The Third Source of Short-Term Variability in the F2 Region

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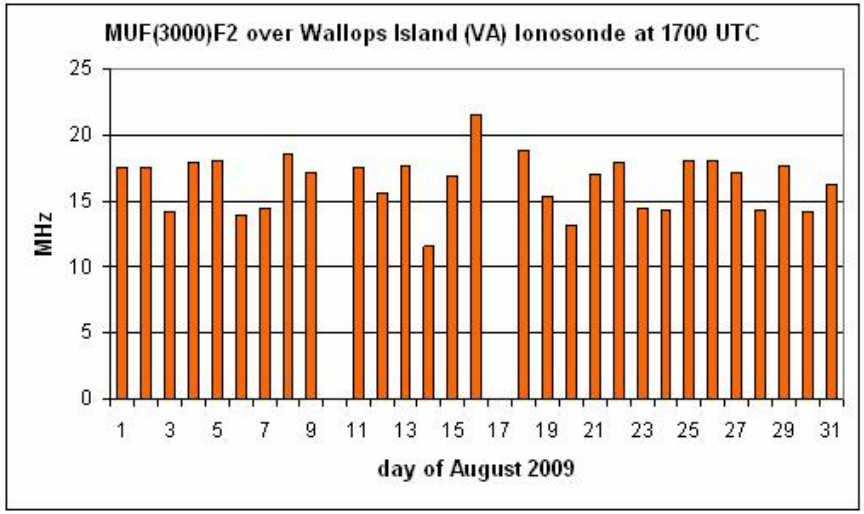
Ionosonde Data from Wallops Island Ionosonde

- Lowest MUF
  - 11 MHz on August 14
- Highest MUF
  - 22 MHz on August 16
- 2:1 ratio
- Let's look at sunspots, 10.7 cm solar flux and Ap indices for August 2009

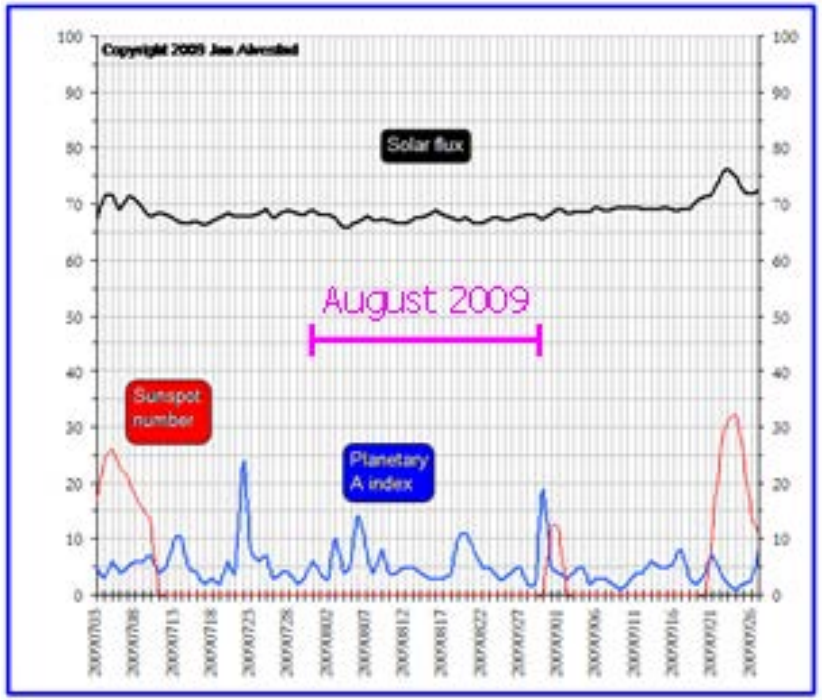
August 2009



a month's worth of data

Space Weather Data for August 2009

- August 2009 was at solar min
- Sunspot number was zero
- 10.7 cm solar flux was constant
  - 67.5 +/- 2.0 units (+/- 3%)
- 26-34 nm EUV varied by +/- 2.2%
  - https://dornsifecms.usc.edu/space-sciences-center/download-sem-data/
  - 26-34 nm accounts for approximately 60% of the F2 region ionization
- Mid latitude A index ≤ 12
- Mid latitude K index ≤ 3



JASTP Article: "Patterns of F2-layer Variability"

- H. Rishbeth and M. Mendillo, Journal of Atmospheric and Solar-Terrestrial Physics, 2001
- Analyzed data from 13 ionosondes from 1957-1990
- Determined that

$$\frac{\text{std dev}}{\text{mean}} \text{ for NmF2} = 20\% \text{ (daytime)}$$

- More analysis done – partitioned this into 3 sources

1. Solar radiation = 3%
2. Geomagnetic field activity = 13%
3. Meteorology = 15%

$$(3\%)^2 + (13\%)^2 + (15\%)^2 = (20\%)^2$$

meteorology implies events in the lower atmosphere coupling up to the ionosphere

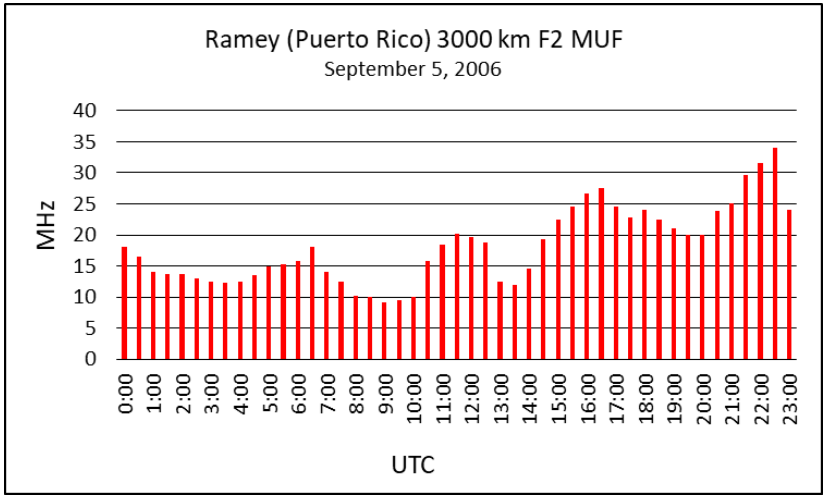
A Possible Conclusion

The Rishbeth and Mendillo paper suggests that the variation in the Wallops Island F2 region ionosonde data during August 2009 was mainly due to events in the lower atmosphere coupling up to the ionosphere (meteorology) since solar radiation was constant and geomagnetic field activity was low

The Coupling Mechanism – A Simplification

- An event in the lower atmosphere may cause an atmospheric gravity wave (AGW)
  - Not to be confused with 'gravity waves' when two black holes collide
  - In an AGW, 'gravity' is the buoyancy force that tries to restore equilibrium in the atmosphere
  - For more on AGWs, visit https://www.atoptics.co.uk/highsky/hgrav.htm
- An AGW may couple up to the ionosphere
- The manifestation of an AGW coupling up to the ionosphere may be a traveling ionospheric disturbance (TID)

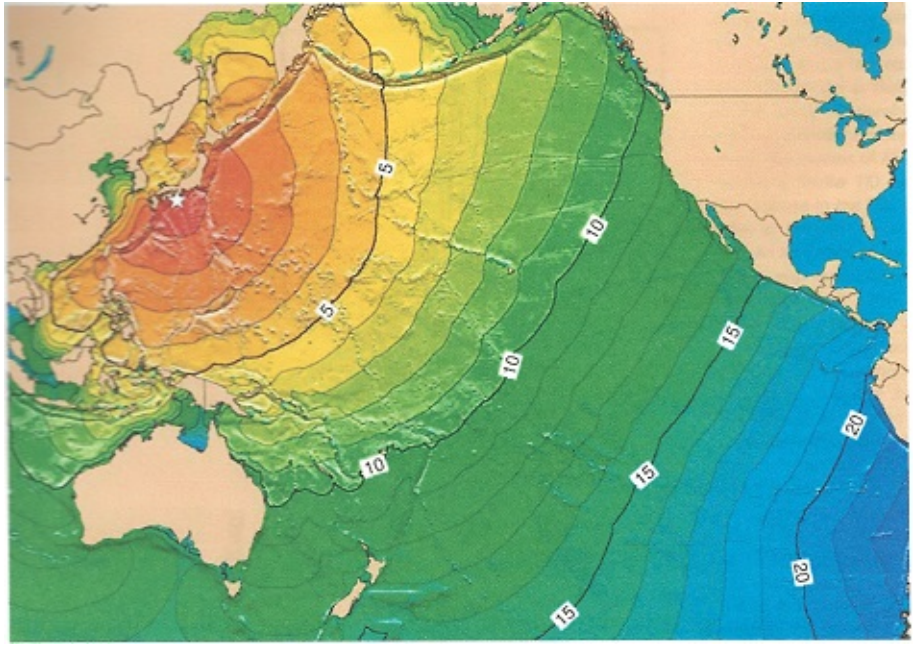
possible TID



What caused this? Perhaps Hurricane Ernesto (Aug 24 to Sep 1) and/or Hurricane Florence (Sep 3 to Sep 13) played a role – or something else!

Tsunami – An Extreme Example

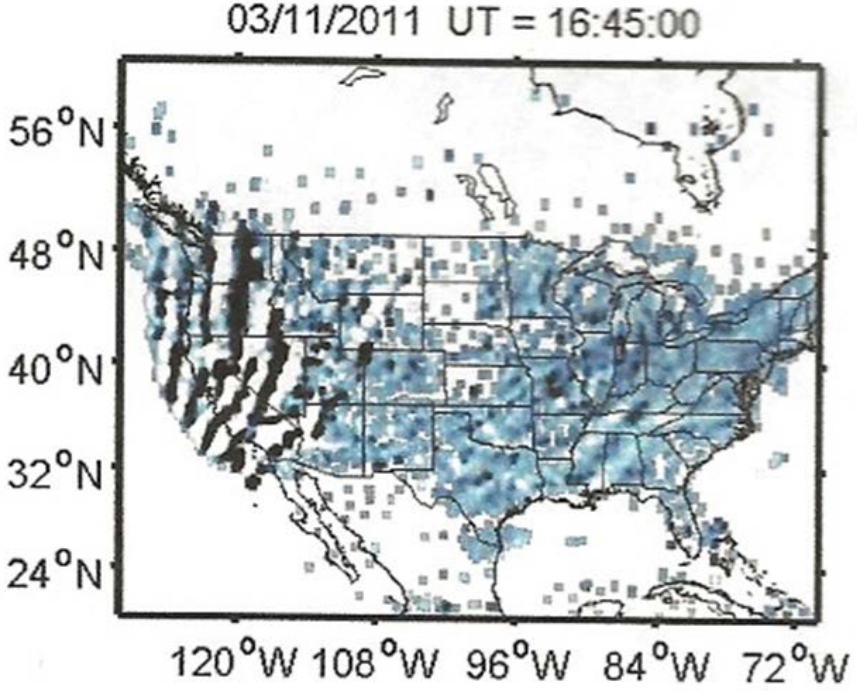
- March 11, 2011 Tohoku (Japan) earthquake (mag 9.0) at 0546 UTC
- Generated a tsunami – arrived at the US West Coast 11 hours later
- Irfan Azeem, et al, “Traveling ionospheric disturbances over the United States induced by gravity waves from the 2011 Tohoku tsunami and comparison with gravity wave dissipative theory”, JGR: Space Physics, 122, 3430-3447, 2017



tsunami arrival times in hours

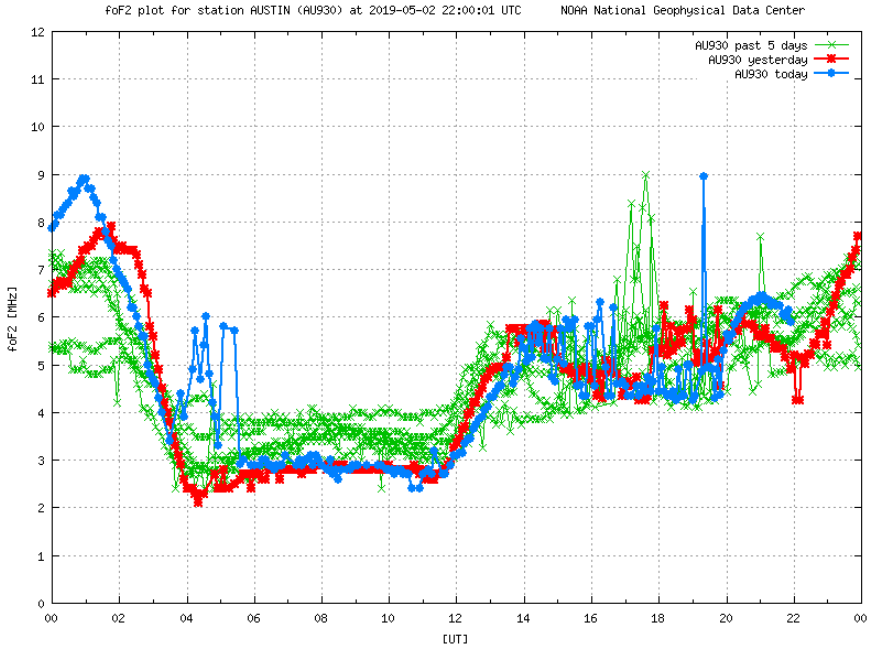
Tsunami – Effect on the Ionosphere

- Perturbations in TEC (not TEC itself) on West Coast started 11 hours after earthquake
- Light blue is up to +0.03 TECU
- Dark blue is up to -0.03 TECU
- Alignment of TEC perturbations similar to alignment of tsunami arrival times

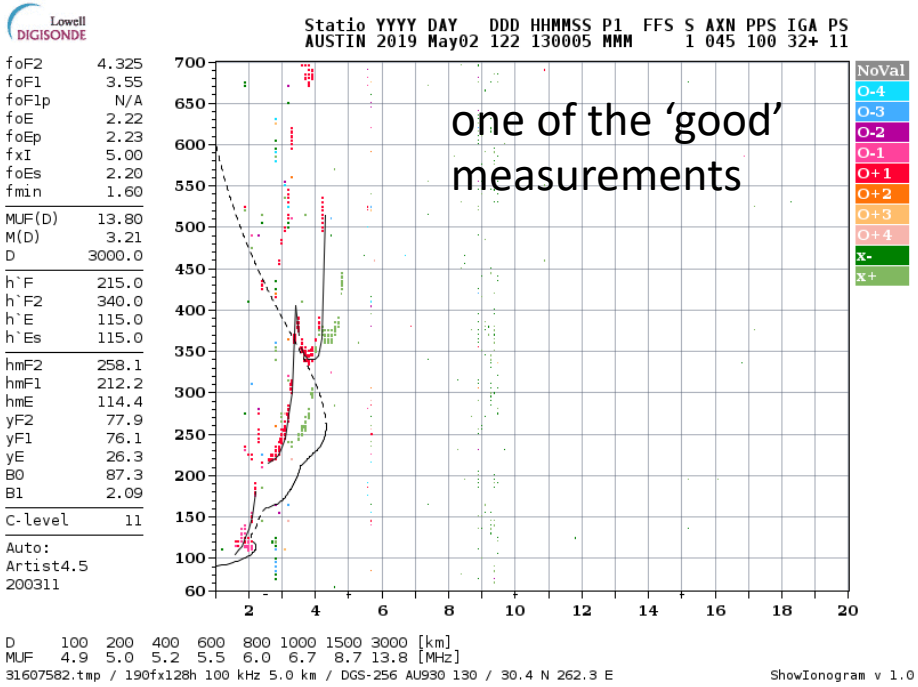


Recent Example – Ionosonde Data

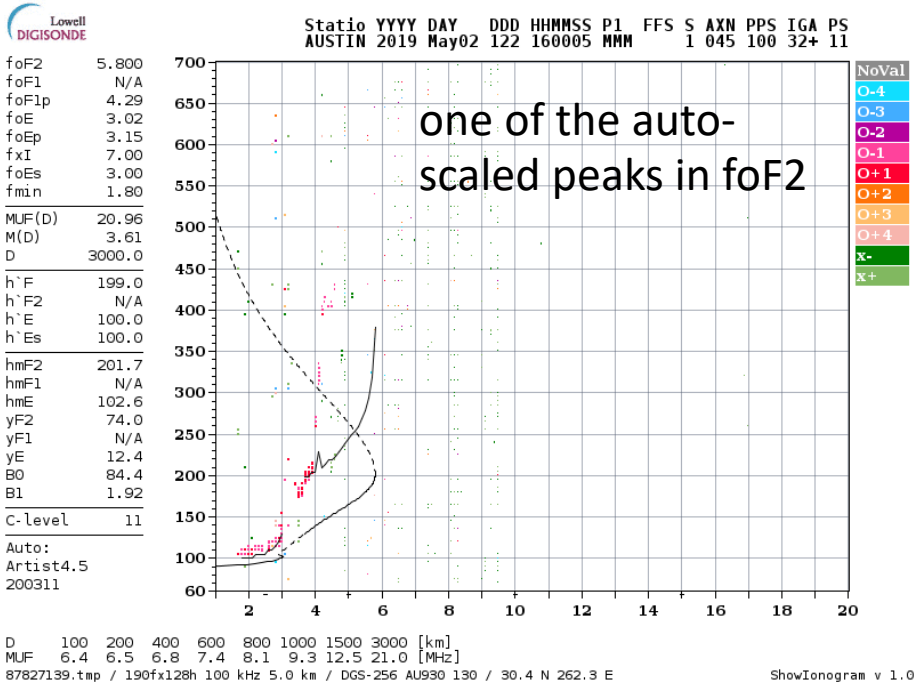
- Larry N6NC, C. Gabriel (Scripps Institution of Oceanography, University of California San Diego) and I are trying to capture a weather event, an AGW and a TID
- Thunderstorms in Texas on May 2
- Austin ionosonde May 2 – blue curve
- Note ups-and-downs of foF2 beginning around 1400z – TID? Noise?
- Ionograms do not show clear foF2 asymptotic line for all the foF2 peaks
  - Auto-scaling made an educated guess
- So is this an actual TID?



Recent Example – A Look at the Ionograms



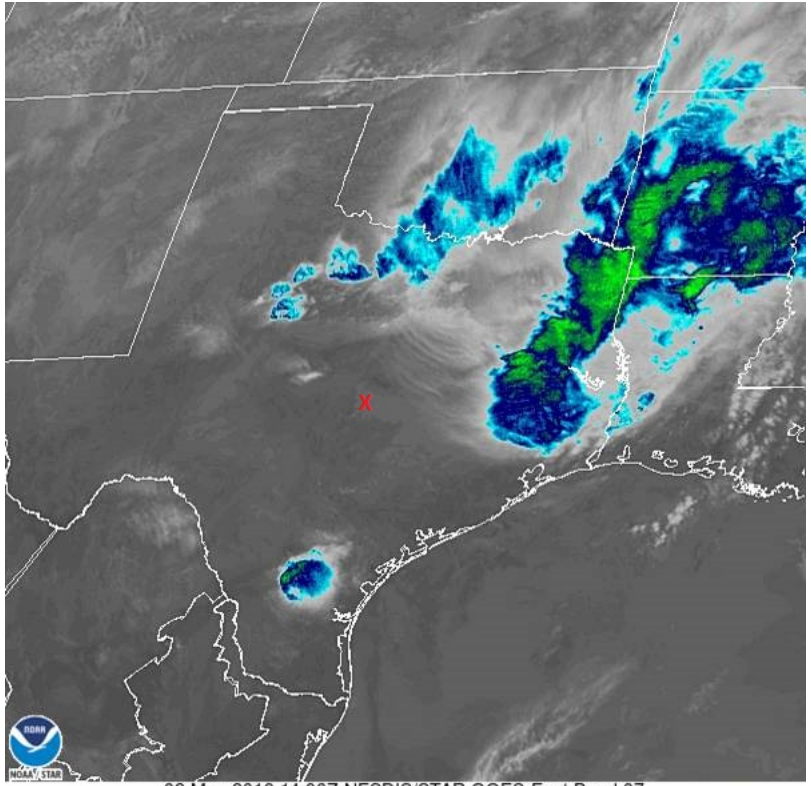
foF2 = 4.325 MHz from asymptotic o-wave



foF2 = 5.800 MHz from ???
looks like it really should be about 4.1 MHz

Recent Example – GOES Image

- GOES satellite data for 2 May 2019 at 1406z at 3.9 µm
- Austin ionosonde is the red x
- Note ripples northeast of Austin
  - Remnant of farther NE thunderstorms?
  - Austin ionosonde does not report off-zenith echoes
- Are these indicative of an AGW?
- We have more work to do!
  - Review existing research
  - Likely need LIDAR, NEXRAD and models to "see" an AGW



Model of Solar Radiation

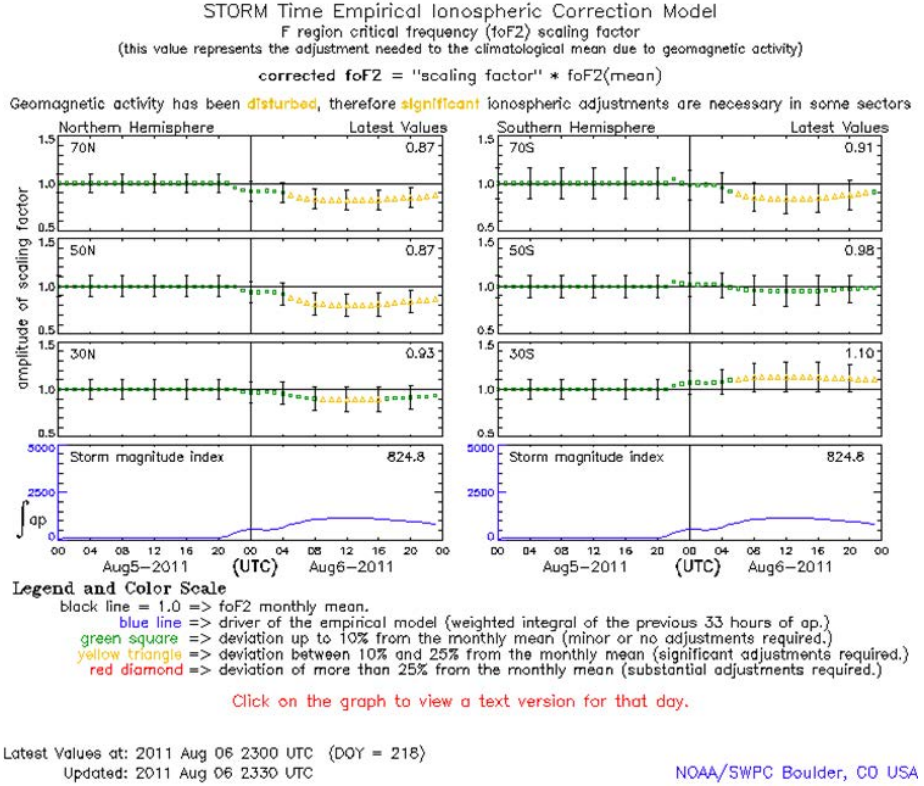
- The source that appears to contribute the least to daytime F2 region variability is the one that we know the most about

Electron density = Production – Loss + Transport

- Parameters for the model
  - sunspot number, 10.7 cm solar flux, EUV

Model of Geomagnetic Field Activity

- ICEPAC and W6ELProp allow input of a K index
  - A single K index is inadequate
- STORM model uses the last eleven K indices to predict the change in foF2
  - By hemisphere and latitude
- I believe this is the best we have at the moment
- Parameter for the model – the K index (translated to the linear 3-hr ap index)



Model of Events in the Lower Atmosphere

- We don't know how big a terrestrial event has to be to cause an AGW
- We don't know which AGWs couple up to the ionosphere
- We don't know if all AGWs cause a TID
- We don't have a parameter (or parameters) to characterize a terrestrial weather event
  - Do we have to characterize each step in the process (wx event, AGW, TID) with a parameter?
  - But what if all these processes talk to each other (are coupled)? We have to consider them all at once (whole atmosphere coupling) – this is the research community's frontier

Summary

- Three sources of F2region variability
  - Solar radiation starts the ionization process and causes a small amount of short-term variation
  - Amount of ionization is modified by geomagnetic field activity and events in the lower atmosphere coupling up to the ionosphere
- Lots of research occurring now – need to look globally
- Propagation predictions use a monthly median F2 region model
  - But it has its problems – doesn't take into account eclipses, changes in the Earth's magnetic field, global warming, the NEW sunspot numbers
- Some day we may have daily predictions using a physical model
  - The best we can do right now is to assimilate ionosonde data and TEC data into our model to give a "real-time" update – for example, GAIM (Global Assimilation of Ionospheric Measurements) by Utah State Univ