Effects on GNSS from heating using the Arecibo HF facility

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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
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
HEX Overview

- ROTHRR 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
Deployment Overview

- TID monitor near Arecibo
- ROTH 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
GNSS network

TIDs
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]
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 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
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

Cindy
20-23

Don
17-18

Franklin
7-10

Harvey
17-1

Katia
5-9

Lee
15-30

José
5-22

Max observed TID

Bret
19-20

Four
5-7

Emily
31-2

Gert
13-17

Irmá
30-12

Maria
16-30

Saffir–Simpson hurricane wind scale

TD TS C1 C2 C3 C4 C5
GNSS network

Scintillation
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
Weak evidence for increased scintillation during heating
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
Questions?