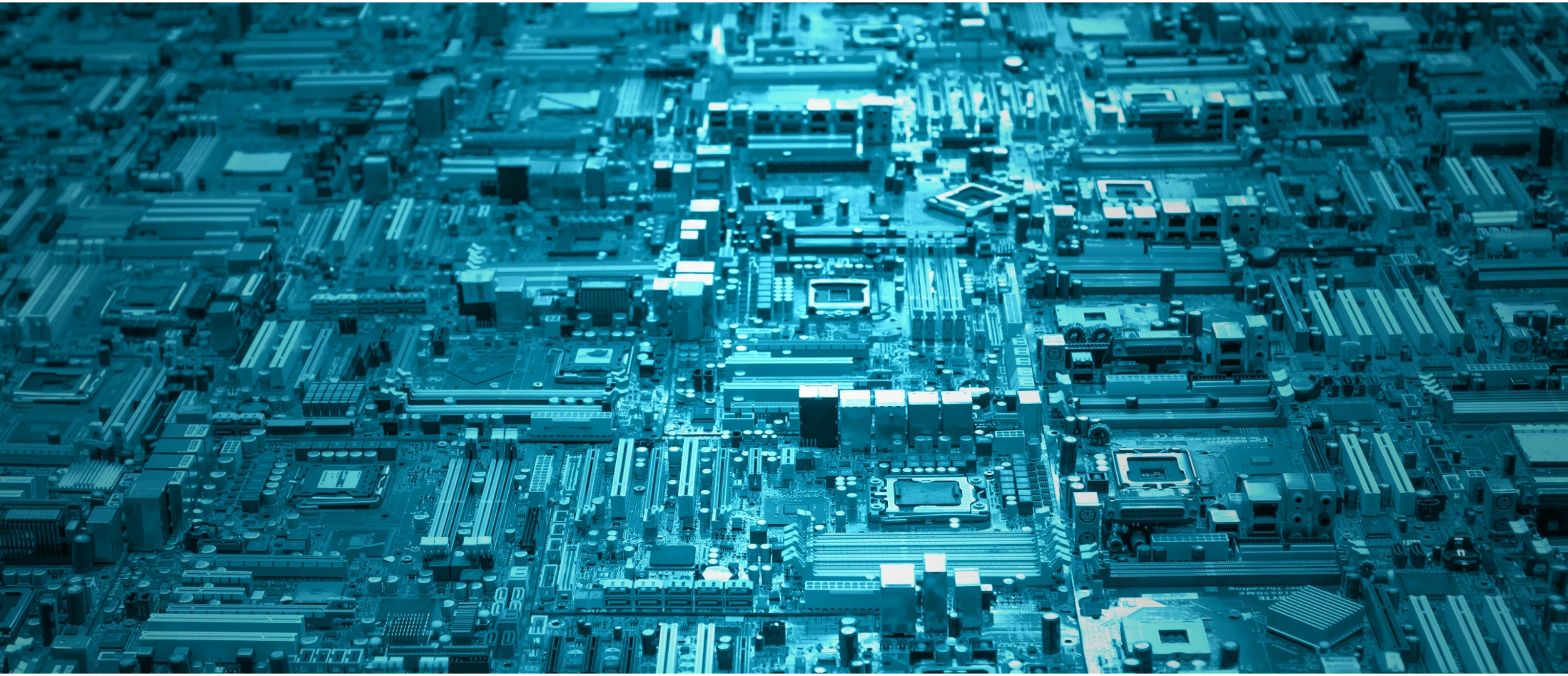

Summary of Findings Associated with the 5 MHz Experiment

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Space Weather Knowledge Exchange Workshop: 'HAMSCI UK'

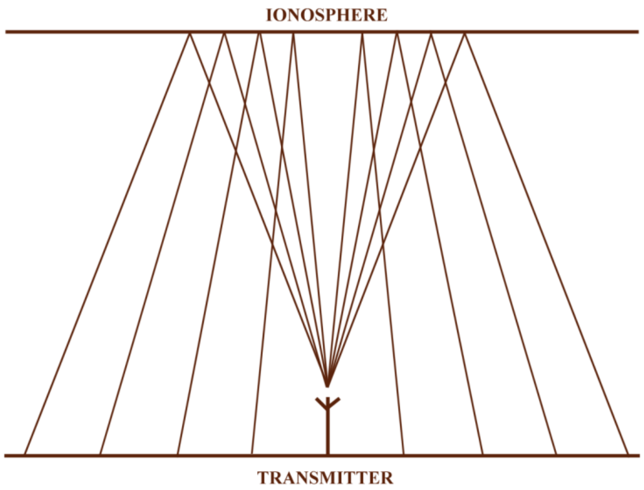
13 October 2017

Overview of Presentation

- Introduction
- The 5 MHz Experiment
- Findings to date
  - Ordinary and extraordinary wave propagation
  - Signal power measurements versus HF propagation predictions
  - Ionosonde measurements versus HF propagation predictions
  - VOACAP sanity check for NVIS links
  - Above-the-MUF loss measurements versus ITU-R model
- Summary

Introduction

- NVIS: Near-Vertical Incidence Skywave
- HF ionospheric propagation technique
- Low HF frequencies (typically 2–10 MHz)
- High angle radiation
- Short ranges (up to 500 km)
- No skip zone
- Terrain insensitive



NVIS Users

- Military
  - Tactical communications
- Humanitarian
  - Aid agencies
  - Governmental
- Amateur radio
  - Humanitarian support (e.g. disaster relief)
  - Military support (e.g. Military Auxiliary Radio System in USA)

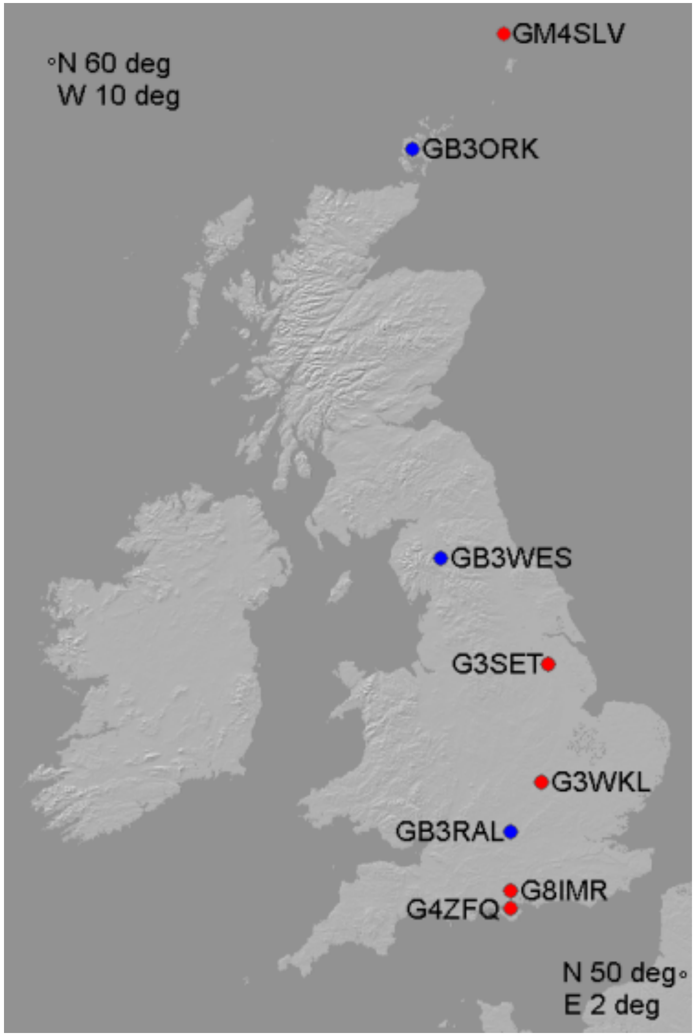
The 5 MHz Experiment

- Initiated in 2002
- UK MoD and Ofcom allow amateurs access to some 5 MHz channels
- Radio Society of Great Britain (RSGB) launch 'The 5 MHz Experiment'
- Encourage antenna and propagation experiments
- Beacon network established
- Large database of automatic beacon measurements

Transmitter and Receiver Locations

- 3 transmitters
- 5 receivers
- 9 NVIS links < 500 km

Station	Great-Circle Range (Bearing)		
	GB3RAL	GB3WES	GB3ORK
G3SET	210 km (14°)	189 km (133°)	646 km (164°)
G3WKL	70 km (33°)	302 km (154°)	785 km (167°)
G4ZFQ	92 km (181°)	435 km (168°)	929 km (172°)
G8IMR	74 km (180°)	418 km (167°)	911 km (171°)
GM4SLV	968 km (0°)	639 km (6°)	170 km (34°)

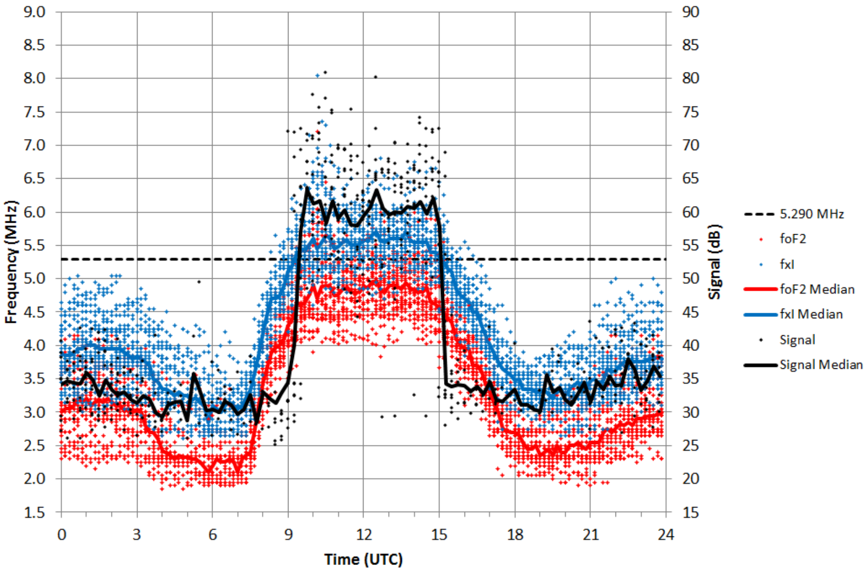


Overview of Transmitters and Receivers

- Transmitters
  - Operating frequency: 5.290 MHz
  - Peak conducted power: 10 W
- Receivers
  - Direct conversion (zero-IF) without AGC
  - Calibrated for signal power
- Antennas
  - Dipoles (inverted-V, asymmetric), small loops
  - Simulated using NEC-2 with ground loss

Findings (1)

- Beacon measurements show NVIS propagation when none might be expected based on current practical NVIS literature
- Practical significance of extraordinary wave propagation for NVIS links
  - ‘Rediscovered’
  - Long understood in:
    - Ionospheric physics
    - HF propagation predictions



Reference:

M. C. Walden, "The extraordinary wave mode: Neglected in current practical literature for HF NVIS communications", IET 11th International Conference on Ionospheric Radio Systems and Techniques (IRST 2009), Edinburgh, UK, 28-30 April 2009. doi:10.1049/cp.2009.0028

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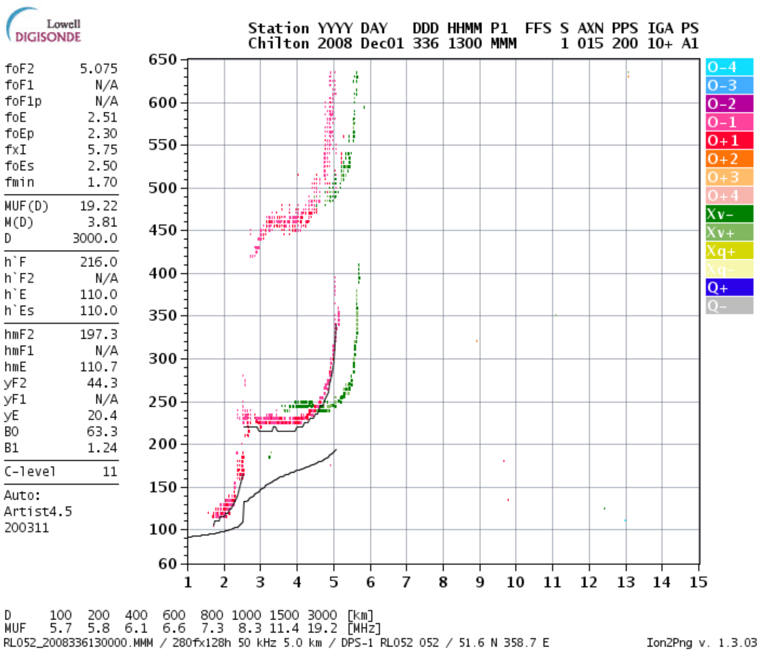
Critical Frequencies (1)

- Two characteristic waves propagating through ionosphere
  - Ordinary wave (red trace)
  - Extraordinary wave (green trace)
- F2 region has two critical frequencies
  - foF2
    - Related to peak electron density in F2 region
  - fxF2
    - Effect of Earth's magnetic field
- fxF2 is maximum frequency



Critical Frequencies (2)

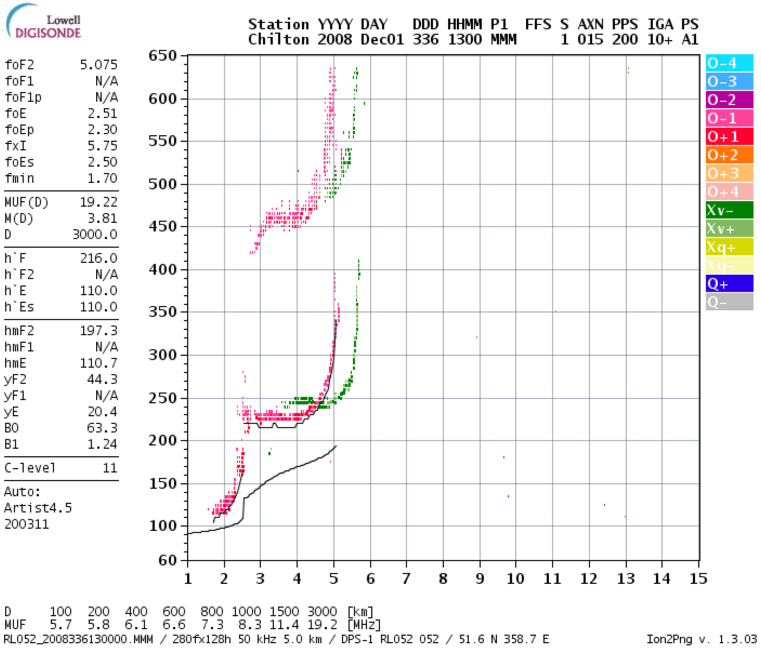
- Critical frequencies related through electron gyrofrequency f_H
  - Exact:

$$foF2^2 = fxF2^2 - fxF2 f_H$$

  - Approximate:

$$fxF2 - foF2 \approx \frac{f_H}{2}$$

- $f_H \approx 1.4$ MHz over UK
  - $f_H/2 \approx 700$ kHz
- Ionogram fxI used in lieu of fxF2



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MUF

- MUF - Maximum useable frequency
  - MUF ambiguous in current HF usage
  - Context dependent
- Instantaneous MUF
  - Maximum observed frequency (MOF) at given time and date
  - e.g. Digisonde MUF at measurement time for different distances
- Monthly median MUF
  - HF propagation predictions give monthly median MOF for given time and date (e.g. VOACAP)

Findings (2)

- Beacon measurements compared with ASAPS and VOACAP signal-level predictions during solar minimum
  - Small RMS difference during September, October, November and March
  - Large RMS difference during winter and spring/summer
    - Anomalously high absorption associated with the winter anomaly
    - Sporadic E during summer

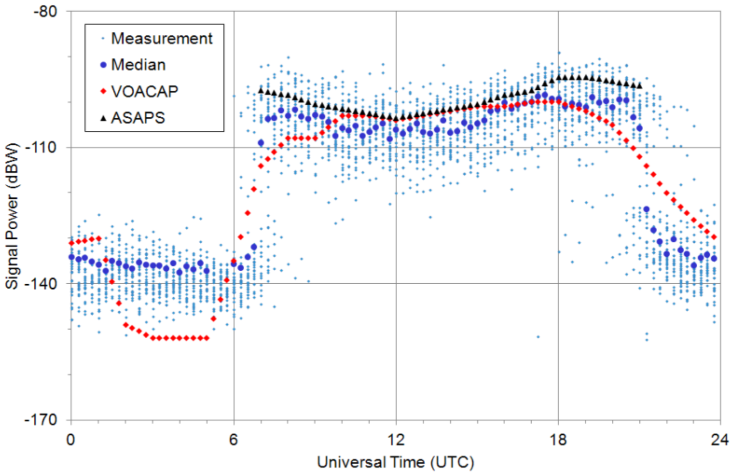
References:

M. C. Walden, "Comparison of propagation predictions and measurements for midlatitude HF near-vertical incidence sky wave links at 5 MHz", Radio Science, 2012. doi:10.1029/2011RS004914

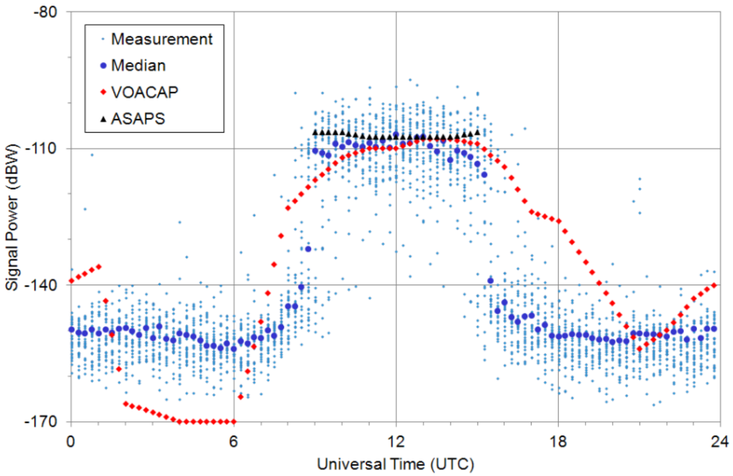
M. C. Walden, "Comparison of Propagation Predictions and Measurements for Mid-Latitude HF NVIS Links at 5 MHz", 13th International Ionospheric Effects Symposium (IES2011), Alexandria, VA, USA, 17-19 May 2011.

Examples – Good Agreement

- GB3RAL–G3WKL
  March 2010

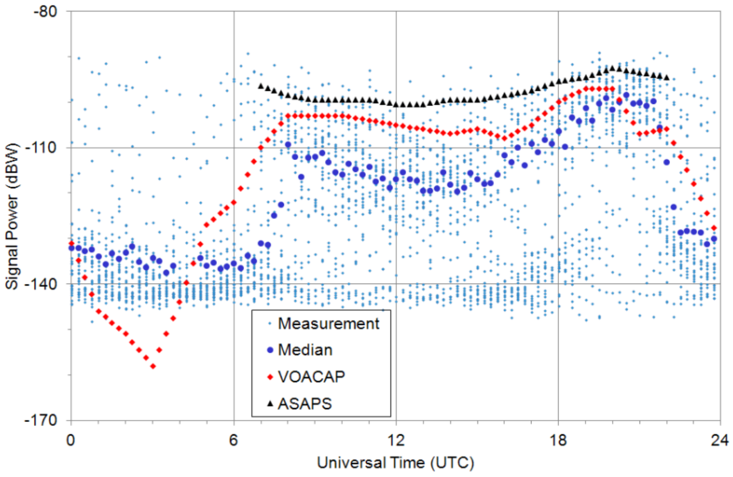


- GB3ORK–GM4SLV
  November 2009

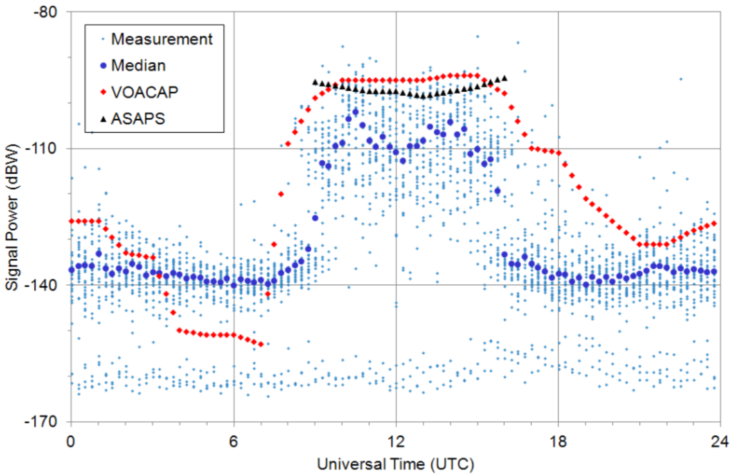


Examples – Less Good Agreement

- GB3RAL–G3SET
  August 2009

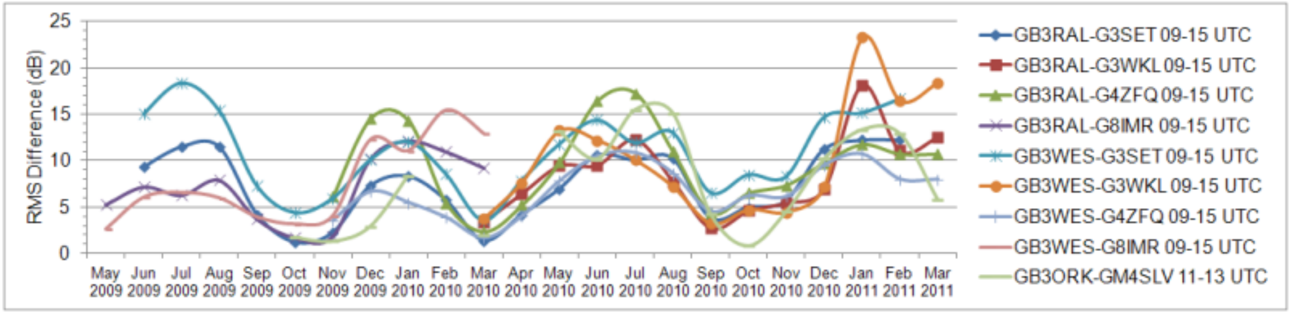


- GB3RAL–G4ZFQ
  January 2010

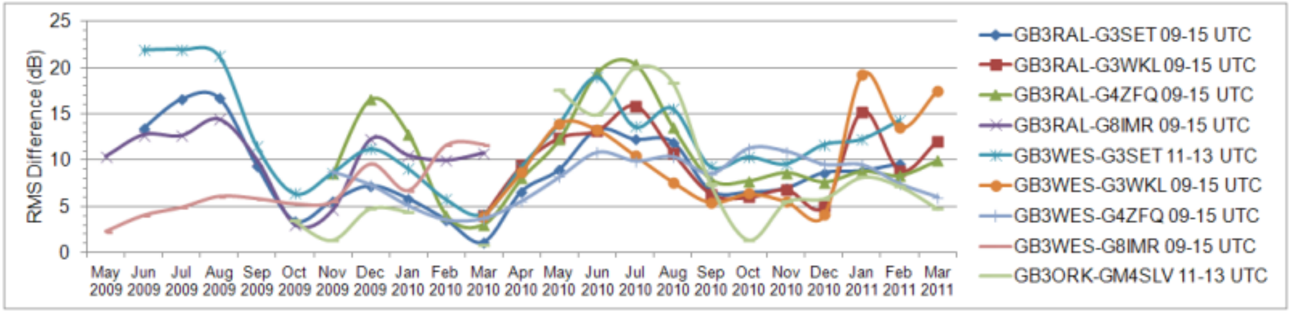


RMS Differences ~1200 UTC

- RMS differences show cyclic pattern
  - VOACAP



  - ASAPS



Findings (3)

- Ionosonde measurements compared with ASAPS and VOACAP frequency predictions
  - Results UK specific
  - ASAPS basic MUF predictions generally agree with Chilton fxI measurements
  - VOACAP predictions more conservative

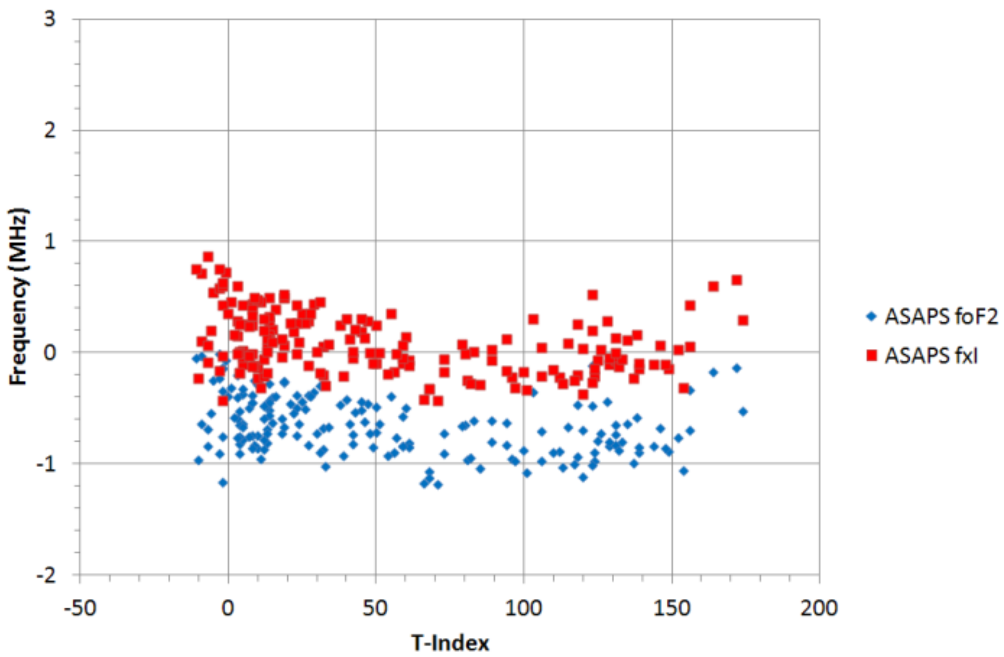
References:

M. C. Walden, "Analysis of Chilton Ionosonde Critical Frequency Measurements During Solar Cycle 23 in the Context of Midlatitude HF NVIS Frequency Predictions", IET International Conference on Ionospheric Radio Systems and Techniques (IRST 2012), York, UK, 15-17 May 2012. doi:10.1049/cp.2012.0373

M. C. Walden, "Analysis of Chilton Ionosonde Critical Frequency Measurements During Solar Cycle 23 in the Context of Midlatitude HF NVIS Frequency Predictions (Use of T-Index with VOACAP)", Presented at HF Industry Association meeting, York, UK, 6 September 2012.

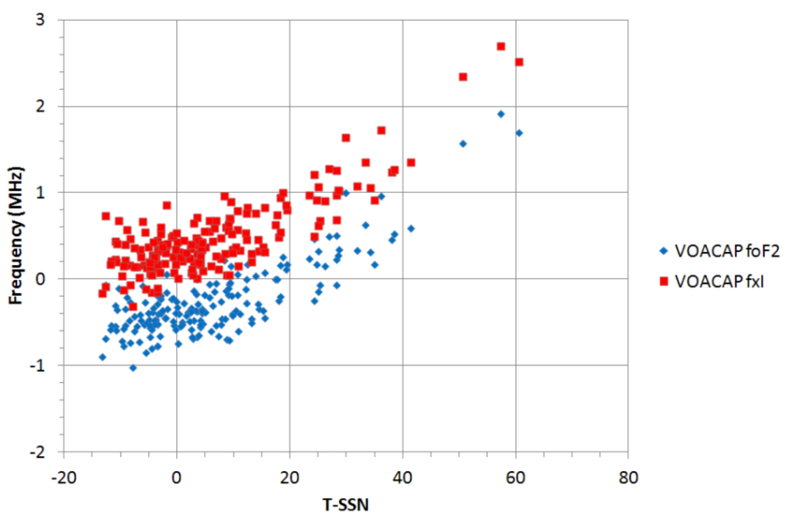
ASAPS vs VOACAP Frequency Predictions (1)

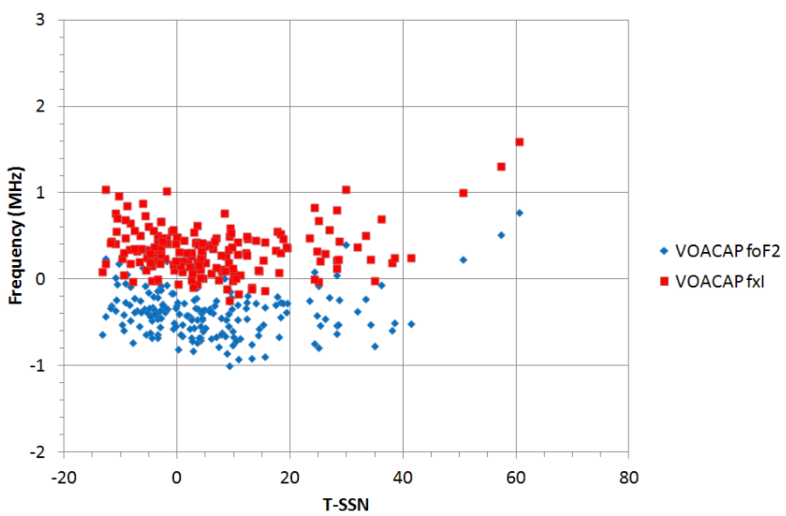
- ASAPS basic MUF predictions generally agree with Chilton fxI measurements
  - ASAPS errors increase at low or negative T index



ASAPS vs VOACAP Frequency Predictions (2)

- VOACAP more conservative
  - Particularly around solar maximum using SSN
  - Large errors when T−SSN > ~15
  - Errors reduced when using T index





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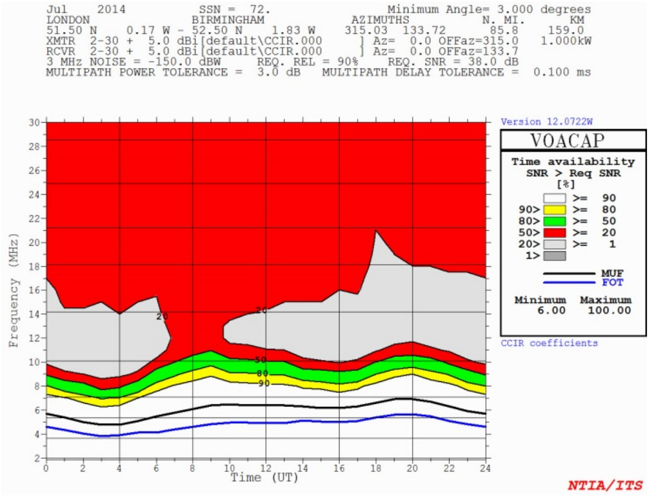
Findings (4)

- VOACAP reliability predictions can be in error for NVIS links
  - e.g. Good reliability predicted when no ionospheric support predicted
- User interpretation required to validate VOACAP prediction
  - VOACAP tells us when it is having difficulties
  - Carry out sanity check on prediction data
  - Avoid decision errors based on false predictions



Reference:

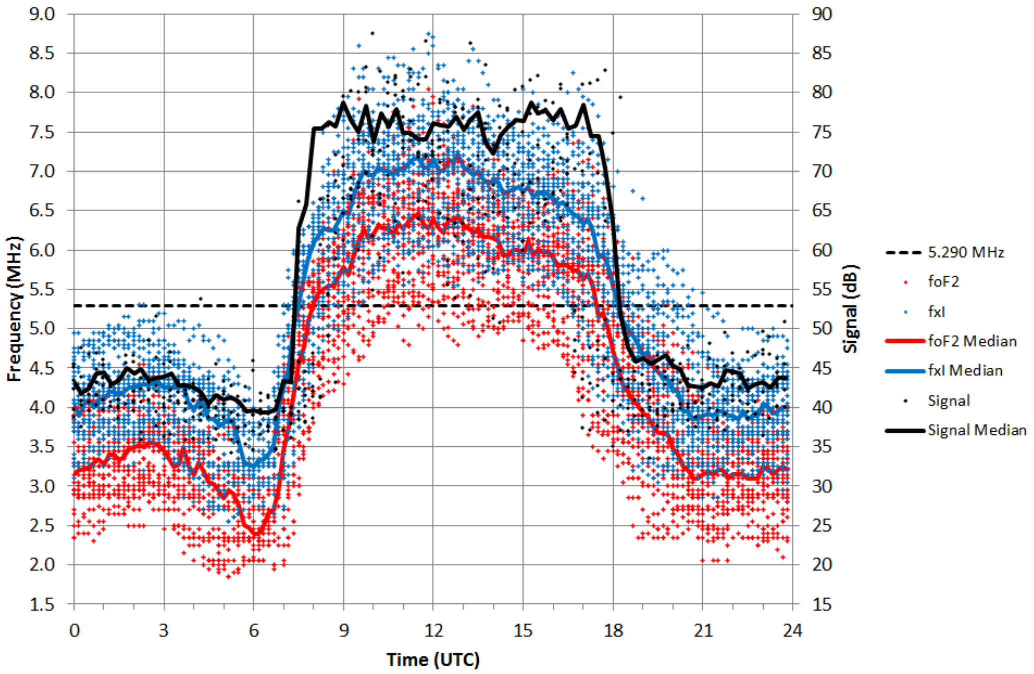
M. C. Walden, "VOACAP Reliability (REL) Predictions: A Sanity Check for HF NVIS Links", Presented at HF Industry Association meeting, Portsmouth, UK, 11 September 2014.

Findings (5)

- Identified inconsistency in ITU-R model for above-the-MUF loss
  - Above-the-MUF loss model uses foF2 for basic MUF
  - Basic MUF model tends to fxF2 from above for vertical incidence and NVIS links

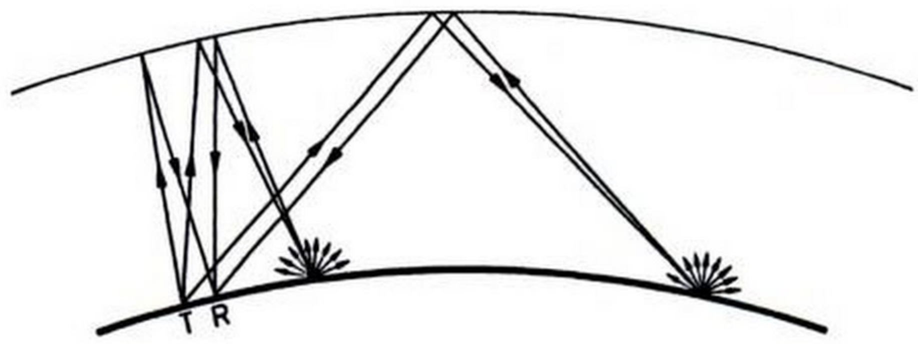
Above-The-MUF Propagation (1)

- 5 MHz data frequently shows beacon reception 'above-the-MUF'
- GB3RAL–G4ZFQ February 2010
  - Approximately 1830-0730 UTC
  - Reception most days of month



Above-The-MUF Propagation (2)

- Most likely mechanism
  - Two-hop ground side-scatter



- Relevance
  - Signal strength prediction of interfering signals
  - Prediction of desired signal less useful because propagation mechanisms involved result in larger delay spread

Reference:

R. Hanbaba, "Performance prediction methods of HF radio systems", Annali di Geofisica, Vol. 41, No. 5-6, November-December 1998.

ITU-R Recommendation P.533-12

- Above-the-MUF loss for F2 modes, smaller of:

$$L_m = 36\left[\left(\frac{f}{f_b}\right) - 1\right]^{\frac{1}{2}}$$

$$L_m = 62 \text{ dB}$$

  - where f_b is basic MUF and f is operating frequency
- Basic MUF tends to fxF2 from above for vertical incidence and NVIS links
  - Not foF2

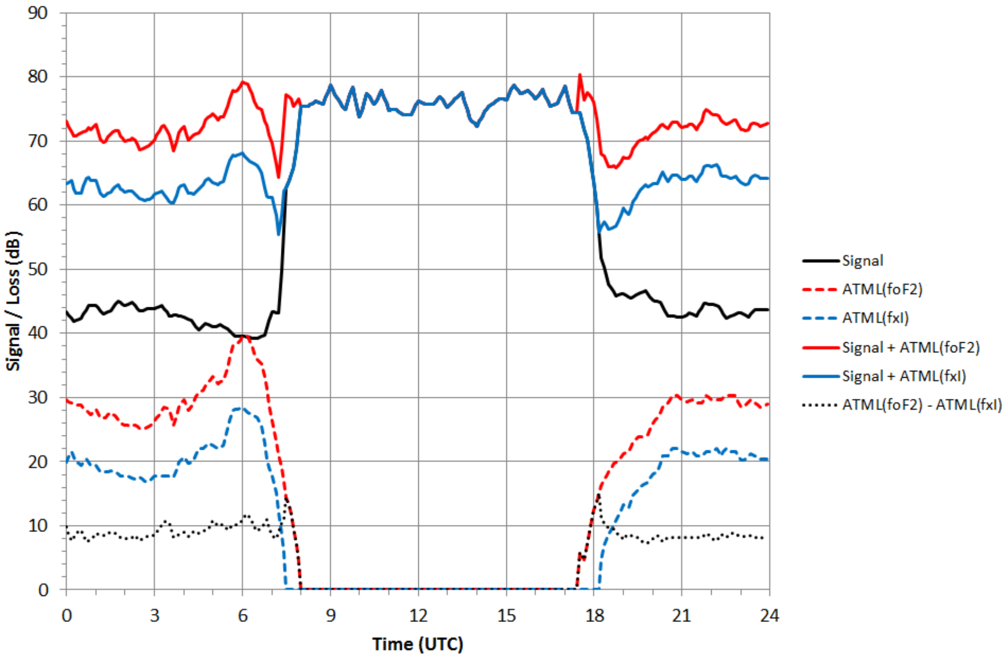
VOACAP Above-The-MUF Loss

- VOACAP ‘Above-the-MUF’ loss limited to 25 dB
- George Lane (www.voacap.com)
  - “Personally, I think it is too low and probably should be allowed to go to 40 to 50 dB”
- VOACAP above-the-MUF predictions require user sanity check
  - Avoid decision errors based on false predictions

Measurements

- Determine expected above-the-MUF loss using measured Chilton foF2 and fxI
- Adjust measured signal level by above-the-MUF loss

- GB3RAL–G4ZFQ February 2010



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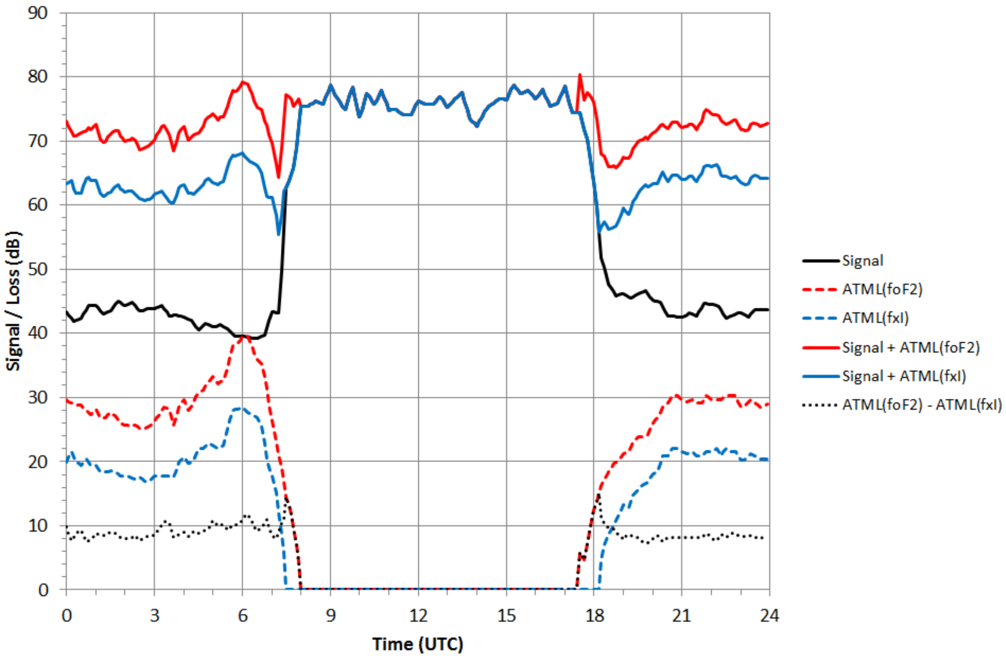
Observations (1)

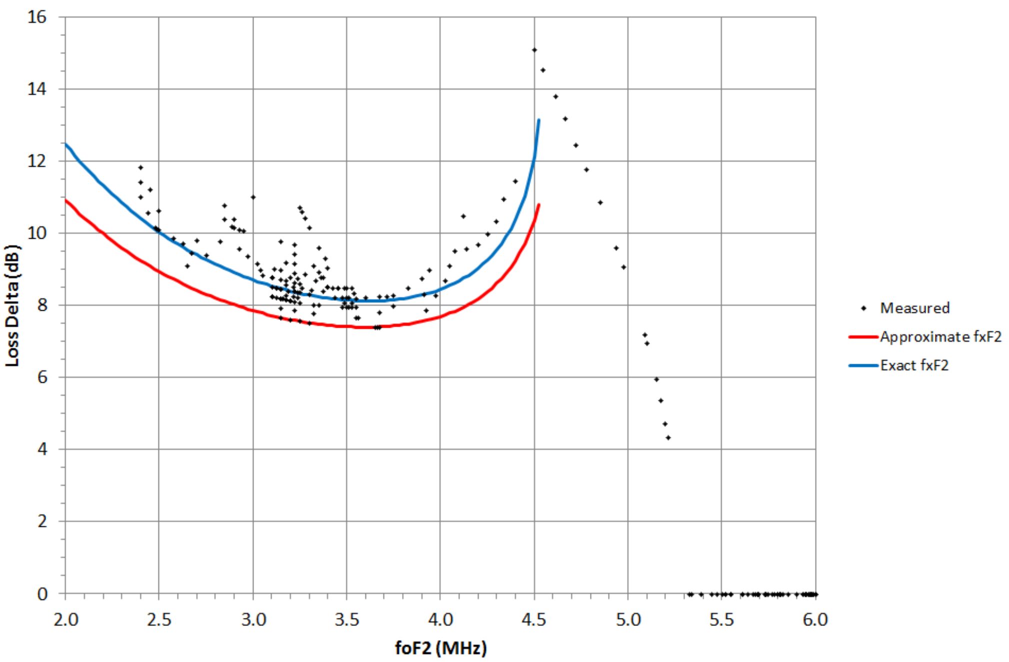
- Measurements indicate that ITU-R above-the-MUF loss model uses foF2 for basic MUF
- Inconsistent with ITU-R basic MUF definition
  - Basic MUF tends to fxF2 from above for vertical incidence and NVIS links
- Using fxF2 (or fxI) underpredicts above-the-MUF loss by ~8–14 dB



Observations (2)

- Using fxF2 (or fxI) underpredicts above-the-MUF loss by ~8–14 dB

- GB3RAL–G4ZFQ February 2010
  - Difference between above-the-MUF loss models using foF2 and fxF2 (or fxI) versus foF2
  - f_H = 1.4 MHz



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Summary

- The 5 MHz Experiment
- Findings to date relating to NVIS propagation
  - Practical significance of extraordinary wave propagation for NVIS Links
  - Comparison of beacon measurements with ASAPS and VOACAP signal-level predictions
  - Comparison of ionosonde measurements with ASAPS and VOACAP frequency predictions
  - VOACAP reliability predictions can be in error for NVIS links
  - Inconsistency in ITU-R model for above-the-MUF loss

Reference:

M. C. Walden, "High-Frequency Near Vertical Incidence Skywave Propagation: Findings associated with the 5 MHz Experiment", IEEE Antennas and Propagation Magazine, Vol. 58, No. 6, pp. 16-28, December 2016. doi: 10.1109/MAP.2016.2609798

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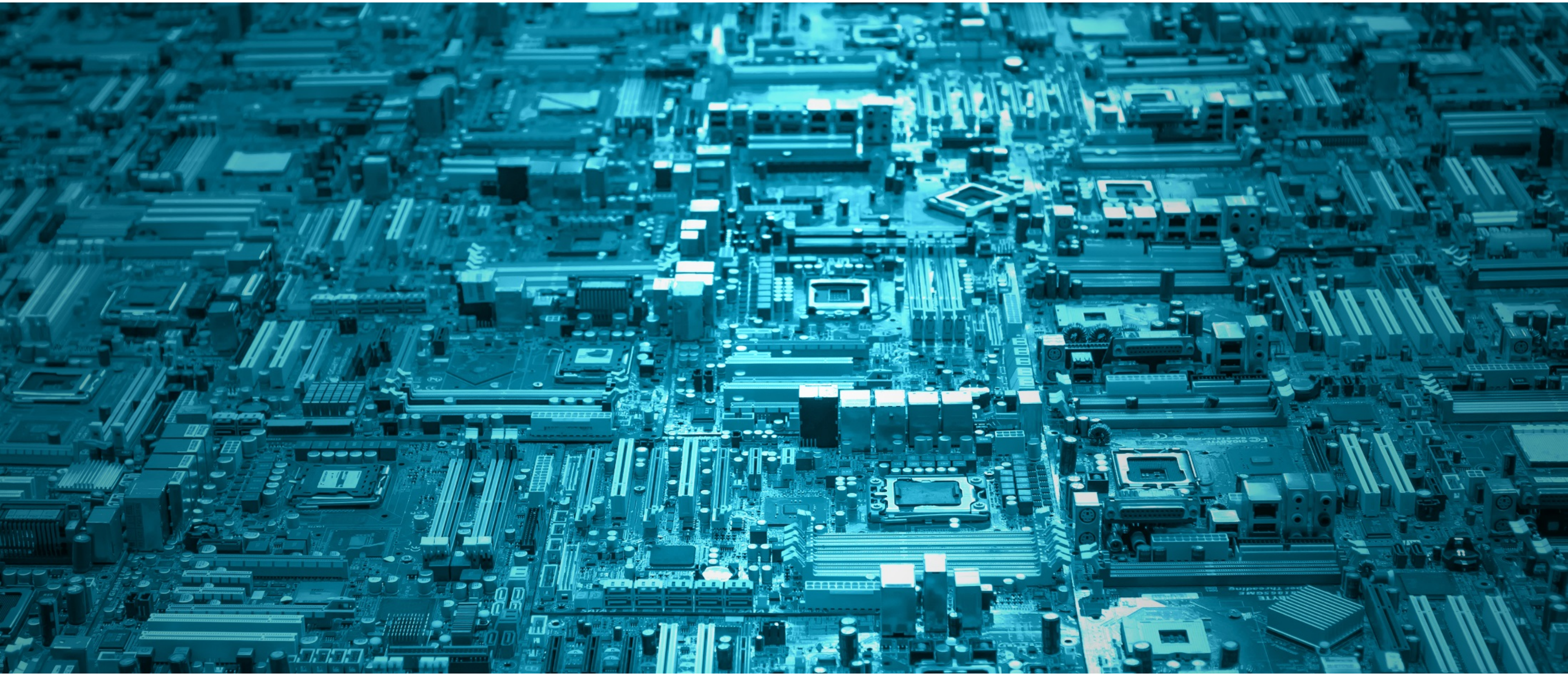
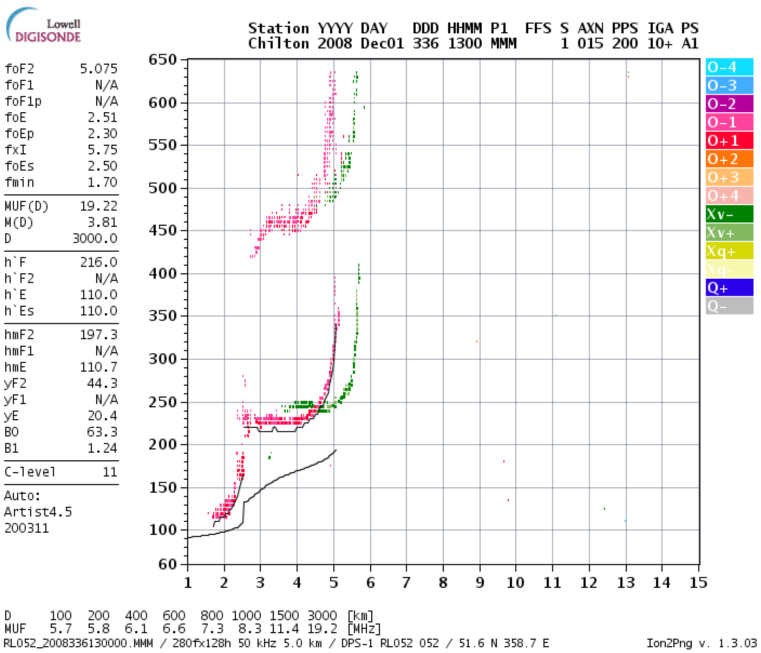


Additional Slides

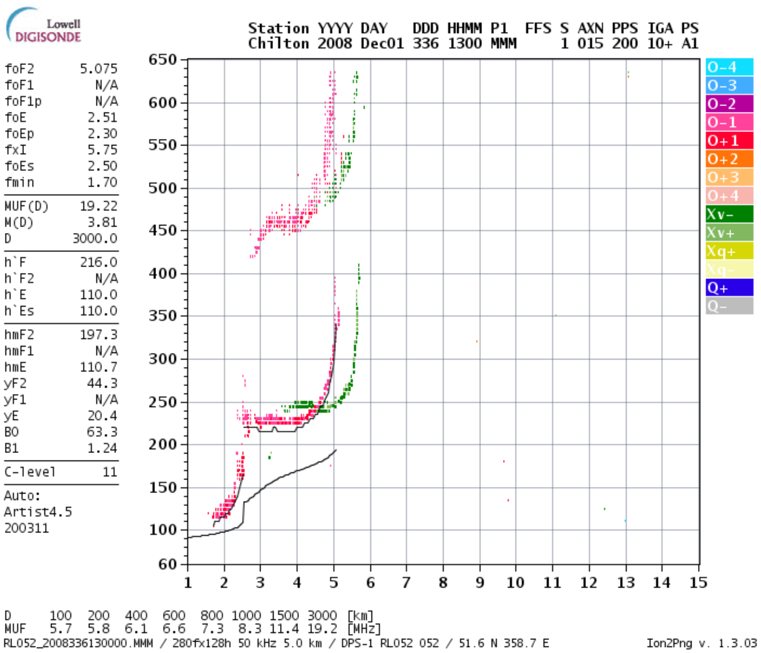
Some Current Practical NVIS Guidelines (1)

- foF2 is maximum frequency supported by ionosphere at vertical incidence (INCORRECT)
  - Observed in some practical HF system literature for professional applications
  - foF2 - Ordinary wave critical frequency for F2 region
  - fxF2 - Extraordinary wave critical frequency for F2 region
  - fxF2 is maximum frequency



Some Current Practical NVIS Guidelines (2)

- FOT ≈ 85% of foF2 (INCORRECT)
  - Frequently observed in amateur/MARS literature
  - FOT ≈ 85% of MUF
  - MUF ≠ foF2 at vertical incidence
  - MOF = fxF2 at vertical incidence



‘Happy Hour’ (1)

- Term coined by Dutch researchers
  - Witvliet *et al*
- Time period when only extraordinary wave propagates
- ‘Happy hour’ window variable depending on ionosphere
  - Window can be minutes to many hours

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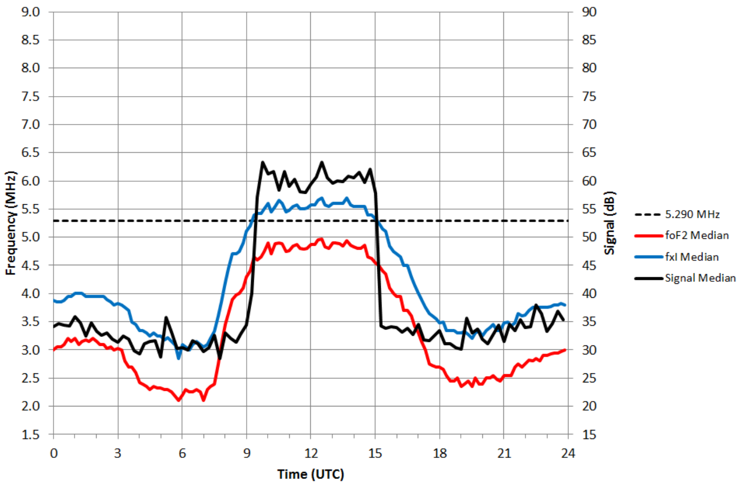
‘Happy Hour’ (2)

- GB3RAL–G3WKL
  January 2009
  - Long ‘Happy Hour’



- GB3RAL–G4ZFQ
  February 2010
  - Short ‘Happy Hour’