QinetiQ

Preliminary results from a small scale travelling ionospheric disturbance (TID) network deployed near Arecibo as part of the Heating EXperiment (HEX)

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Collaborators and Acknowledgements

- **QinetiQ**
  - Richard Penney, Poppy Martin, Rachel Buckland, Thomas Morton-Orr
- **NRL**
  - Paul Bernhardt, Stan Briczinski
- **Arecibo**
  - Eliana Nossa, Christiano Brum, Mike Sulzer, Carlos Perez
- **APL**
  - Ethan Miller
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HEX summary

- **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)**
- **TID network deployed around Arecibo on 15th February 2017**
  - Network left running to collect background statistics
- **Transmissions from ROTHR sites on mainland USA and Puerto Rico**

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
- Used both CW and pulses

Deployment overview

- **TID monitor in near Arecibo**
- **ROTHR in VA, TX and PR**
- **1x QinetiQ IRIS2 HF RX (Trinidad)**
- **1x APL HF RX in near Arecibo (Culebra)**
- **1x NRL HF RX Camuy**
- **e-POP satellite**
- **ISR to provide**
  - Ion lines
  - Plasma lines
  - Enhanced ion line plasma

Ionospheric heating and GNSS systems

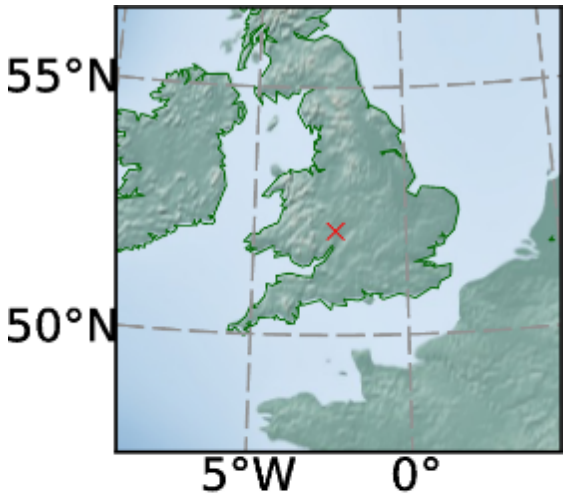
- **Ionospheric heating could create disturbances that might affect satellite systems such as GPS**
  - Bulk changes in electron density, and spatio-temporal variations may delay or refract GNSS signals
  - Variability in heating intensity or environmental factors may create scintillation
  - Physical mechanisms are not currently well understood

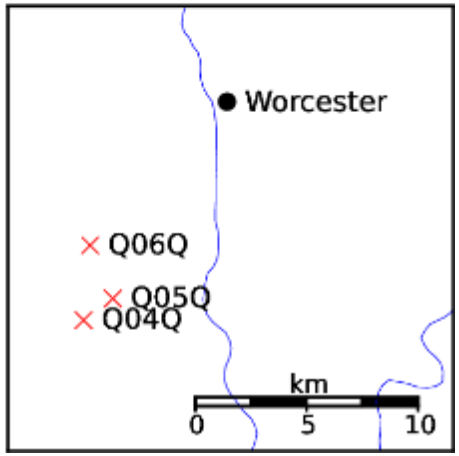
- **A network of 3 multi-constellation GNSS receivers has been deployed to monitor ionospheric effects on RF signals around 1-2GHz**
  - Provides dual-frequency monitoring of GPS, GLONASS, Galileo and BeiDou at 10Hz sample-rate

- **GNSS time-series data allows monitoring of ionospheric scintillation (S4) and travelling ionospheric disturbances (TIDs)**
  - Short timescale (<60s) fluctuations in received signal power allow computation of S4
  - Medium timescale (~1hr) fluctuations in TEC give indication of TID presence
  - Time-delay between TEC waveforms on different receivers gives indication of TID motion

“TEMPLAR” GPS network

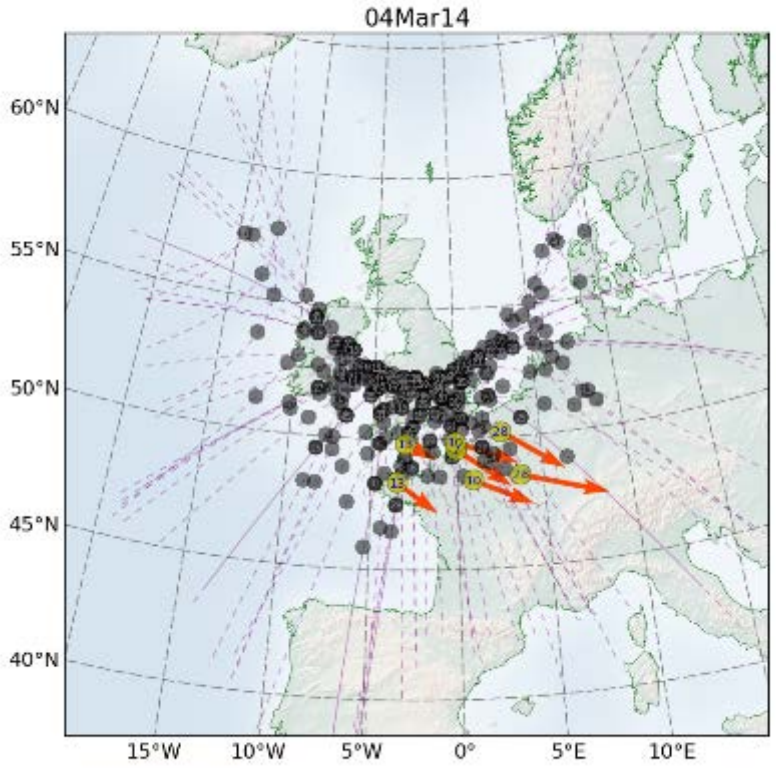
- **Project goals include:**
  - Live ionospheric monitoring from small dedicated GPS arrays
  - Detection and characterisation of TID activity over UK
  - R&D on TID analysis & forecasting techniques
- **Compact network of 3 GPS receivers deployed**
  - Semi-autonomous recording, with 3.4 km baseline
- **Each receiver station comprises:**
  - Navigation-grade COTS dual-band GPS receiver
  - GPS antenna
  - 3G WiFi dongle
  - Rubidium atomic clock
  - Control laptop + external hard drive





TID velocity estimates

- **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
- **South-easterly TID motion at ~150m/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 ~500km
- **See presentation by Richard Penney (Session 9A) for further discussion**

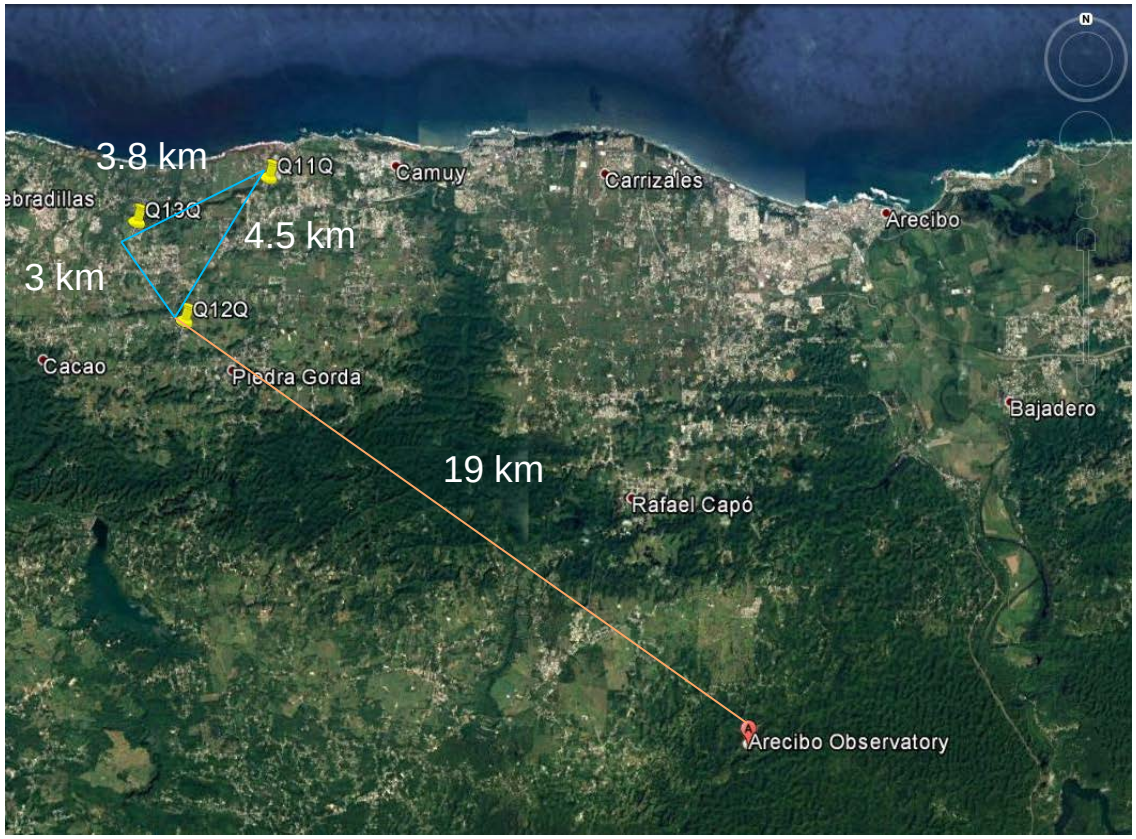


TID upgrades for HEX

- RX logger modified to record data from GPS, Galileo, GLONASS, BeiDou, Egnos, Compass, SBAS
- New pre-processor developed to utilise SBF (Septentrio Binary Format) files
- Scintillation detection

Receivers: Septentrio GPS

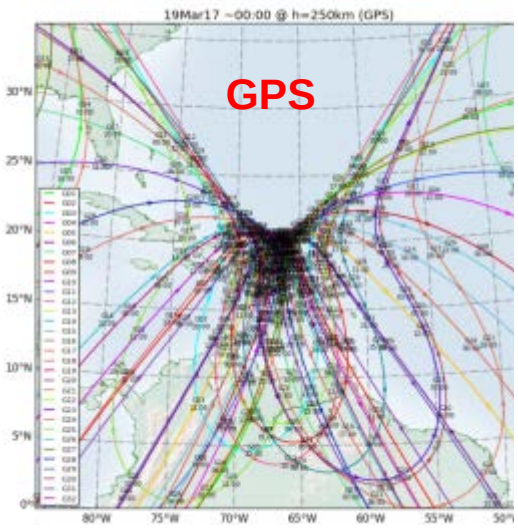
- TID network to be set up round Arecibo
- 3 x Septentrio PolaRx4Pro_SCI

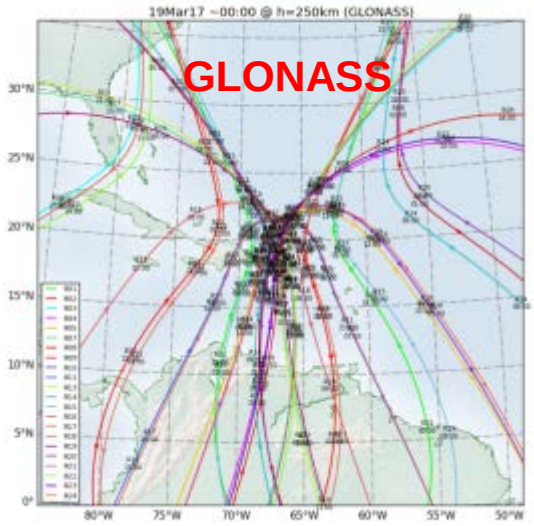


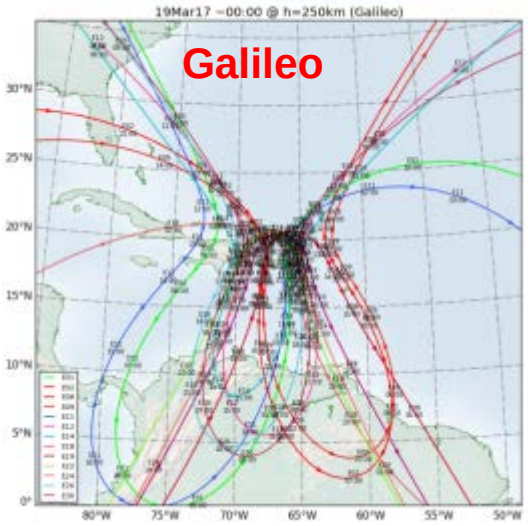
Satellite orbits

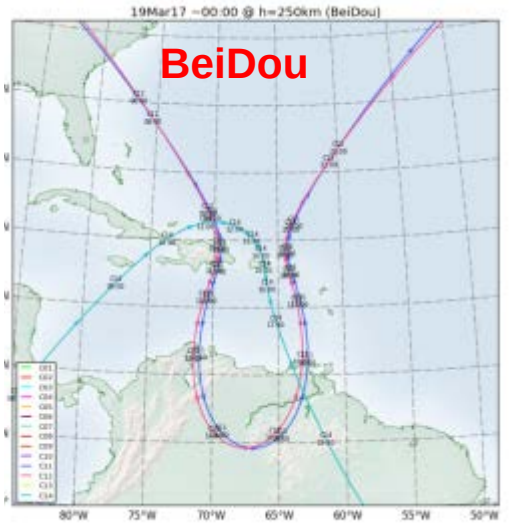
- All GNSS ionospheric measurements are constrained by the geometry of satellite orbits
- Combination of GPS+GLONASS+Galileo+BeiDou gives fairly good coverage around Puerto Rico
- All constellations have gaps in coverage due North of Arecibo

Plots show trajectories of ionospheric pierce-point at 250km altitude around 18/19 March



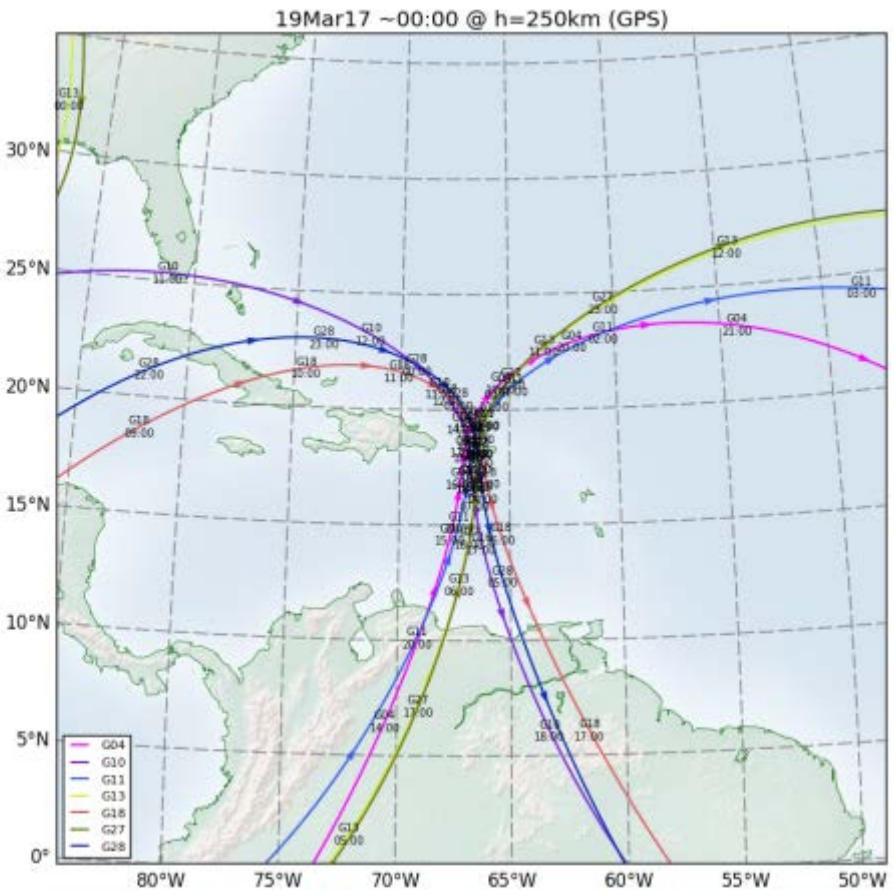






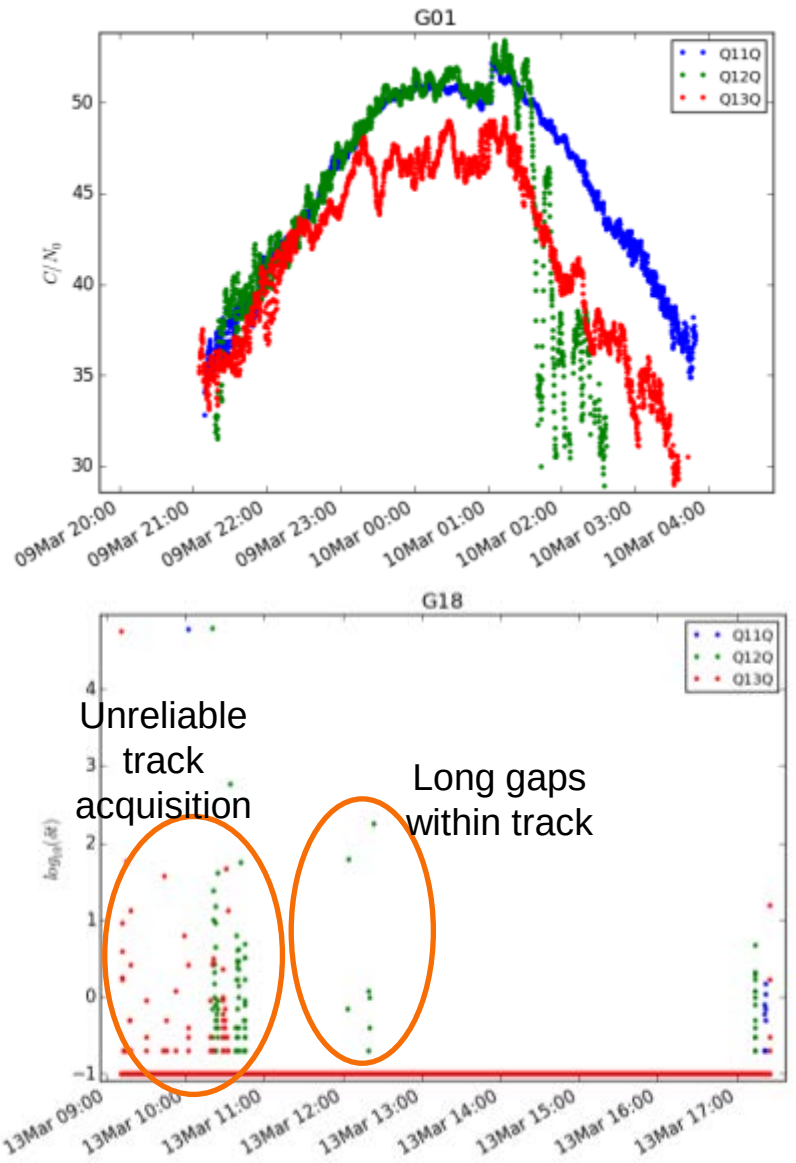
GPS orbits above Arecibo

- **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



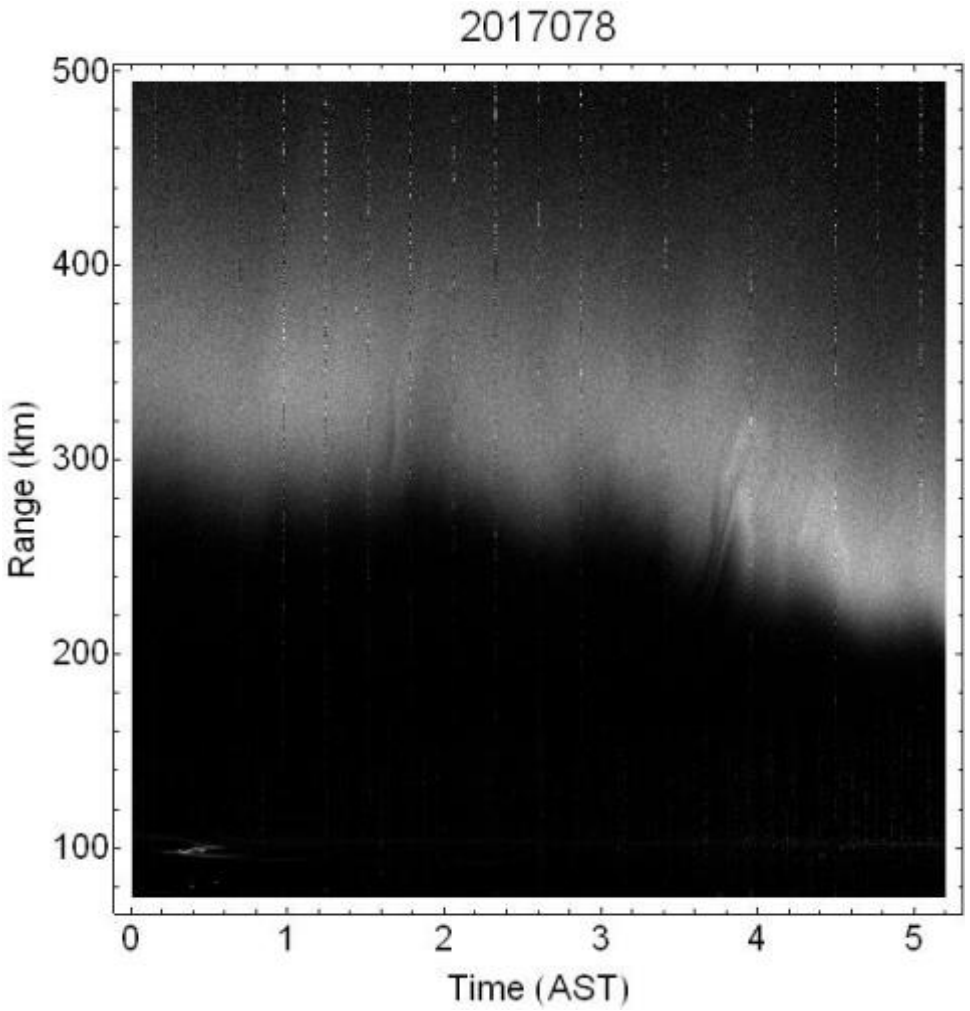
Environmental factors

- **All three GNSS receivers show much poorer data quality than observed in the UK**
  - Drop-outs are much more common
  - Maintaining satellite lock over >30minutes 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 0.1s, especially on Q12Q**
  - Gaps of 10s are quite common
  - Effect is not limited to satellites at low-elevations

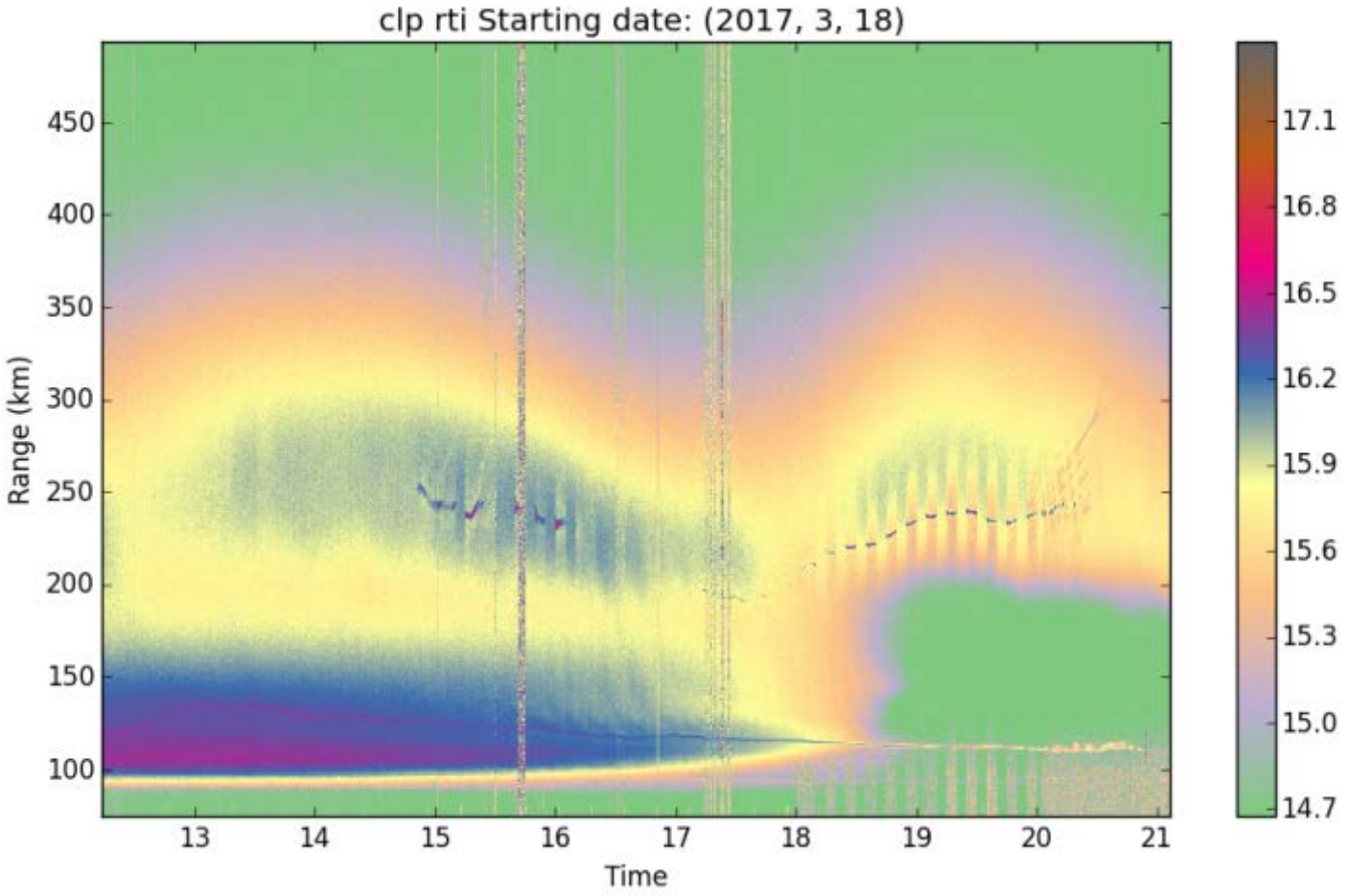


Results

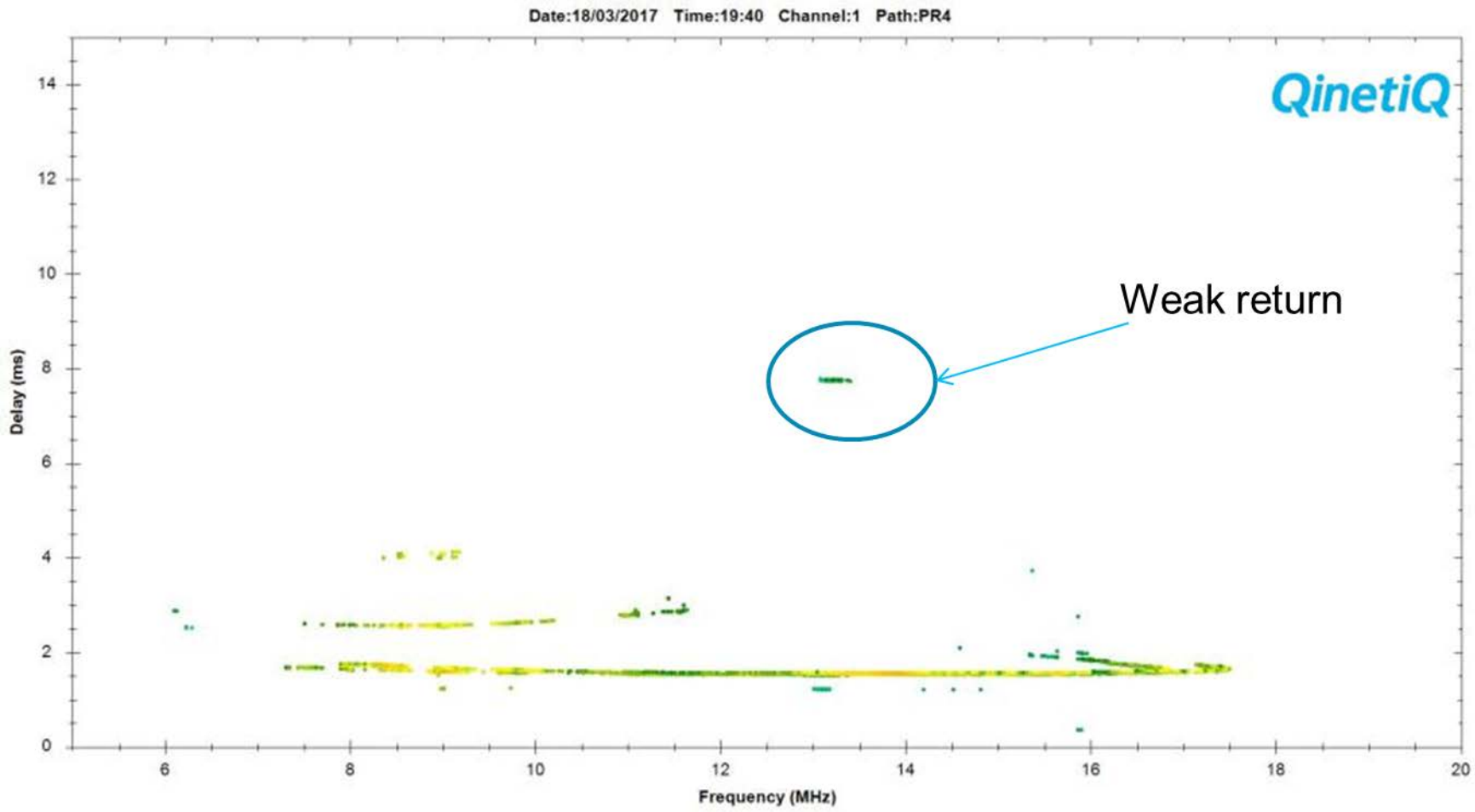
Ion Line Data Over Arecibo, 19 March 2017



Ion Line Data Over Arecibo, 18 March 2017 AST

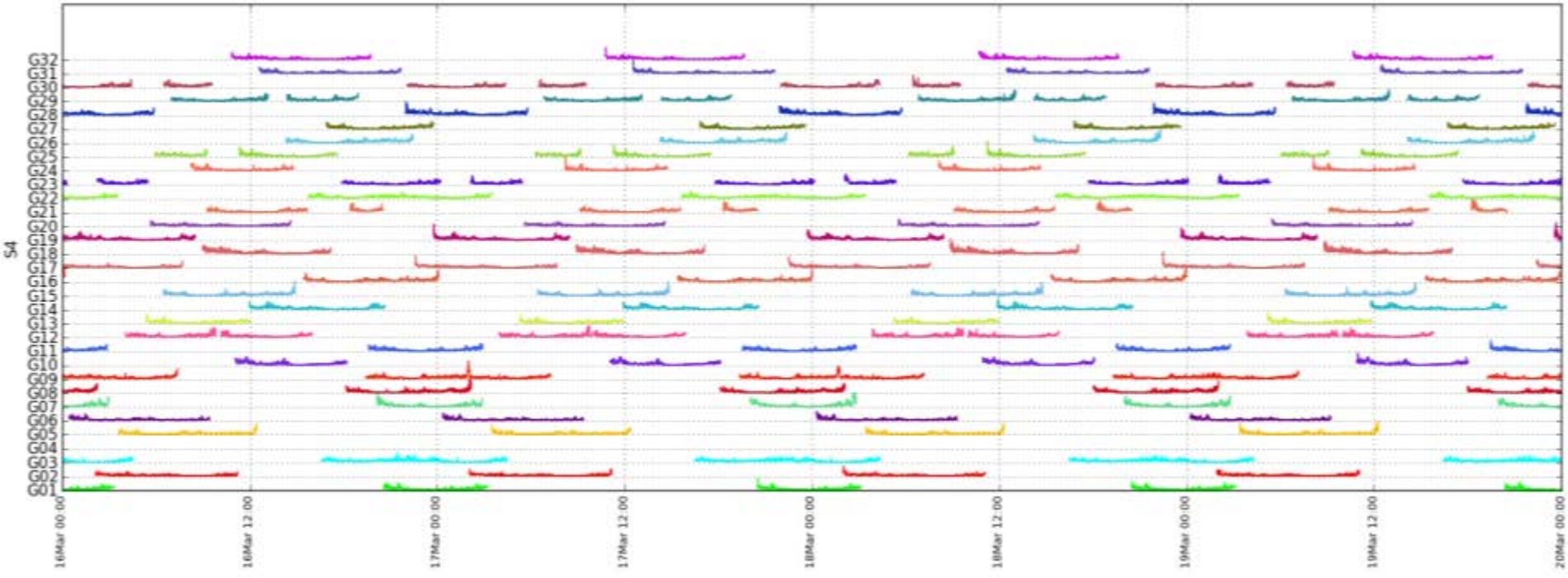


18th March – 19:43 UT Heater on 2/2 pulse: Puerto Rico to Trinidad path



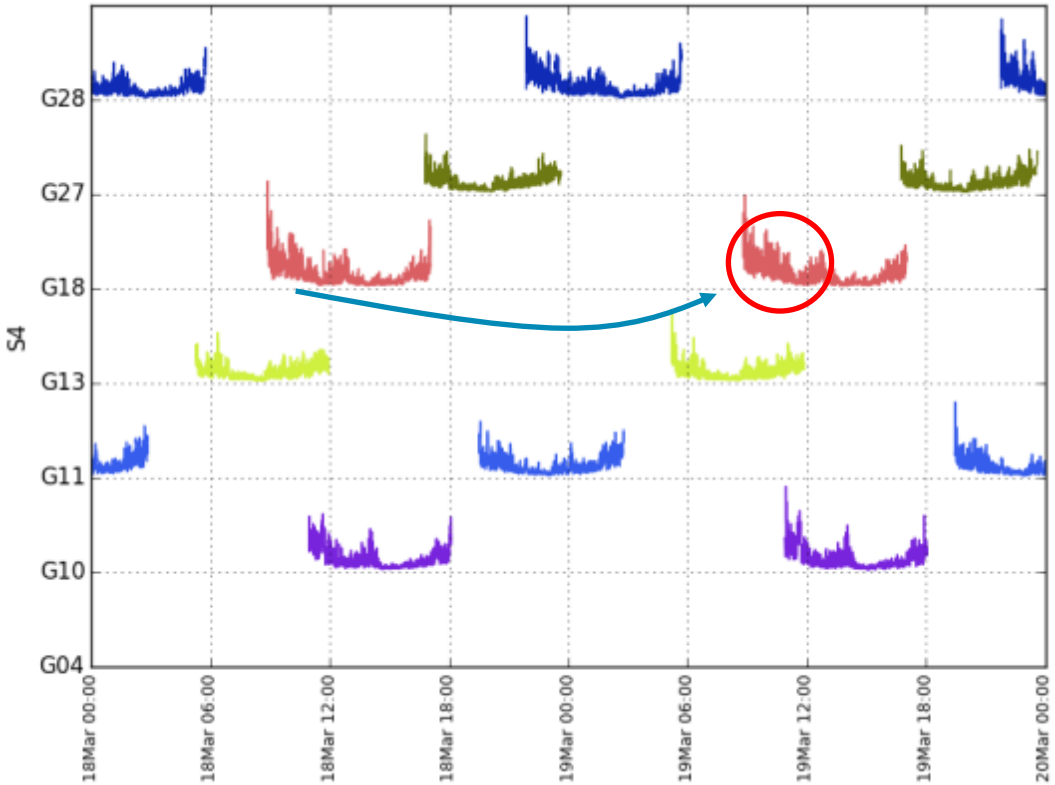
Scintillation

- **Initial attempts to find scintillation were looking for “gross” indicators that distinguish periods of heating from “ordinary” days**
- **No obvious differences seen across period of days, in any satellite constellation**

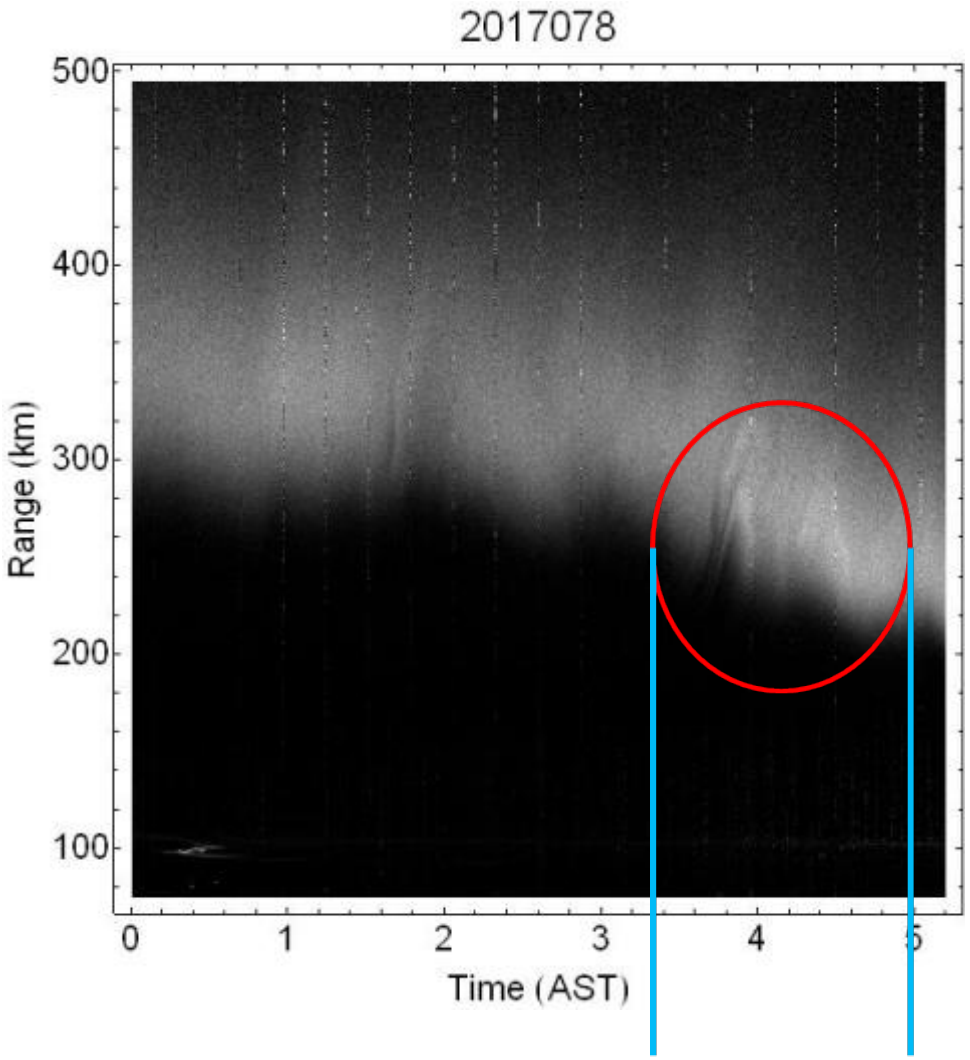


Scintillation for overhead GPS

- **Satellites that pass directly over Arecibo provide best chance of observing heating-induced scintillation**
  - Brief periods may not coincide with actual heating events
- **Possible weak effect seen on G18 around 8am 19th March (UTC)**
  - Not clear whether this is statistically significant

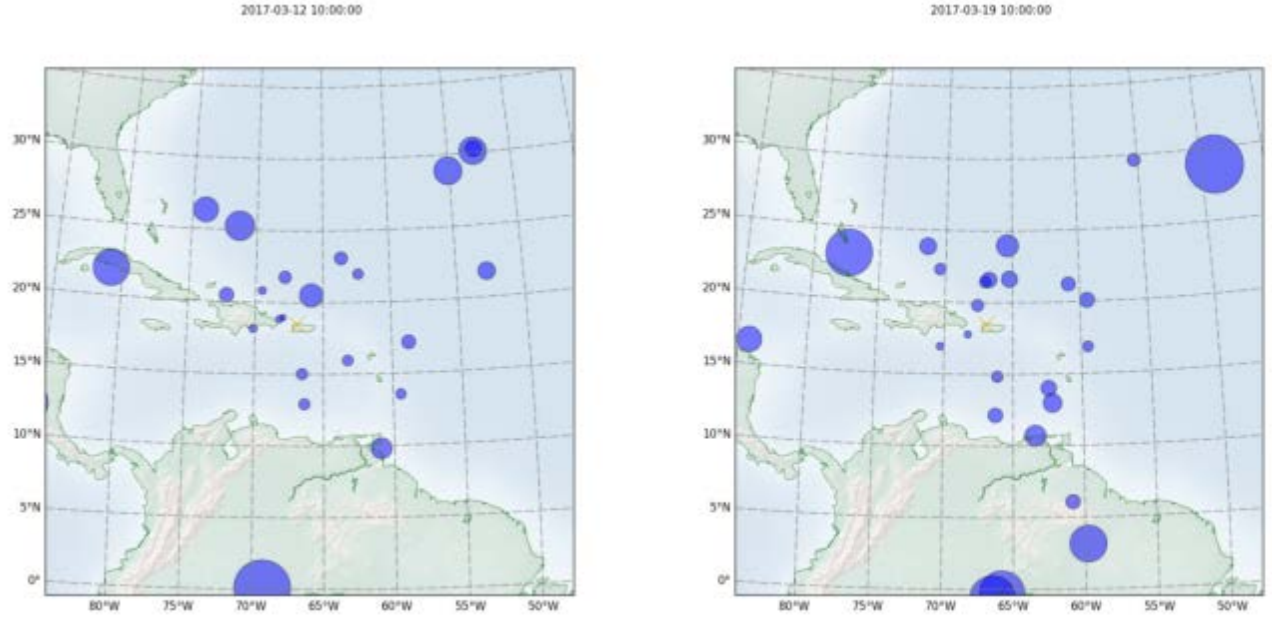


Ion Line Data Over Arecibo, 19 March 2017



Time coincides with activity seen in G18

Spatial distribution of S4

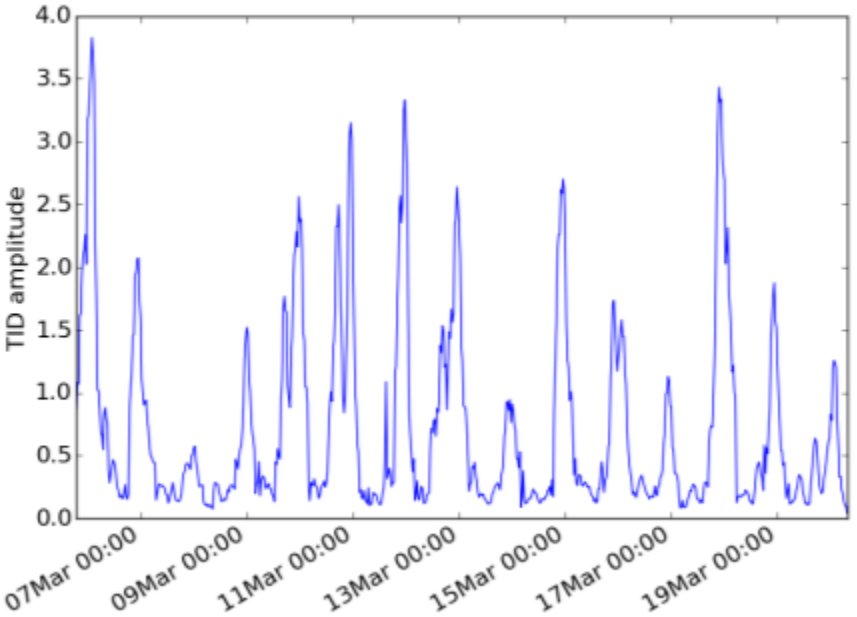


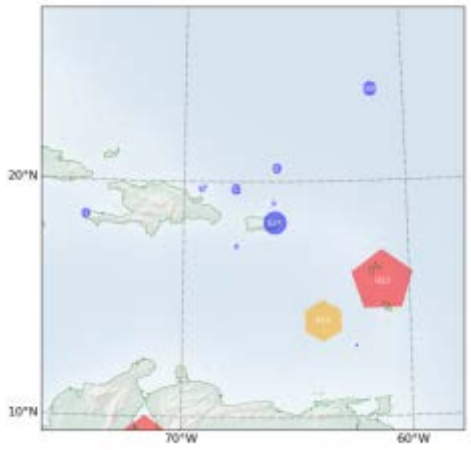
- **Fusing satellite orbits with S4 time-series gives an indication of the spatial distribution of scintillation around Puerto Rico**
  - Circle centres give ionospheric pierce-point locations
  - Circle diameters are proportional to S4

- **Again, few marked differences from the week preceding main HEX experiment**
  - Plots at 15-minute intervals show little qualitative difference from one week to the next

Travelling Ionospheric Disturbances (TIDs)

- **TEC time-series have been analysed to find evidence of wave-like ionospheric disturbances**
  - Oscillatory deviations from background trend give indication of presence of TID
  - TID amplitudes typically largest around midday local-time
- **TID activity is significantly larger than observed over the UK**
- **Again, little obvious signs of effects from Arecibo heater**





Conclusions

- **Large volumes of multi-constellation GNSS data has been analysed for signs of ionospheric disturbances relevant to GPS or similar satellite systems**
  - ~300GB of data in ~2500 files covering ~66 satellites
- **Scintillation and TEC oscillations have been analyses 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**
- **There remains some possibility of more localized, but still weak, effects immediately over the Arecibo transmitter**
  - Very limited data available due to the geometry of satellite orbits
  - Very limited evidence of any statistically significant effects from initial analysis

Questions?