Effects on GNSS from heating using the Arecibo HF facility

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Beacon Satellite Symposium 2019

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The Heating EXperiment (HEX)

- The Heating EXperiment (HEX) was designed to help further our understanding of the phenomena caused by artificially heating the ionosphere, using the Arecibo facility in Puerto Rico.
- This was achieved by utilizing a HF measurement experiment spread over 3500 km and the deployment of a small scale travelling ionospheric disturbance (TID) network near the heater.
- Arecibo was in operation 16:00 on 13th – 06:00 20th March 2017 (LT) and 11:30 (LT) on 21st May to 08:00 (LT) on 26th May
- TID network deployed around Arecibo on 15th February 2017
- Network left running to collect background statistics (including storm data)
- Transmissions from ROTHR sites on mainland USA and Puerto Rico

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Collaborators

- QinetiQ
  - Natasha Jackson-Booth, Richard Penney, Rachel Boon, Thomas Morton-Orr, Mark Esson, Geoff Evans, Tom A Leonard
- NRL
  - Paul Bernhardt, Stan Briczinski, Eliana Nossa
- Arecibo
  - Christiano Brum, Mike Sulzer,
- APL
  - Ethan Miller

ARECIBO OBSERVATORY
PUERTO RICO
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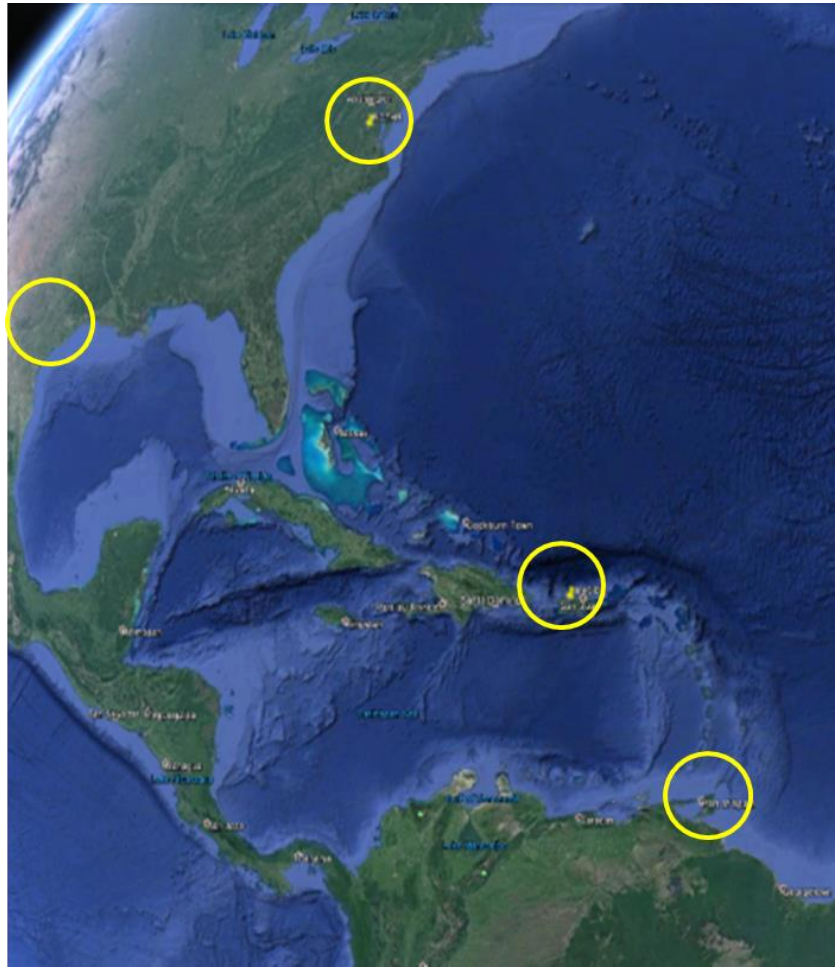
HEX Overview

- ROTHR transmitted from Virginia, Texas and Puerto Rico
- Transmissions passed through heated region of the ionosphere
- Transmissions recorded in Puerto Rico and Trinidad
- Arecibo operated throughout the week and throughout the day
- Used both 8.175 and 5.1 MHz
  - 5.1 MHz is primary mode
- Used both CW and pulses



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Deployment Overview

- TID monitor near Arecibo
- ROTHR in VA, TX and PR
- 1x RX (Trinidad)
- 1x APL RX in near Arecibo (Culebra)
- 1x NRL RX Camuy
- e-POP satellite
- ISR to provide
  - Ion lines
  - Plasma lines
  - Enhanced ion line plasma

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GNSS network

TIDs

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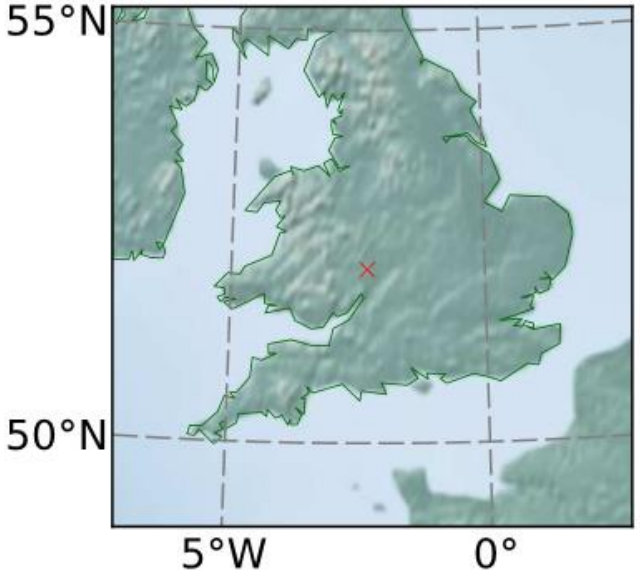
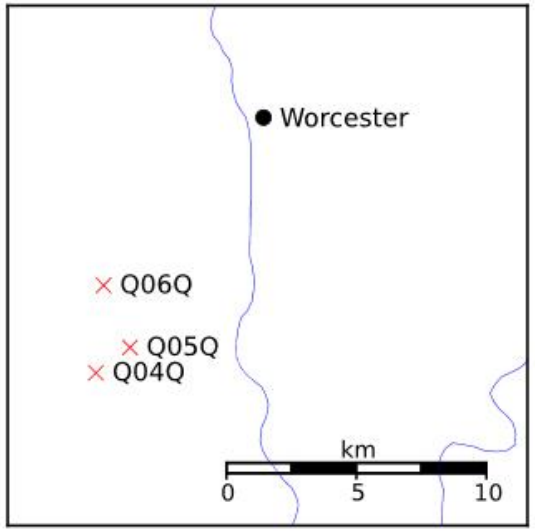
TID network

- Combining GPS data from multiple receivers allows TID speed & heading to be estimated
  - Many open challenges in “repurposing” navigation device as an ionospheric measuring system
- Dedicated array of 3 GPS receivers originally deployed around Malvern
  - 3km baseline
- Typical TID waveform will be observed with a delay of 30 s or less between pairs of receivers
- [Penney & Jackson-Booth, R.Sci., 2015]





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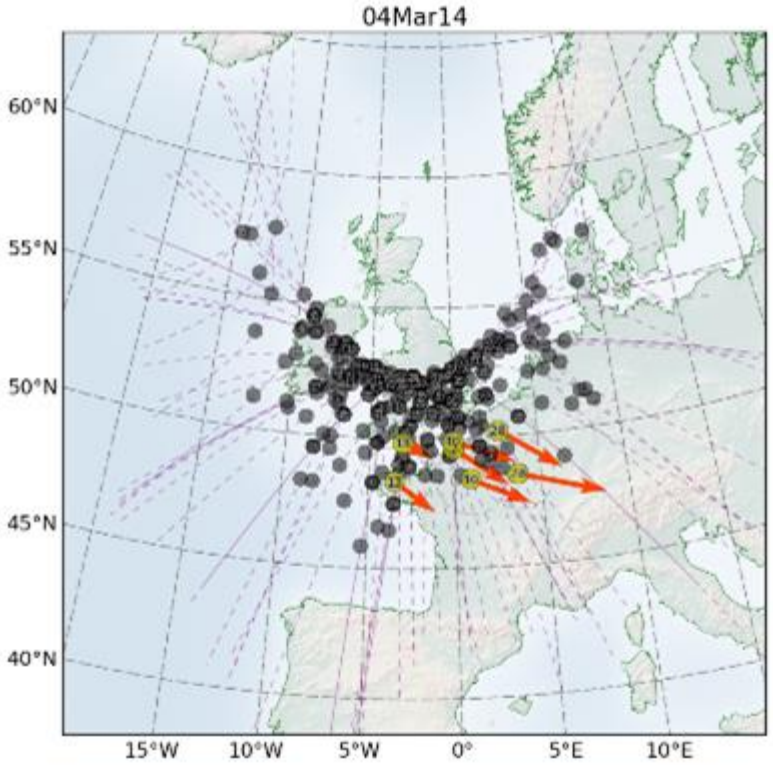
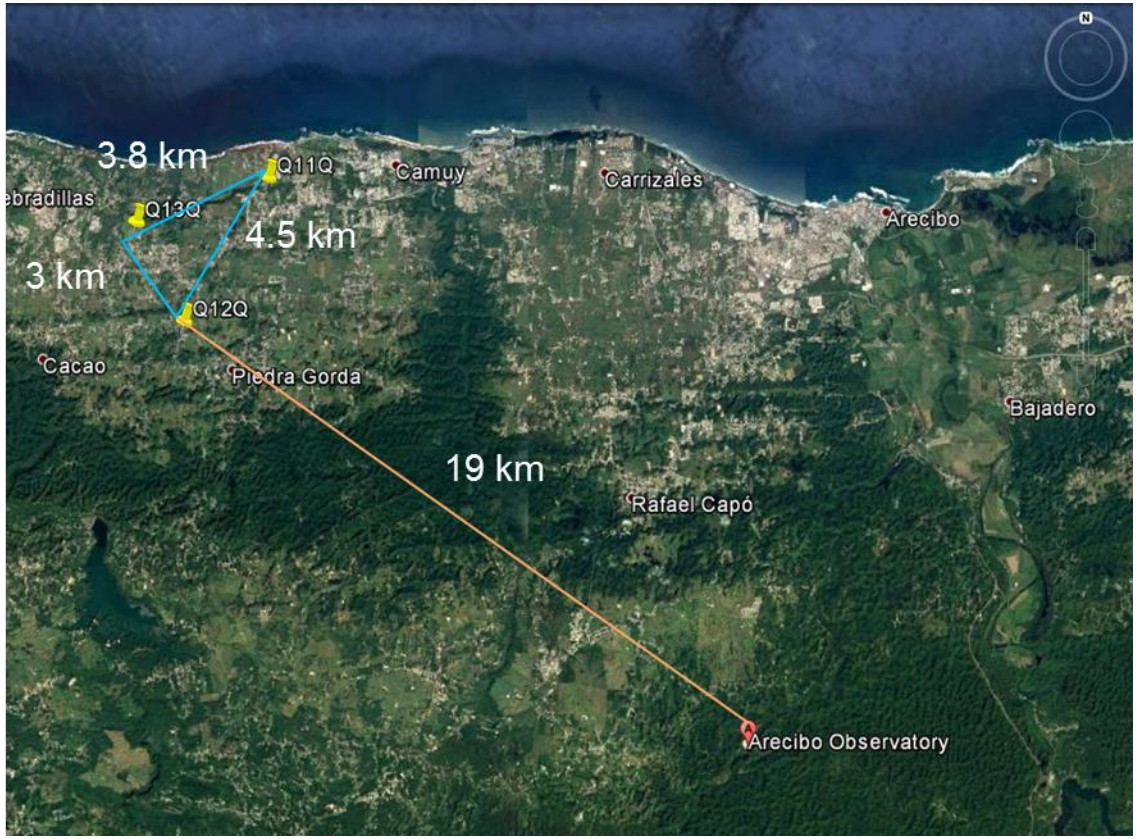
TID velocity estimates

- South-easterly TID motion at ~150 m/s is common over the UK
  - Simulation results confirm that other TID headings are correctly estimated
- Combination of TID footprint and velocity provides basic forecasting of TID effects
  - Timescale of hours, lengthscale of ~500 km



Ionospheric heating and GNSS systems

- Ionospheric heating could create disturbances that might affect satellite systems such as GPS
  - Bulk changes in electron density, and spatio-temporal variations may delay or refract GNSS signals
  - Variability in heating intensity or environmental factors may create scintillation
  - Physical mechanisms are not currently well understood
- A network of 3 multi-constellation GNSS receivers has been deployed to monitor ionospheric effects on RF signals around 1-2 GHz
  - Provides dual-frequency monitoring of GPS, GLONASS, Galileo and BeiDou at 10 Hz sample-rate
  - Allows scintillation estimate as well as TID detection



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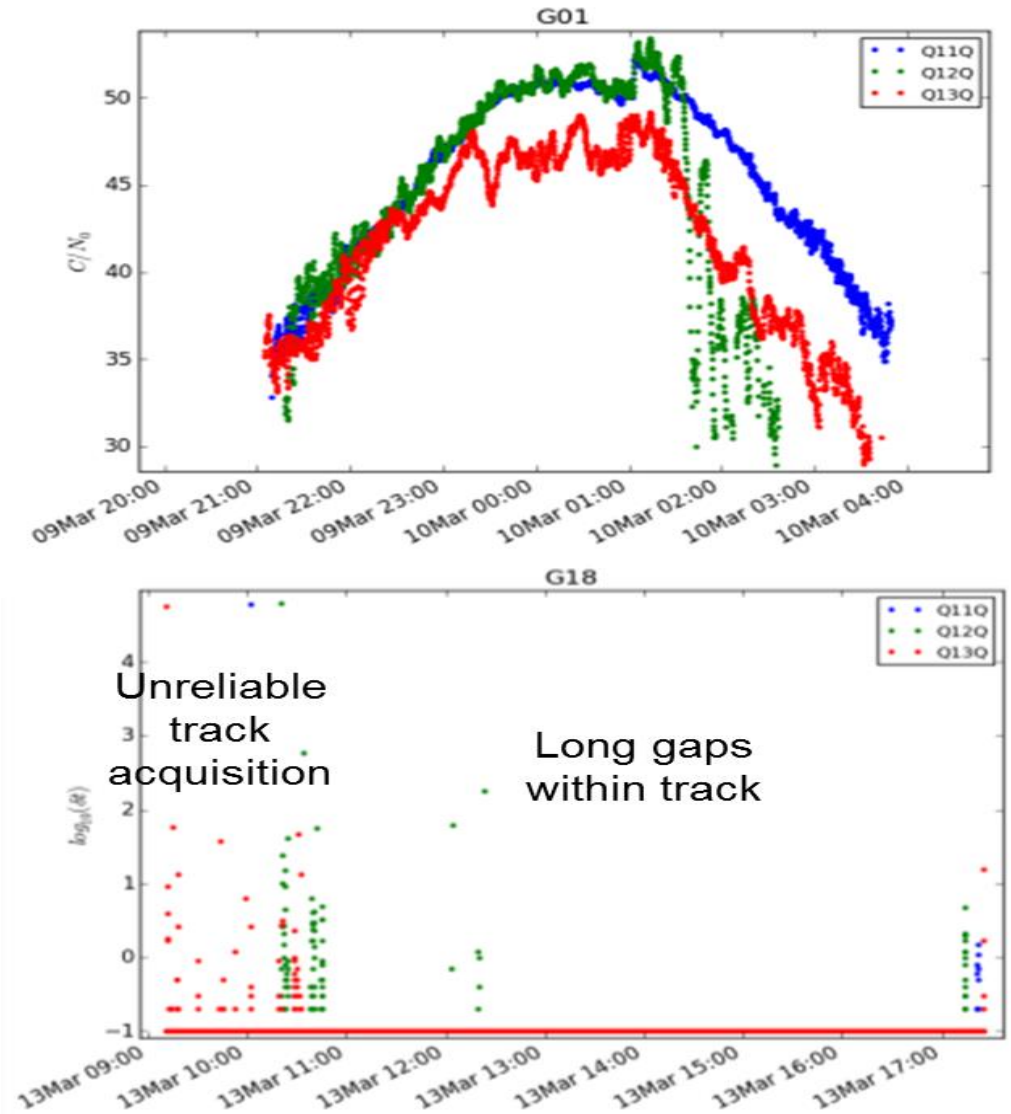
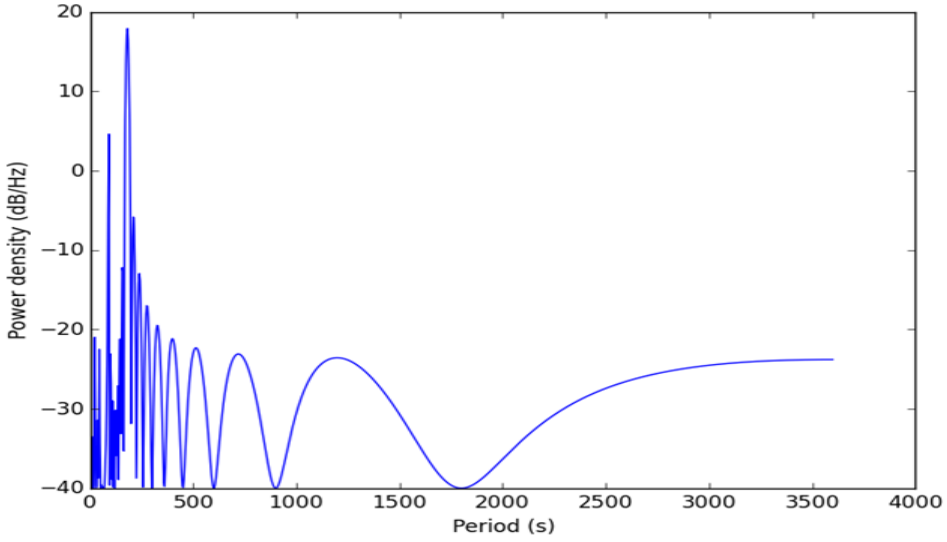
Environmental factors

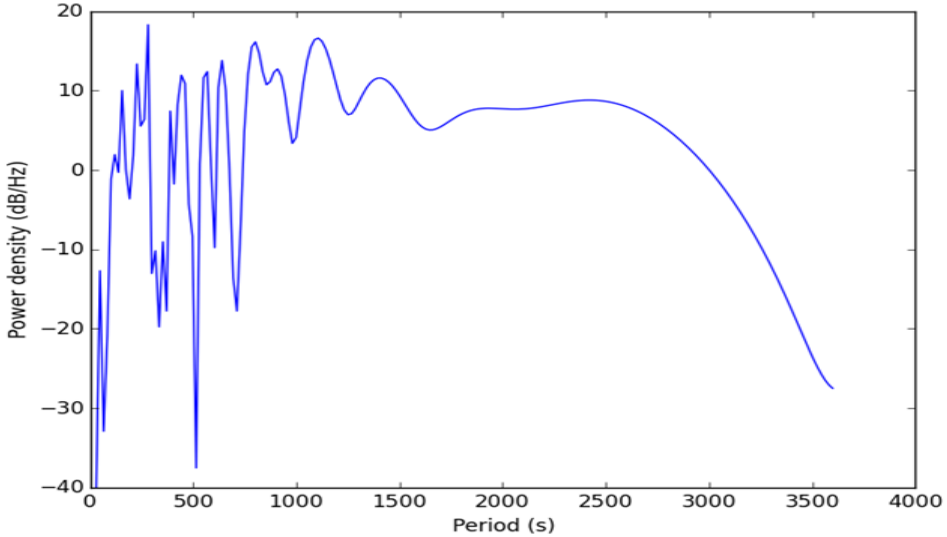
- All three GNSS receivers show much poorer data quality than observed in the UK
  - Drop-outs are much more common
  - Maintaining satellite lock over >30 minutes is challenging
- Significant differences in noise-levels are observed between the three sites
  - Q12Q significantly worse, despite many equipment changes between sites
- Inter-sample times frequently differ significantly from nominal 0.1 s, especially on Q12Q
  - Gaps of 10 s are quite common
  - Effect is not limited to satellites at low-elevations



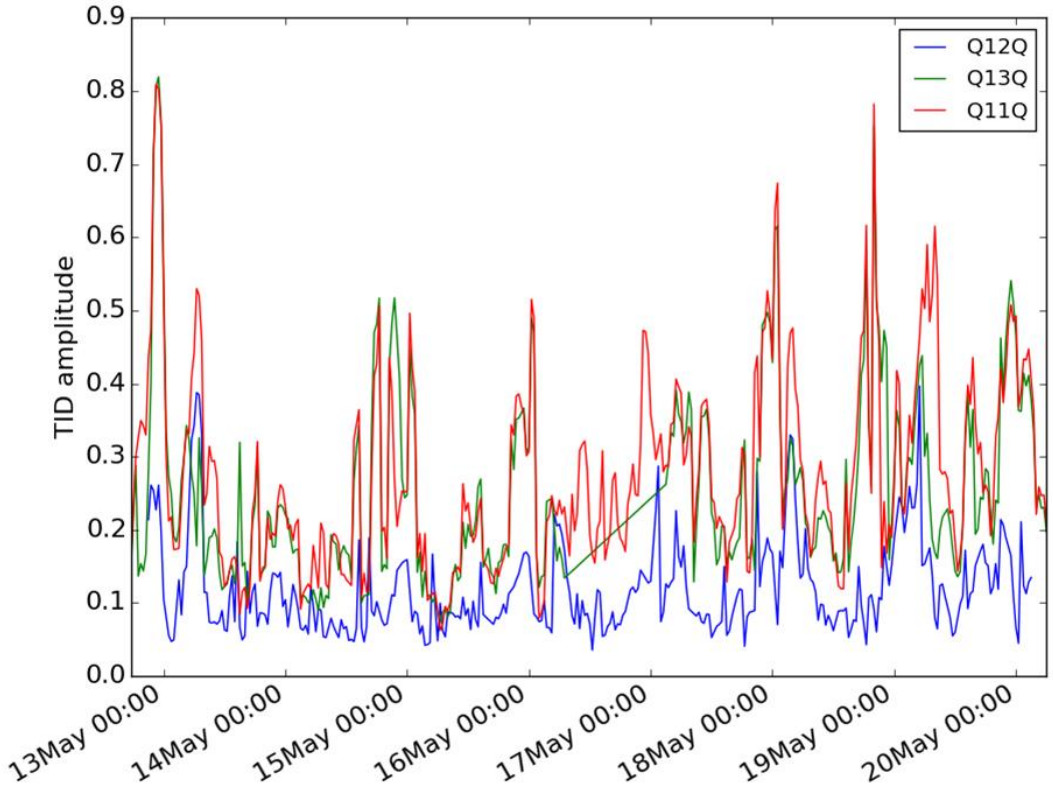
HF heater waveform optimisation

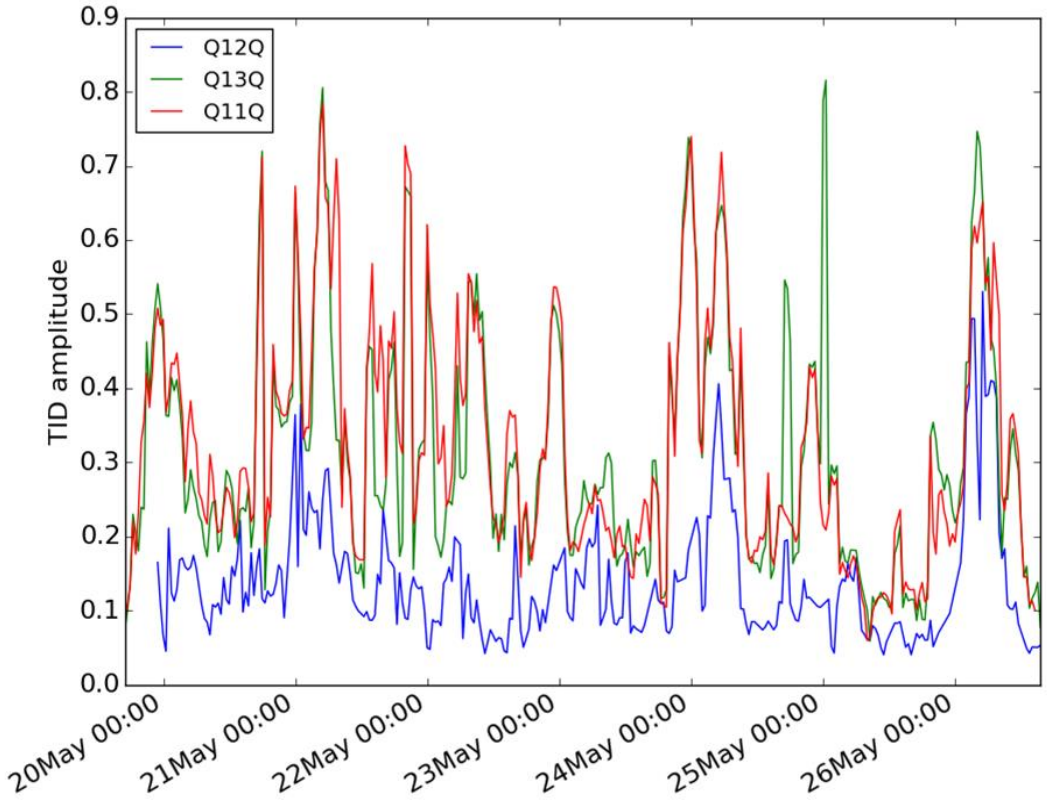
- Initial analysis shows little sign of enhanced TID activity from first set of HEX trials
- Original HEX heating waveform has most energy around 1 minute periods
- Optimal pseudo-random waveform has been designed which is more likely to excite TIDs
  - Orders of magnitude more energy around periods of 10s of minutes



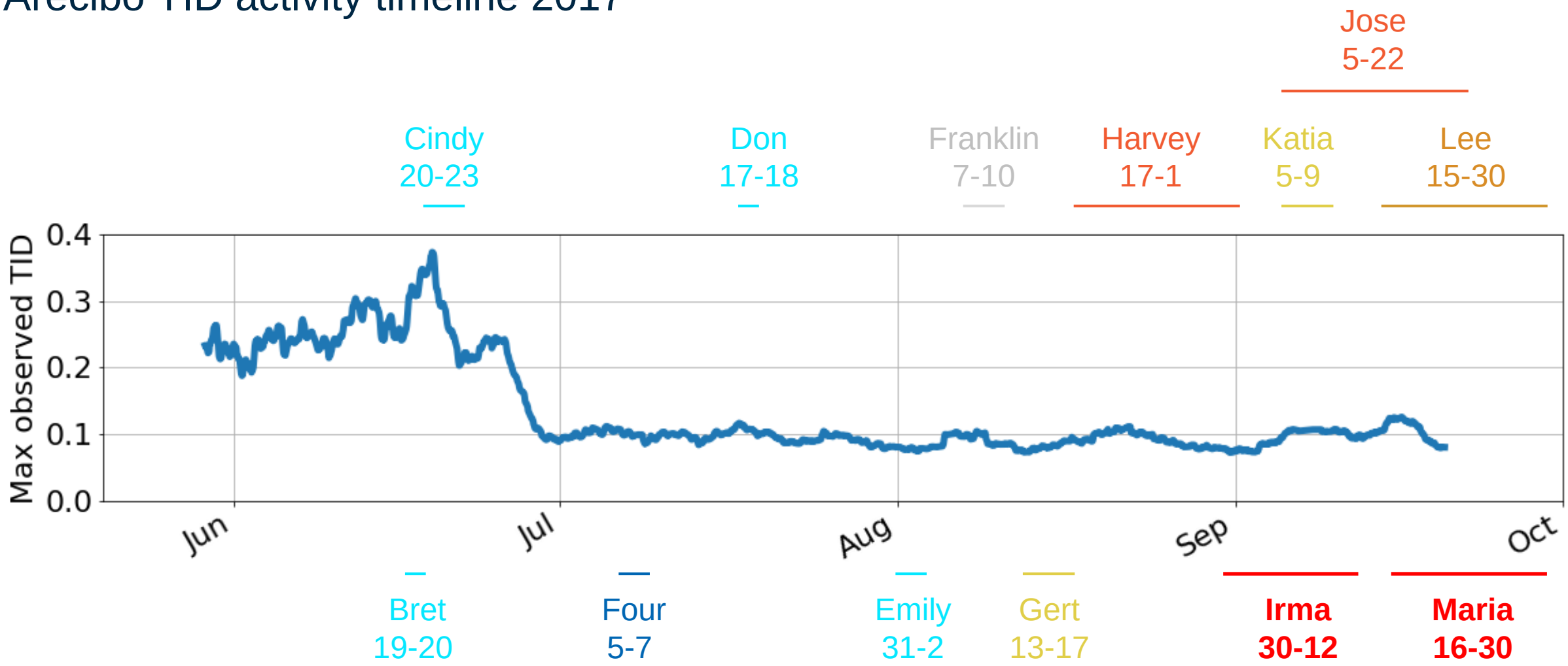


TID activity before and during May campaign





Arecibo TID activity timeline 2017



Saffir–Simpson hurricane wind scale

TD	TS	C1	C2	C3	C4	C5

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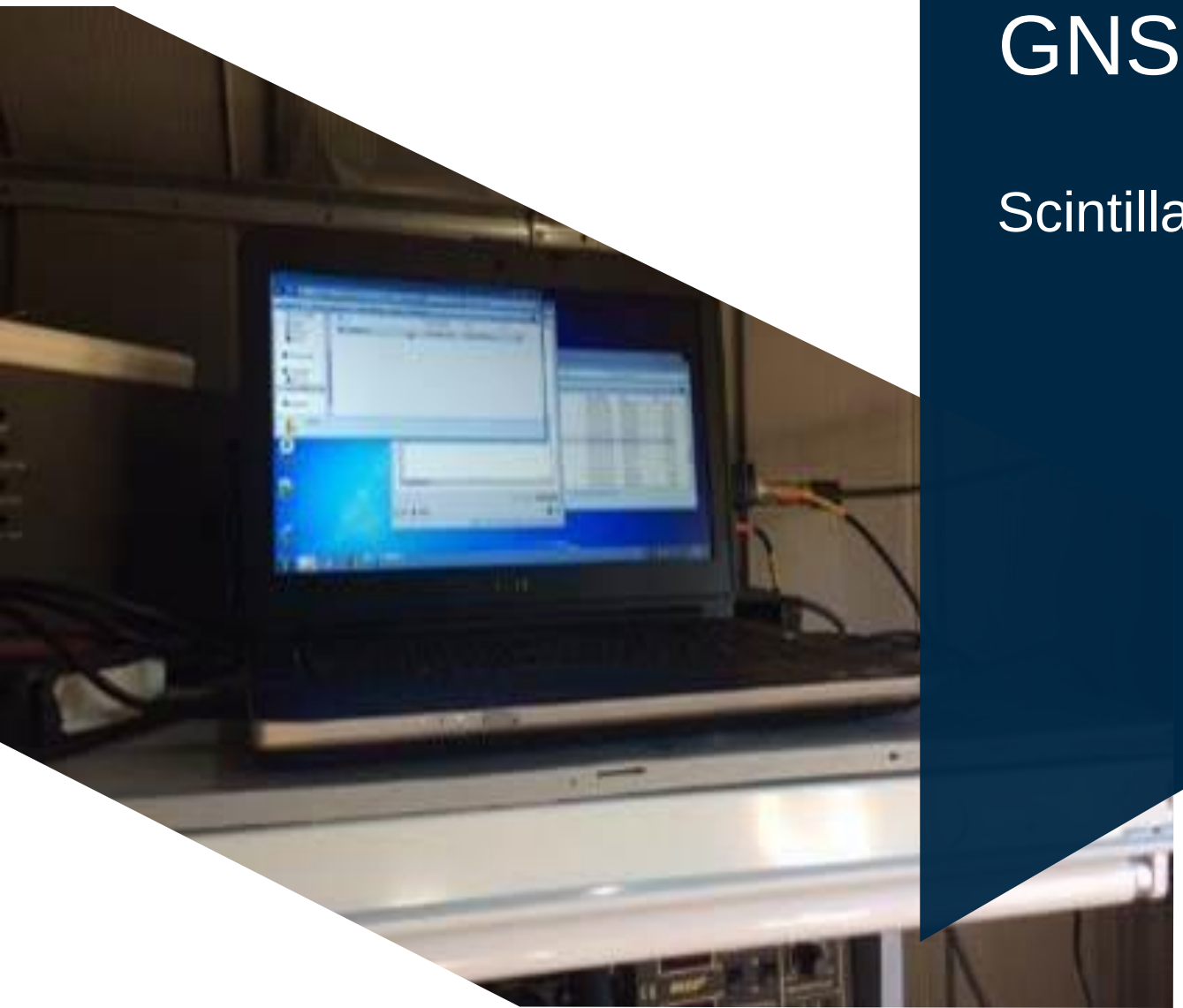

GNSS network

Scintillation

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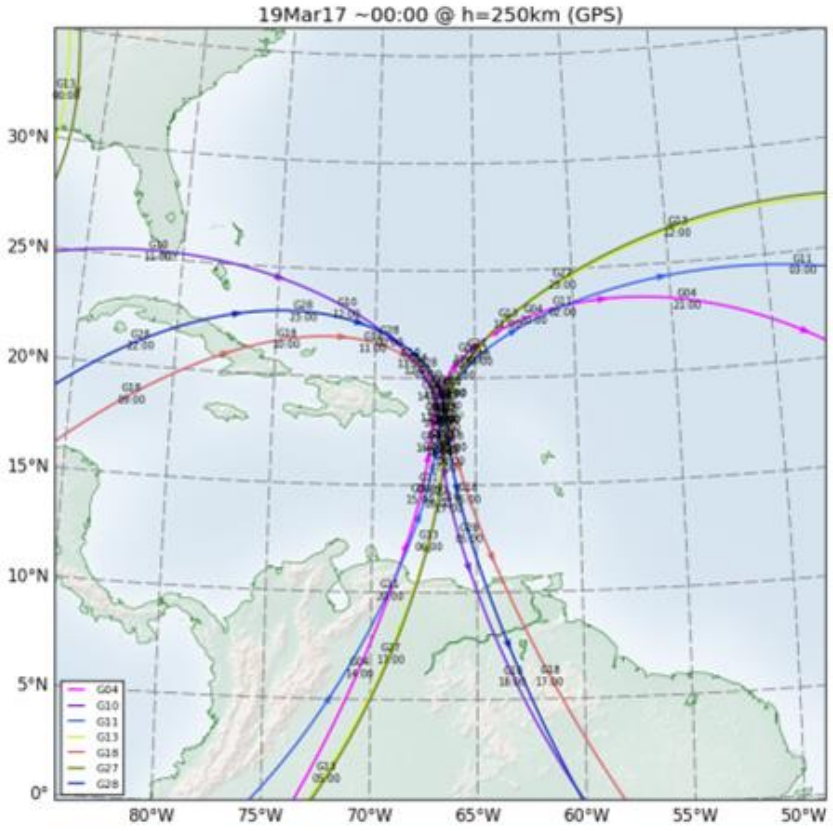
GPS orbits above Arecibo

- HEX ionospheric effects may be quite localized over the Arecibo transmitter
- Most GNSS orbits do not pass immediately overhead
- Some satellites do fortuitously pass intermittently within 10° of boresight
  - Around 20 minutes per day for small subset of satellites
  - e.g. G04, G10, G11, G13, G18, G27, G28
- Tools have been developed to identify these “magic” time-windows
  - May show clearest evidence of scintillation linked to heating



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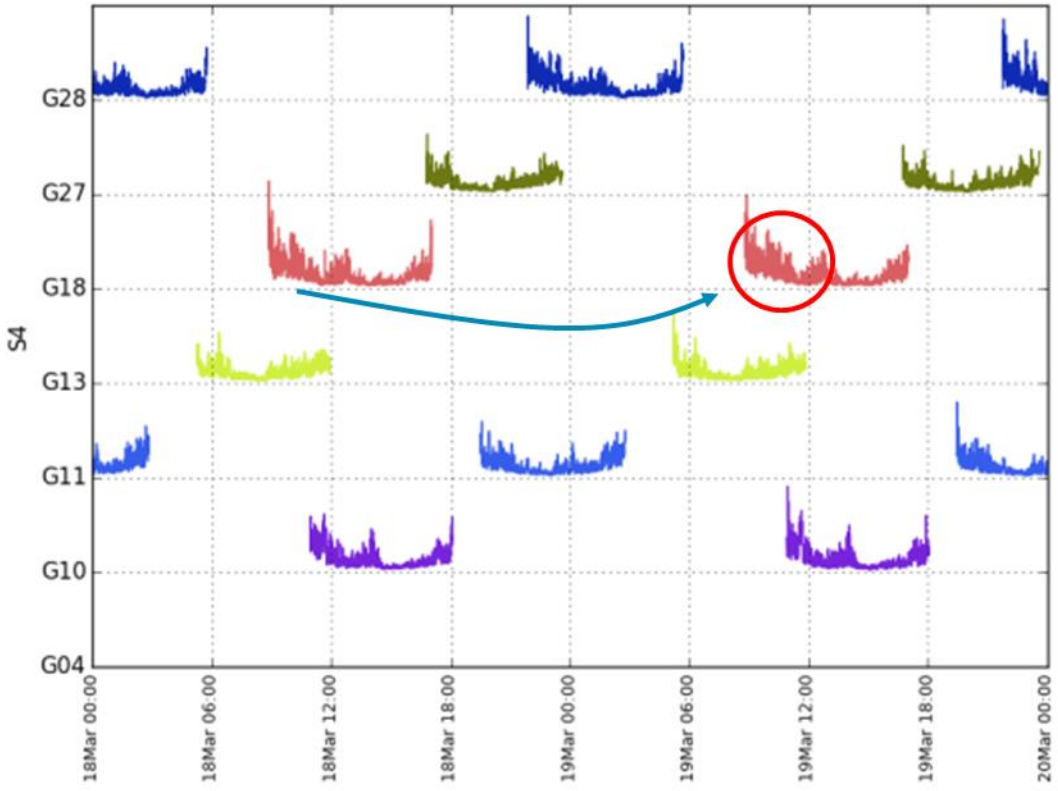
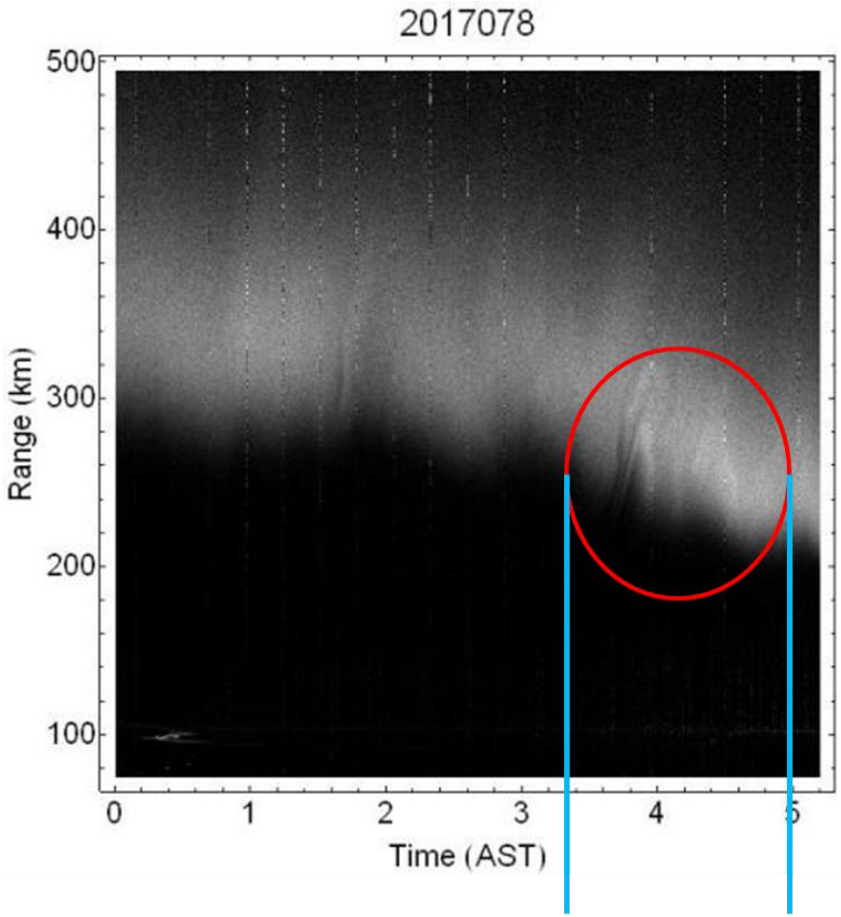
Weak evidence for increased scintillation during heating





Time coincides with activity seen in G18

Summary

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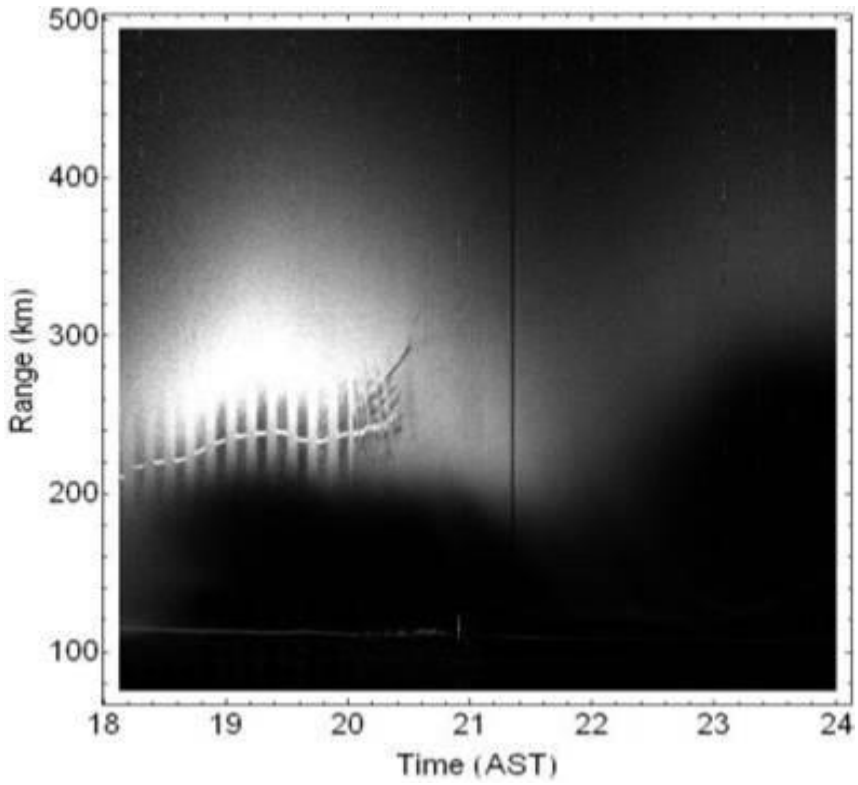
Summary

- Scintillation and TEC oscillations have been analysed for “gross” indicators of the effects of ionospheric heating
- No obvious or widespread indicators of disturbances to GPS, GLONASS, Galileo or BeiDou have been observed beyond a few hundred km of Arecibo
  - Very limited data available due to the geometry of satellite orbits
  - Very limited evidence of any statistically significant effects
- Using a modified waveform for heating shows increase in TID activity



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Questions?