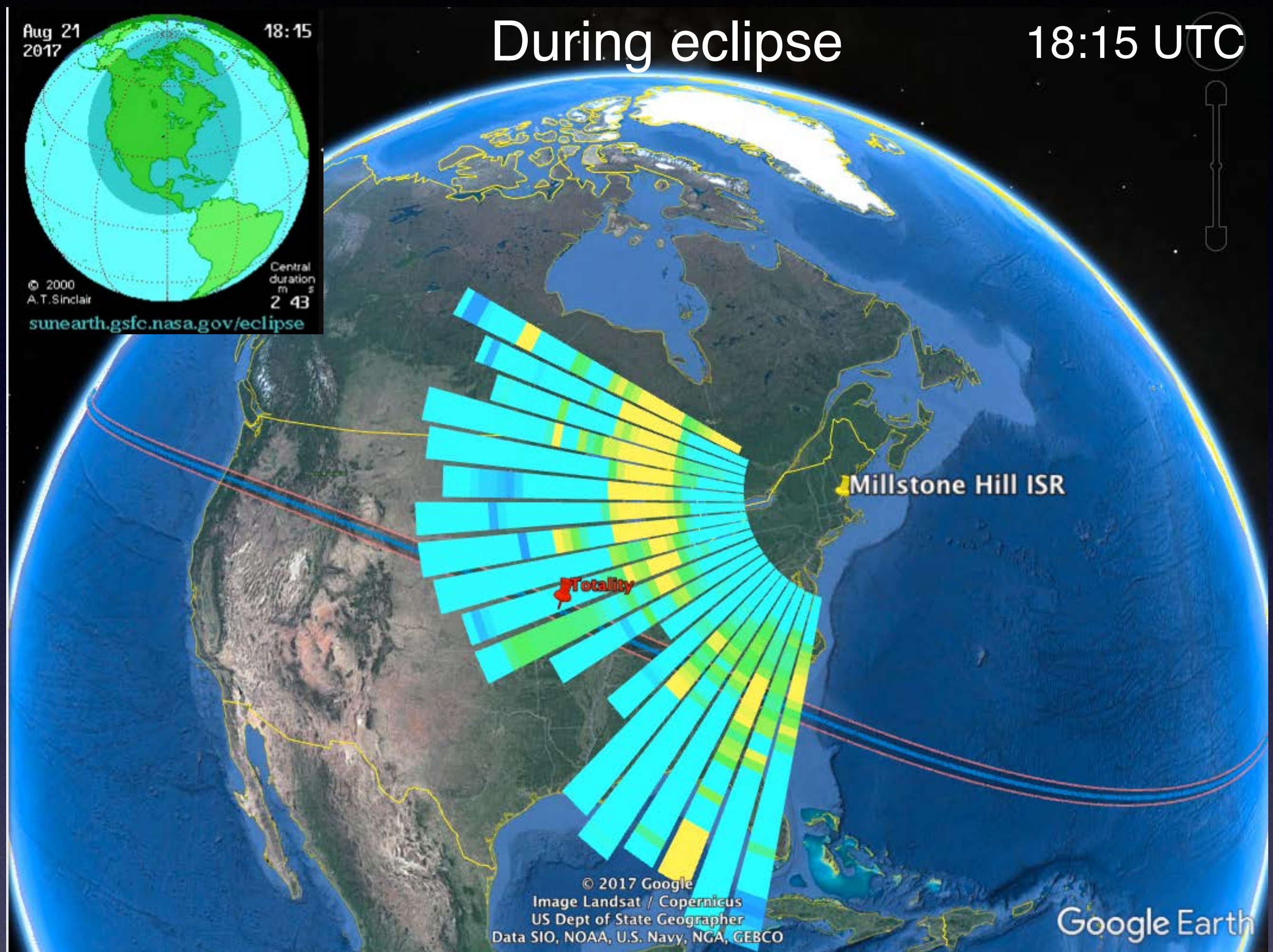
Zhang et al 2017, submitted

# Millstone Hill Geospace Facility: UHF Ionospheric Radar


Thomson / incoherent scatter
Full ionospheric altitude profiles
Wide field of view across eastern US (steerable)

# Ionospheric Changes Over North America During The 2017 Eclipse




**Millstone Hill Geospace Facility**
**Westford, MA, USA**

(figure: W. Rideout, MIT Haystack)

Support: NSF AGS-1242204, NASA NNX17AH71G

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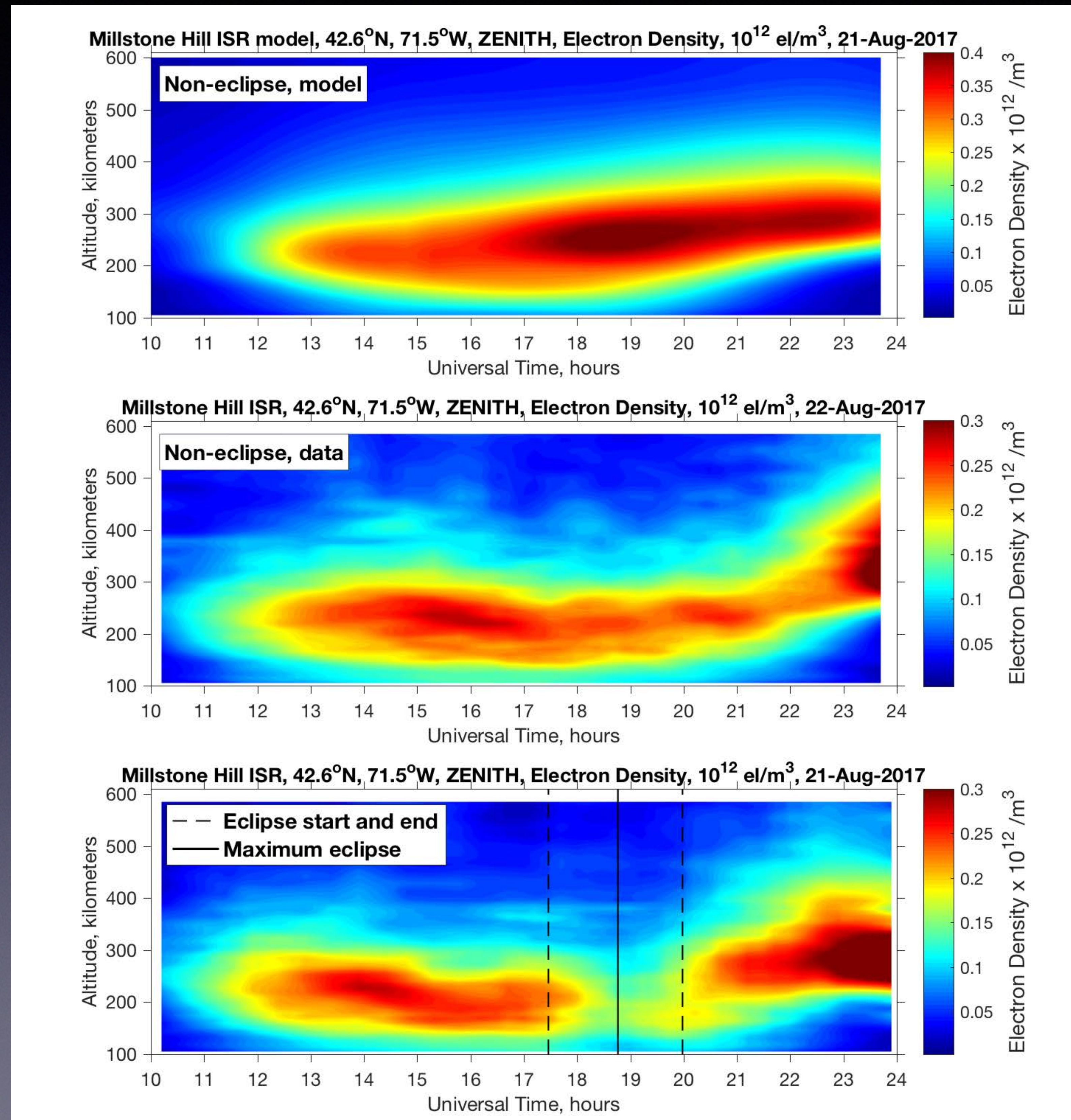
# Ionospheric Changes Over Massachusetts During The 2017 Eclipse




**Millstone Hill Geospace Facility**

**Westford, MA, USA**

(figure: L. P. Goncharenko, MIT Haystack)

Support: NSF AGS-1242204, NASA NNX17AH71G

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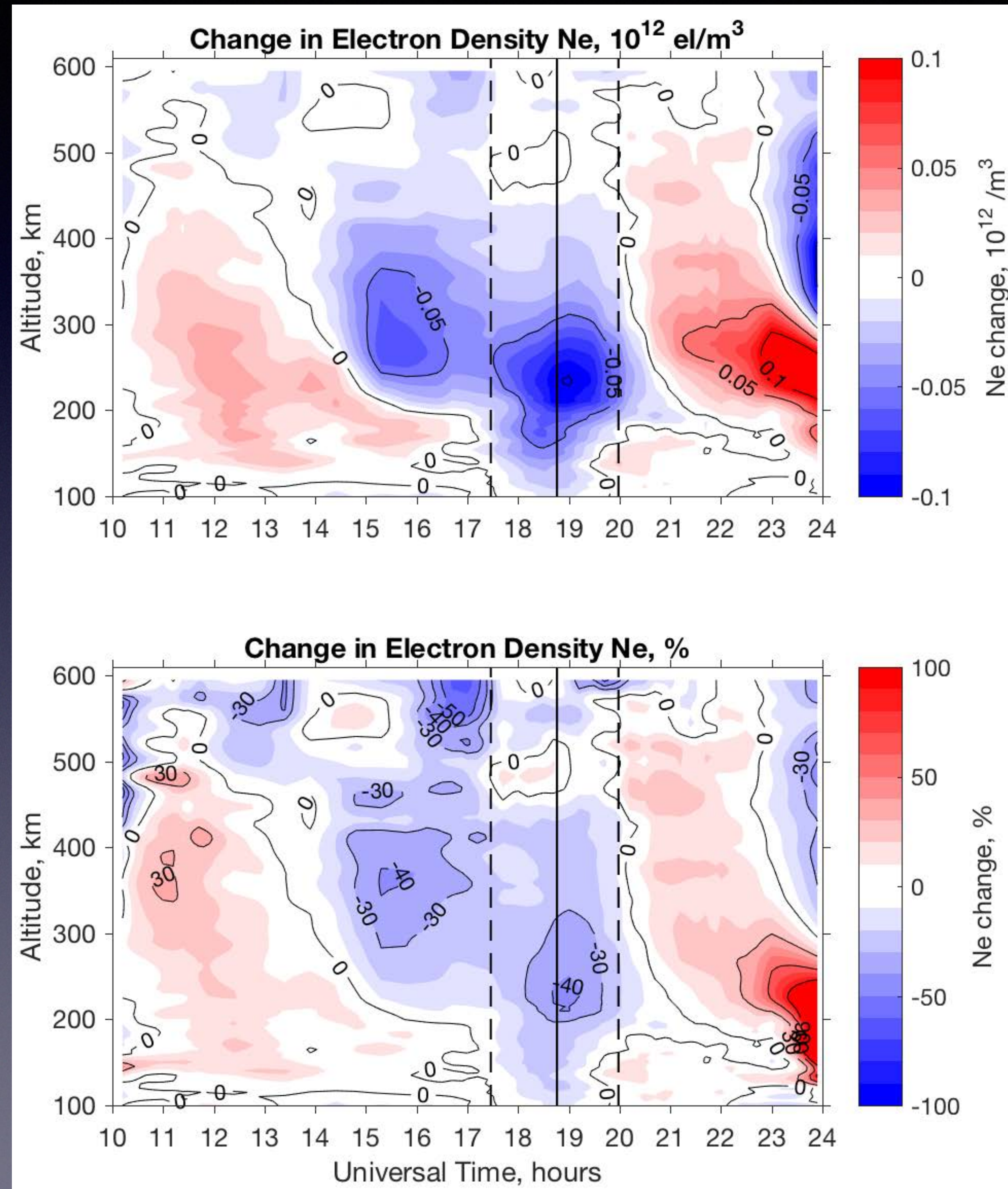
# Ionospheric Changes Over Massachusetts During The 2017 Eclipse




**Millstone Hill Geospace Facility**

**Westford, MA, USA**

(figure: L. P. Goncharenko, MIT Haystack)


Support: NSF AGS-1242204, NASA NNX17AH71G

# Ionospheric Changes Over Massachusetts During The 2017 Eclipse

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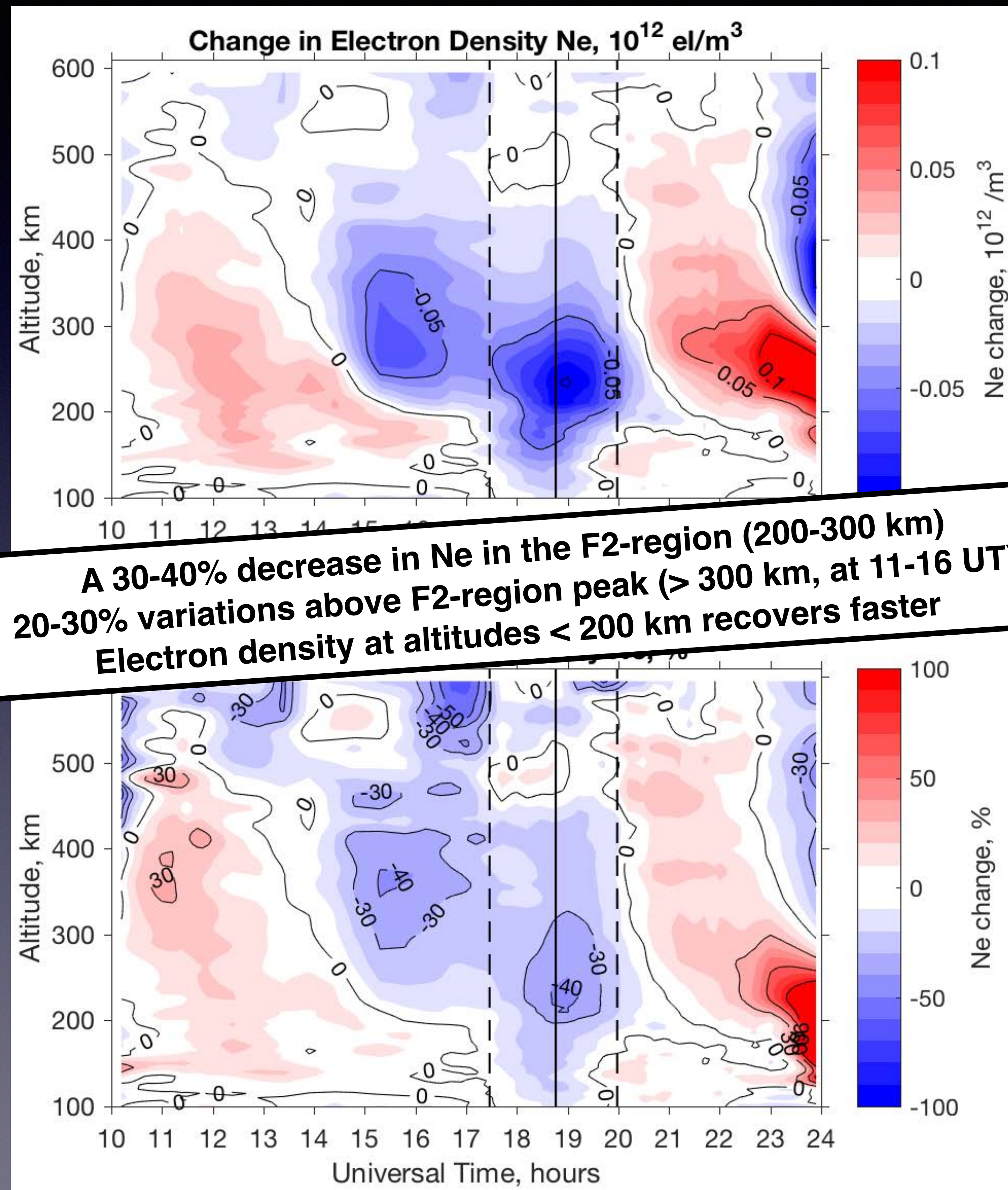
**Millstone Hill Geospace Facility**

**Westford, MA, USA**

(figure: L. P. Goncharenko, MIT Haystack)

Support: NSF AGS-1242204, NASA NNX17AH71G




**A 30-40% decrease in Ne in the F2-region (200-300 km)**
**20-30% variations above F2-region peak (> 300 km, at 11-16 UT)**
**Electron density at altitudes < 200 km recovers faster**

# Millstone Hill Langmuir Mode:
# Precise F2 Peak Electron Density Observations

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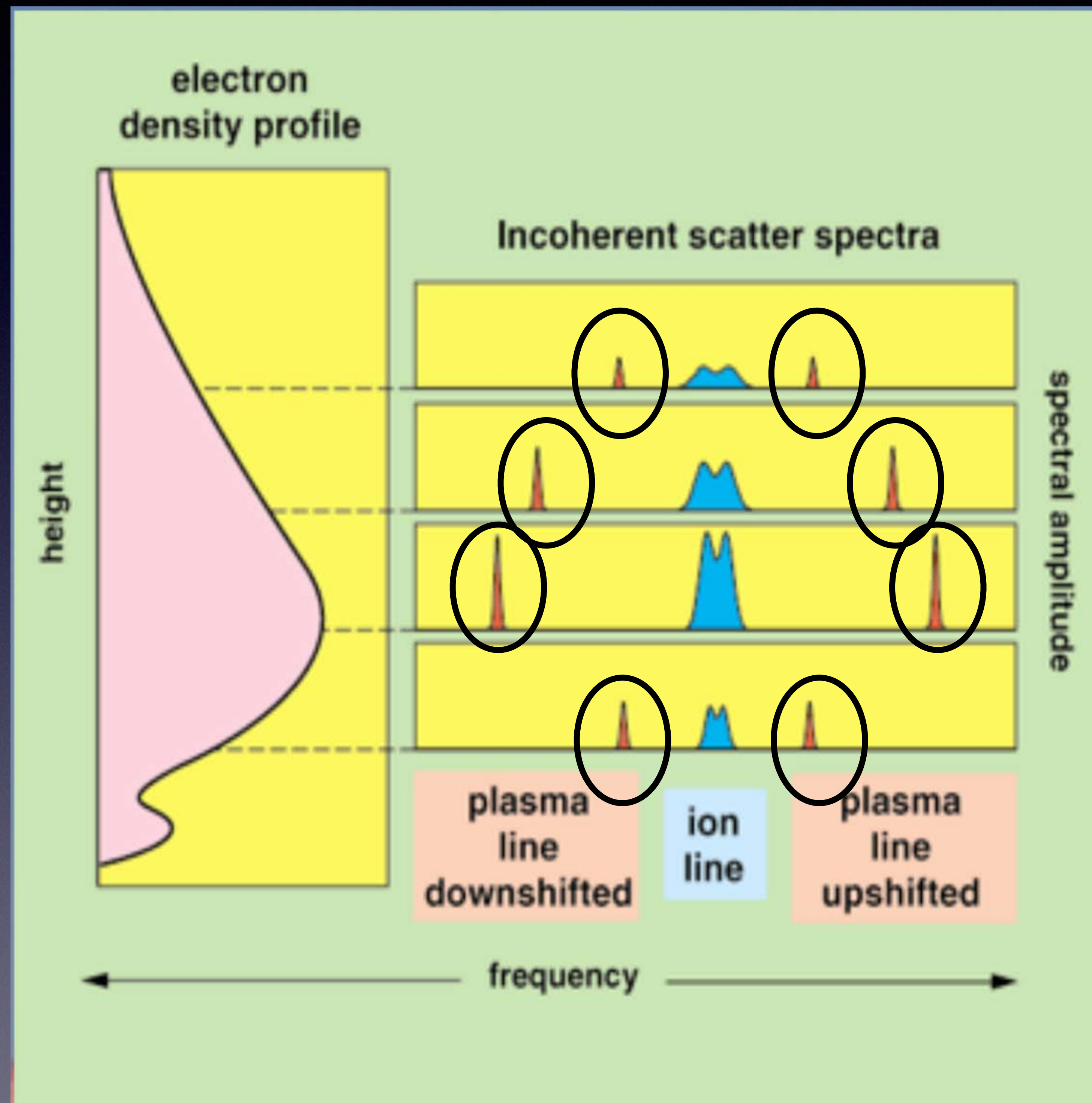

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# Millstone Hill Langmuir Mode:
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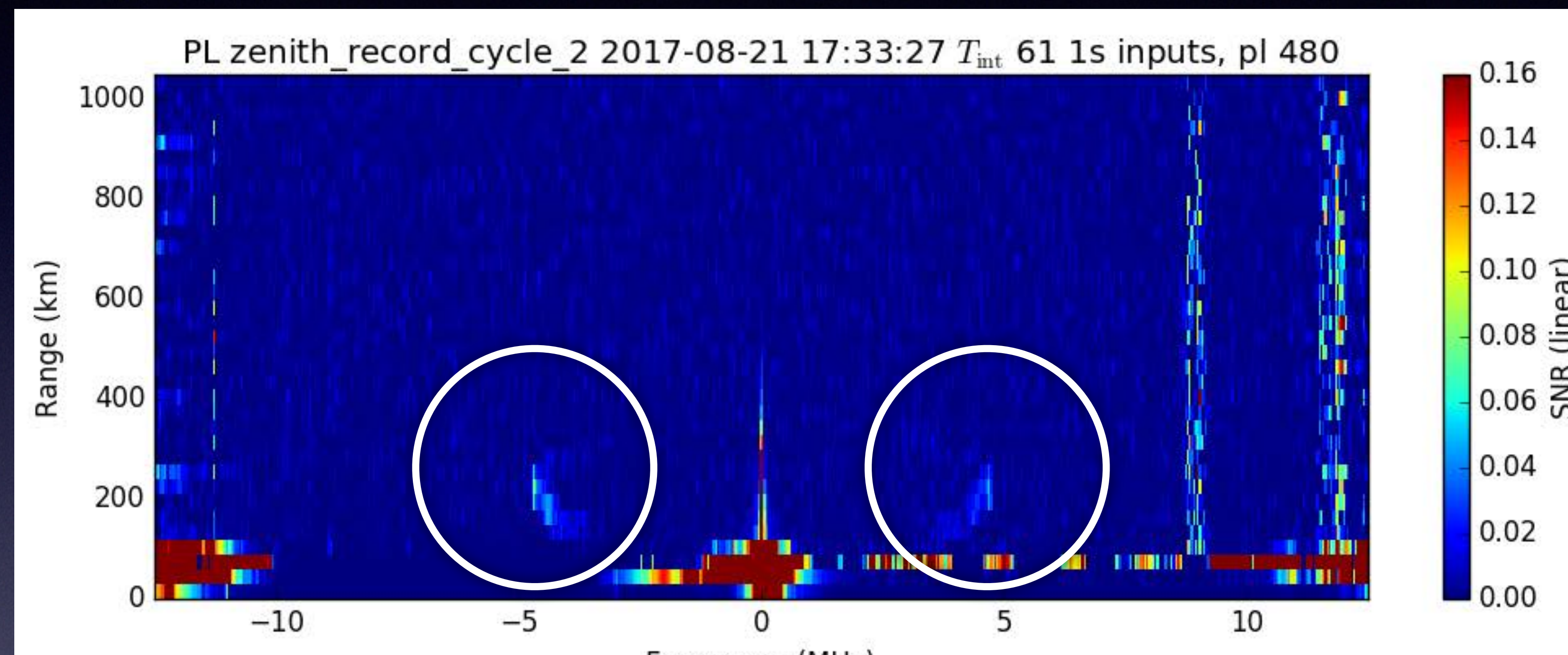


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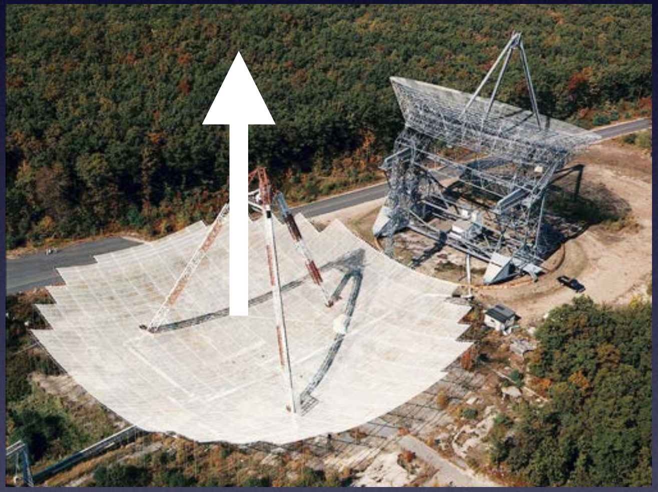
$$\omega^2 = \omega_p^2 + \frac{3}{2}k^2 v_{th}^2$$

$$\omega_p = \left(\frac{n_0 e^2}{\epsilon_0 m}\right)^{1/2}$$

**F2 peak electron density measurement accuracy < 0.1%**
**(1.5 kHz freq resolution)**
**at <= 60 second cadence**

# Millstone Hill Langmuir Mode:
# Precise F2 Peak Electron Density Fluctuations



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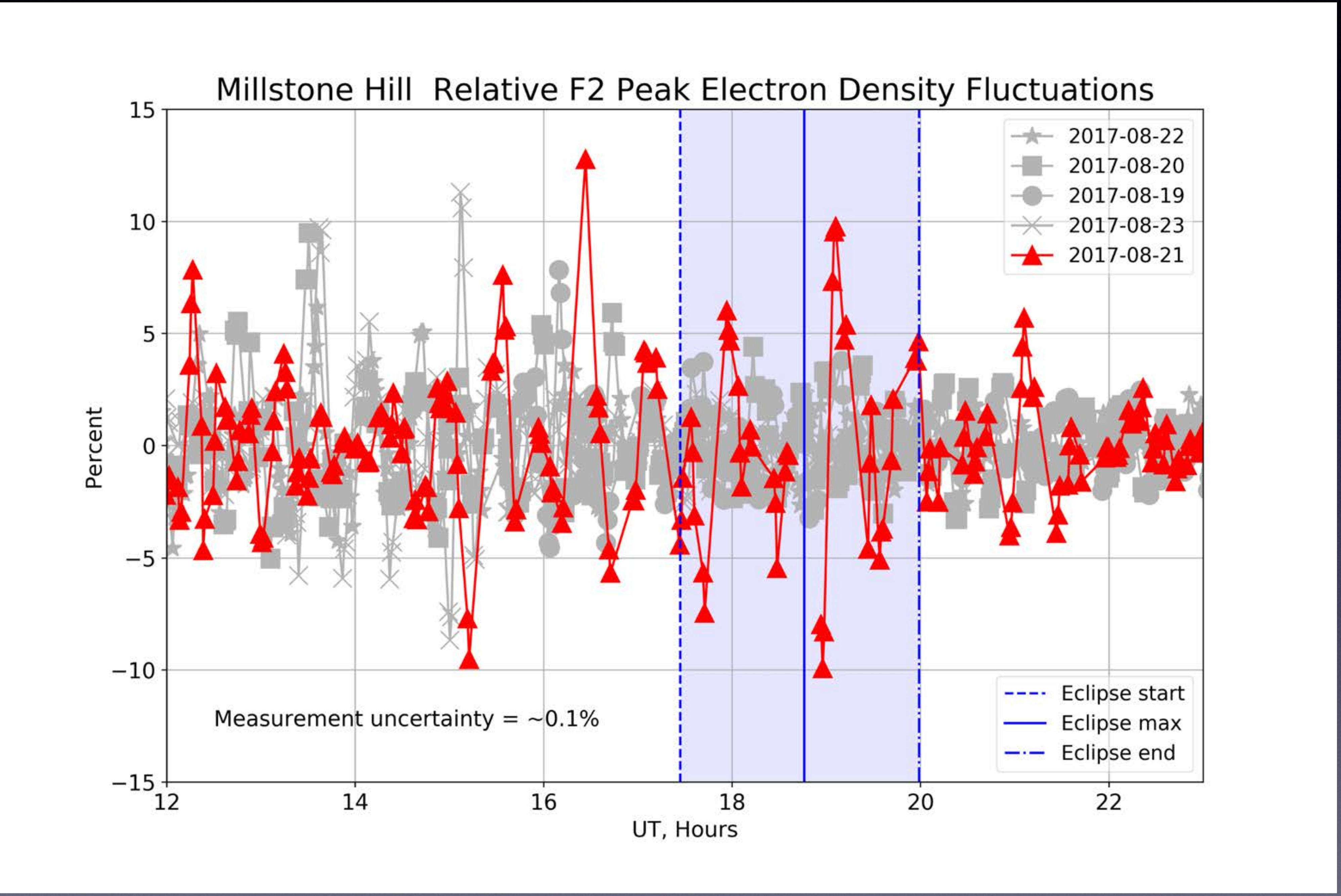
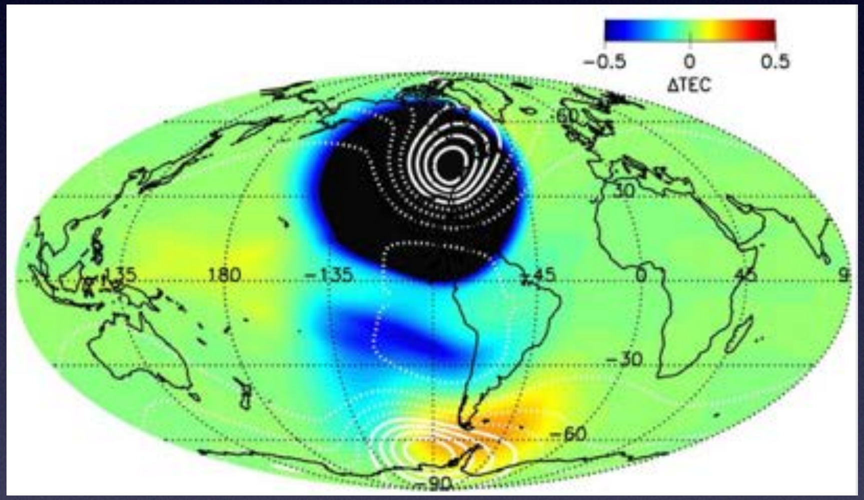


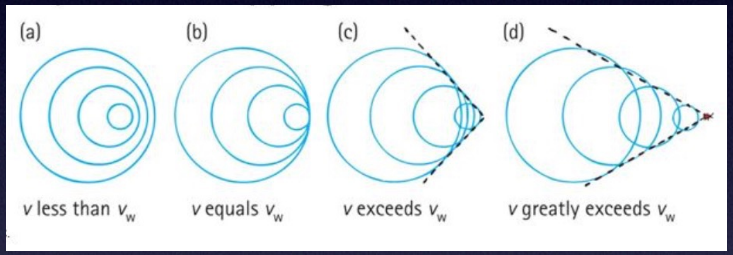

No statistical increase in fluctuations on eclipse day;
under investigation (e.g. does ISR select certain wave modes?)

**Summary:**

**Wave, Plasma Parameter analysis ongoing**
**New information on eclipse perturbations: the ultimate active experiment!**

**Modern observation networks advance understanding even after nearly 100 years of observing eclipse ionospheric effects**

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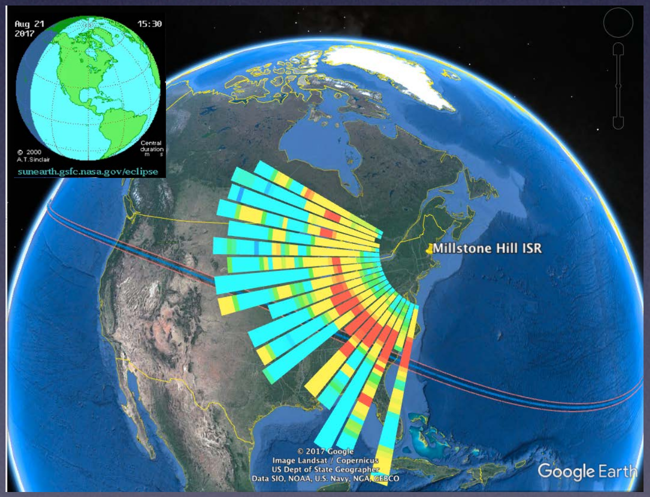


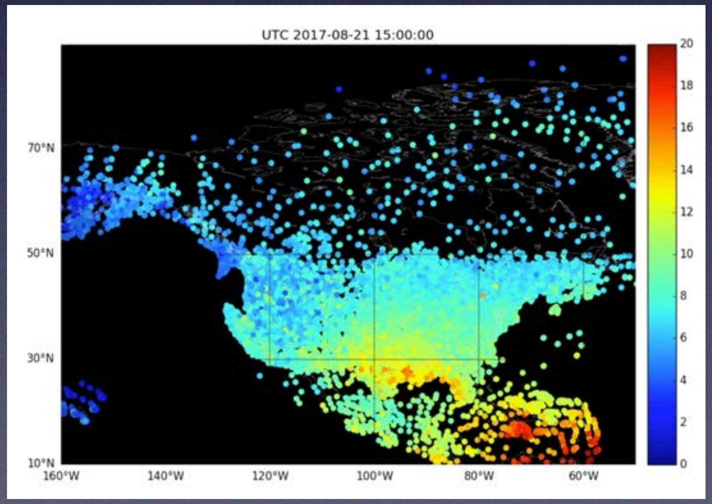


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