VOACAP Reliability (REL) Predictions: A Sanity Check for HF NVIS Links

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Overview of Presentation

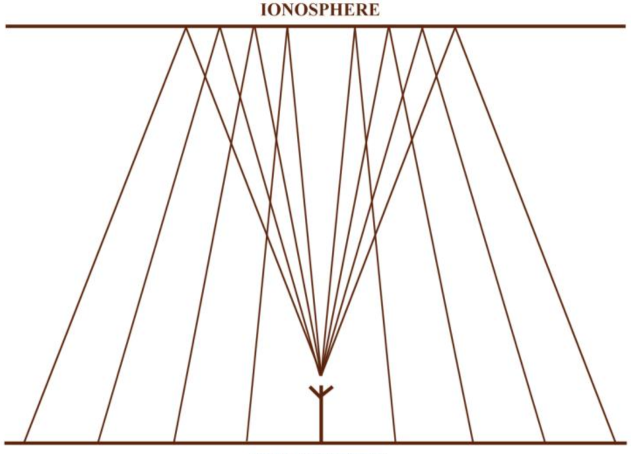
- Motivation and aims
- Introduction
- HF propagation predictions
- VOACAP
- NVIS prediction example
- Discussion
- Summary

Motivation and Aims

- VOACAP propagation predictions can show contradictions for some frequencies
  - High reliability (e.g. REL > 50%)
  - Propagation not supported (e.g. MUFday at or close to zero)
- Specific to HF NVIS links
  - Longer links up to ~1000 km?
- User interpretation required to validate HF NVIS prediction
  - Check VOACAP output parameters
  - e.g. REL, MUFday, SIG LW, SNR LW, etc.
  - User-own reliability prediction?

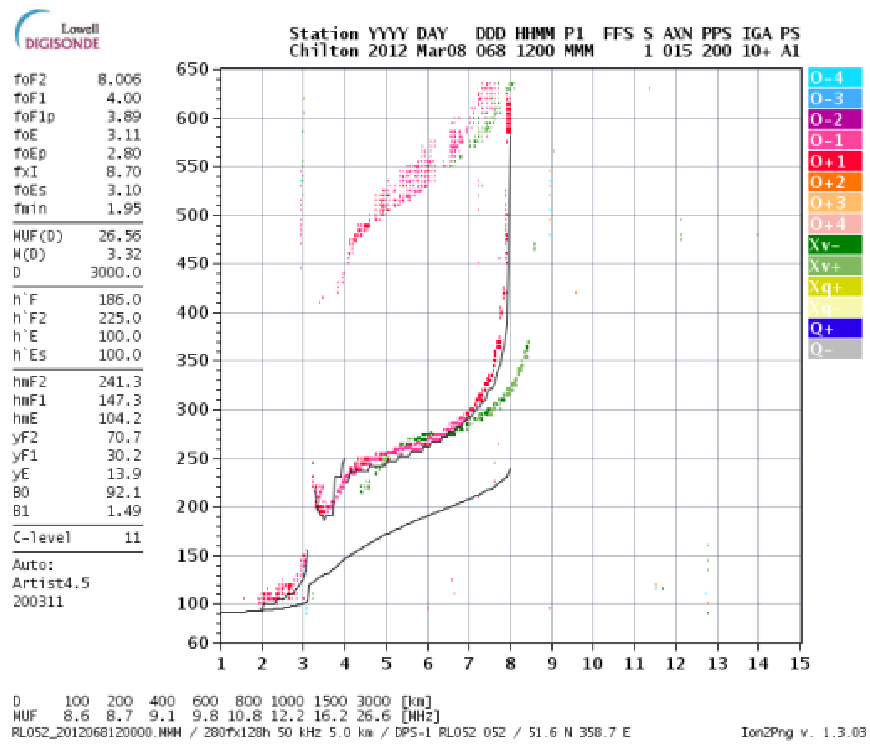
Introduction

- 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



Maximum NVIS Frequencies

- Maximum frequencies supported by F2 region at vertical incidence
  - Ordinary wave *foF2*
  - Extraordinary wave *fxF2*
- Oblique incidence
  - Maximum frequency adjusted using secant law
  - Maximum oblique frequency for NVIS links close to maximum frequency at vertical incidence



Ionospheric Variability

- Ionosphere exhibits variability
- Variation on scale of minutes to years
  - Hourly
  - Diurnal
  - Seasonal
  - Solar cycle
- Real-time measurements track ionospheric variability
  - Absence of real-time measurements?

HF Propagation Predictions (1)

- Long-term propagation predictions used for system planning
- Monthly-median predictions
- Example propagation prediction software
  - VOACAP
    - ITS (USA)
  - ASAPS
    - IPS (Australia)
  - REC533 (now ITUHFPROP)
    - ITU

HF Propagation Predictions (2)

- Two aspects to long-term prediction
- Frequency prediction
  - Is propagation supported at given frequency?
- Signal prediction
  - Estimate signal power, signal-to-noise ratio, signal and noise statistics plus other parameters

HF Propagation Predictions (3)

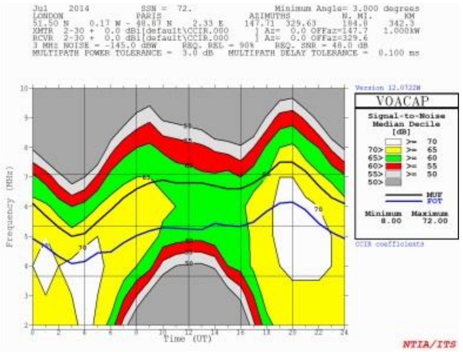
- If frequency of interest not supported by ionosphere
  - Ideally **do not** output signal predictions
- ASAPS
  - Does not provide signal predictions if Probability of ionospheric support is zero **(reassuring)**
- VOACAP
  - Still provides signal predictions if MUFday is zero **(unfortunate)**
  - User interpretation required to avoid decision errors based on false predictions

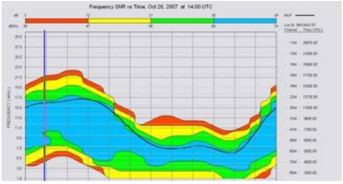
VOACAP

- Voice of America Coverage Analysis Program
  - Version 12.0722
- Derived from IONCAP
- 50+ years of US HF research and development
  - Considered to be “gold standard”
- Limited (or no) support and development
  - VOACAP team retired or no longer with us

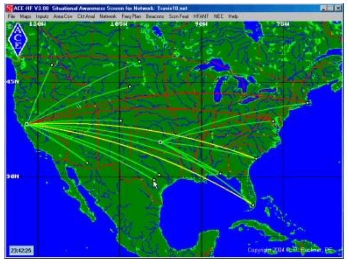
VOACAP Usage

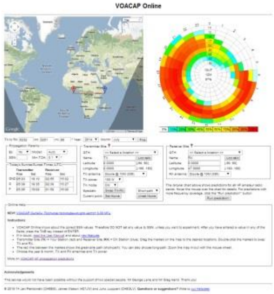
- VOACAP widely used
  - Free-ware
  - Relatively easy to use

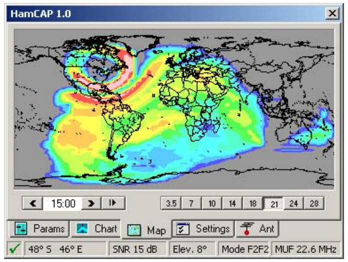




- VOACAP engine frequently used with alternative GUI
  - Third-party software
    - e.g. Propman 2000, ACE-HF, Ham CAP
  - Web-based prediction
    - e.g. www.voacap.com

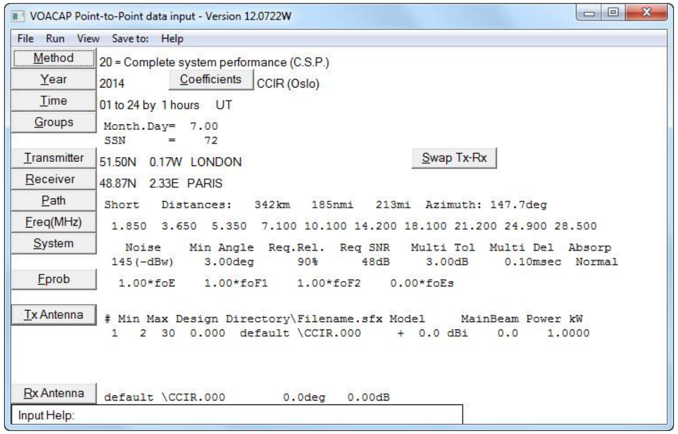






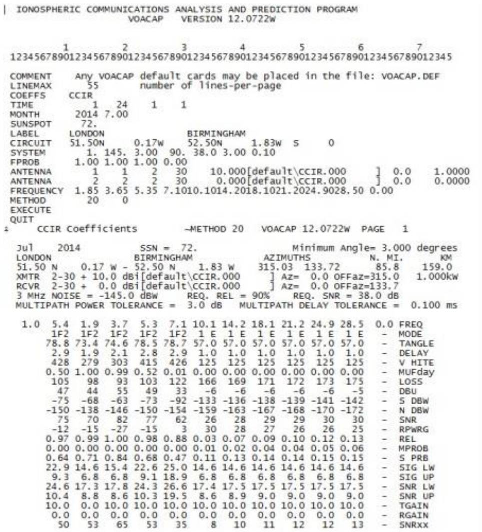
VOACAP Input

- Some key input parameters
  - Method
  - Groups
    - Month, smoothed sunspot number
  - Transmitter and receiver locations
  - System parameters
    - Man-made noise level, required reliability and SNR
  - Transmit and receive antennas
    - Antenna pattern, gain, bearing
    - Transmitter power level



VOACAP Output

- Text output
  - Multiple parameters in table format



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                   VOACAP   VERSION 12.0722W

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1234567890123456789012345678901234567890123456789012345678901234567890123456789012345

COMMENT    Any VOACAP default cards may be placed in the file: VOACAP.DEF
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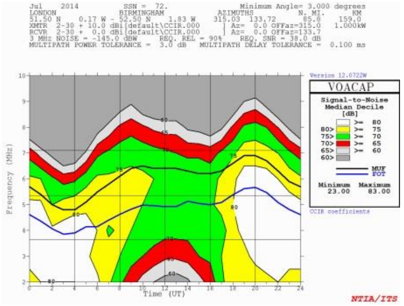
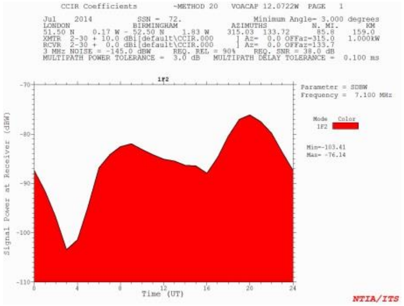
COEFFS     CCIR
TIME          1   24    1    1
MONTH       2014 7.00
SUNSPOT      72.
LABEL      LONDON              BIRMINGHAM
CIRCUIT    51.50N     0.17W    52.50N     1.83W  S     0
SYSTEM        1. 145. 3.00  90. 38.0 3.00 0.10
FPROB       1.00 1.00 1.00 0.00
ANTENNA       1    1    2   30    10.000[default\CCIR.000     ]  0.0    1.0000
ANTENNA       2    2    2   30     0.000[default\CCIR.000     ]  0.0    0.0000
FREQUENCY   1.85 3.65 5.35 7.1010.1014.2018.1021.2024.9028.50 0.00
METHOD       20    0
EXECUTE
QUIT
     CCIR Coefficients        -METHOD 20   VOACAP 12.0722W  PAGE   1

  Jul    2014          SSN =  72.            Minimum Angle= 3.000 degrees
  LONDON              BIRMINGHAM          AZIMUTHS          N. MI.      KM
  51.50 N    0.17 W - 52.50 N    1.83 W    315.03  133.72      85.8    159.0
  XMTR  2-30 + 10.0 dBi[default\CCIR.000     ] Az=  0.0 OFFaz=315.0   1.000kW
  RCVR  2-30 +  0.0 dBi[default\CCIR.000     ] Az=  0.0 OFFaz=133.7
  3 MHz NOISE = -145.0 dBW      REQ. REL = 90%    REQ. SNR = 38.0 dB
  MULTIPATH POWER TOLERANCE =  3.0 dB   MULTIPATH DELAY TOLERANCE =  0.100 ms

   1.0  5.4  1.9  3.7  5.3  7.1 10.1 14.2 18.1 21.2 24.9 28.5  0.0 FREQ
        1F2  1F2  1F2  1F2  1F2  1 E  1 E  1 E  1 E  1 E  1 E   -  MODE
       78.8 73.4 74.6 78.5 78.7 57.0 57.0 57.0 57.0 57.0 57.0   -  TANGLE
        2.9  1.9  2.1  2.8  2.9  1.0  1.0  1.0  1.0  1.0  1.0   -  DELAY
        428  279  303  415  426  125  125  125  125  125  125   -  V HITE
       0.50 1.00 0.99 0.52 0.01 0.00 0.00 0.00 0.00 0.00 0.00   -  MUFday
        105   98   93  103  122  166  169  171  172  173  175   -  LOSS
         47   44   55   49   33   -6   -6   -6   -6   -6   -5   -  DBU
        -75  -68  -63  -73  -92 -133 -136 -138 -139 -141 -142   -  S DBW
       -150 -138 -146 -150 -154 -159 -163 -167 -168 -170 -172   -  N DBW
         75   70   82   77   62   26   28   29   29   30   30   -  SNR
        -12  -15  -27  -15    3   30   28   27   26   26   25   -  RPWRG
       0.97 0.99 1.00 0.98 0.88 0.03 0.07 0.09 0.10 0.12 0.13   -  REL
       0.00 0.00 0.00 0.00 0.00 0.01 0.02 0.04 0.04 0.05 0.06   -  MPROB
       0.64 0.71 0.84 0.68 0.47 0.11 0.13 0.14 0.14 0.15 0.15   -  S PRB
       22.9 14.6 15.4 22.6 25.0 14.6 14.6 14.6 14.6 14.6 14.6   -  SIG LW
        9.3  6.8  6.8  9.1 18.9  6.8  6.8  6.8  6.8  6.8  6.8   -  SIG UP
       24.6 17.3 17.8 24.3 26.6 17.4 17.5 17.5 17.5 17.5 17.5   -  SNR LW
       10.4  8.8  8.6 10.3 19.5  8.6  8.9  9.0  9.0  9.0  9.0   -  SNR UP
       10.0  0.0 10.0 10.0 10.0 10.0 10.0 10.0 10.0 10.0 10.0   -  TGAIN
        0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0   -  RGAIN
         50   53   65   53   35    8   10   11   12   12   13   -  SNRxx
```

- Graphical output
  - Multiple parameters to view
  - Variation of parameters with distance or time for specific frequency





VOACAP 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
  - VOACAP MUF prediction of monthly median MOF for given time and date

VOACAP FOT and HPF

- FOT – Frequency of optimum traffic
  - “Frequency where the MOFs will be higher on at least 90% of the days of the month at that hour”
  - Propagation supported on most days of month
  - Not necessarily ‘optimum’ frequency for SNR

- HPF – Highest probable frequency
  - “Frequency where no more than 10% of the hourly MOFs will be higher”
  - Frequencies above MUF supported on some days of month

VOACAP Frequency Predictions

- Method 9 predicts range of frequencies supported by ionosphere
  - MUF
  - FOT
  - HPF
- Useful sanity check

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ANTENNA        2    2    2   30      0.000[default\CCIR.000      ]  0.0    0.0000
FREQUENCY   1.85 3.65 5.35 7.1010.1014.2018.1021.2024.9028.50 0.00
METHOD         9    0
EXECUTE
QUIT
     CCIR Coefficients         METHOD  9   VOACAP 12.0722W  PAGE   1

  Jul    2014          SSN =  72.             Minimum Angle= 3.000 degrees
  LONDON               BIRMINGHAM             AZIMUTHS         N. MI.      KM
  51.50 N    0.17 W - 52.50 N    1.83 W    315.03  133.72      85.8    159.0


          MUF(....)        FOT(XXXX)        HPF(++++)

      00  02  04  06  08  10  12  14  16  18  20  22  00
   MHZ+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+MHZ
    40-                                                 -40
      -                                                 -
    38-                                                 -38
      -                                                 -
    36-                                                 -36   GMT   MUF   FOT   HPF
      -                                                 -
    34-                                                 -34    1.0   5.4   4.4   6.3
      -                                                 -      2.0   5.0   4.1   6.0
    32-                                                 -32    3.0   4.8   3.9   5.7
      -                                                 -      4.0   4.8   3.9   5.7
    30-                                                 -30    5.0   5.1   4.1   6.1
      -                                                 -      6.0   5.5   4.2   6.6
    28-                                                 -28    7.0   5.8   4.4   7.0
      -                                                 -      8.0   6.1   4.6   7.4
    26-                                                 -26    9.0   6.4   4.8   7.7
      -                                                 -     10.0   6.5   5.0   7.6
    24-                                                 -24   11.0   6.4   5.0   7.5
      -                                                 -     12.0   6.4   4.9   7.5
    22-                                                 -22   13.0   6.4   4.9   7.5
      -                                                 -     14.0   6.3   5.1   7.3
    20-                                                 -20   15.0   6.2   5.0   7.2
      -                                                 -     16.0   6.2   5.0   7.1
    18-                                                 -18   17.0   6.3   5.1   7.2
      -                                                 -     18.0   6.6   5.4   7.6
    16-                                                 -16   19.0   6.9   5.6   8.0
      -                                                 -     20.0   6.9   5.7   8.0
    14-                                                 -14   21.0   6.7   5.5   7.7
      -                                                 -     22.0   6.3   5.1   7.3
    12-                                                 -12   23.0   5.9   4.8   6.9
      -                                                 -     24.0   5.7   4.6   6.7
    10-                                                 -10
      -                                                 -
    08-                 + + +                 + + + +   -08
      - +           + + +       + + + + + + . . . . + + + -
    06- . + + + + +   . . . . . . . . . . .   X X   . . . -06
      - X . . . . . . .   X X X X X X X X X X X   X X X X -
    04-   X X X X X X X                                 -04
      -                                                 -
    02-                                                 -02
      -                                                 -
   MHZ+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+MHZ
```

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VOACAP REL and MUFday

- REL (Reliability)
  - “The reliability of a communications system over a circuit is usually expressed as the fraction of time that the actual SNR exceeds the minimum level associated with the grade of service required by the user”

- MUFday
  - “Fraction of the days in the month at that hour that the operating frequency is below the MUF for the **<u>most reliable mode</u>**”

VOACAP Methods

- Method 20 – Complete system performance
- Method 25 – All modes table
  - Verbose
  - Useful for detailed investigation
- Method 30 – Short/Long smoothing (7-10000 km)
  - Signal power continuity between the Short-Path Model and the Long-Path Model
  - Applies smoothing function from 7,000 km out to 10,000 km

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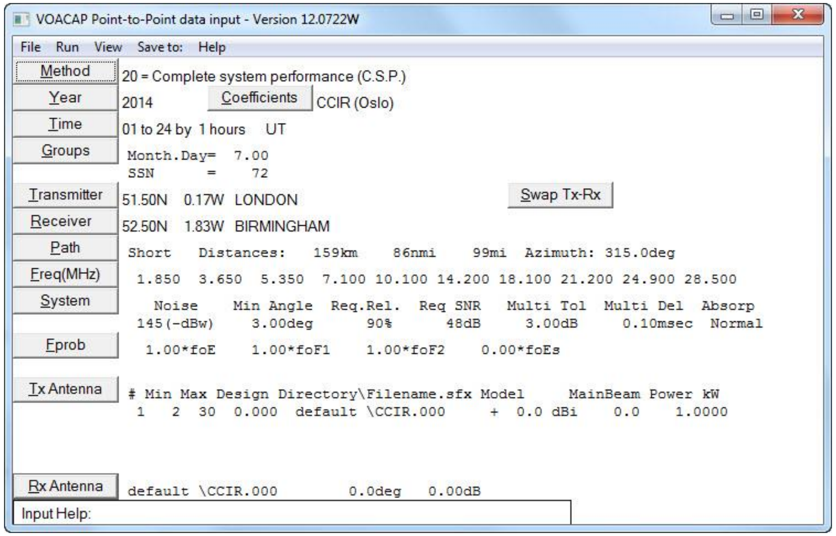
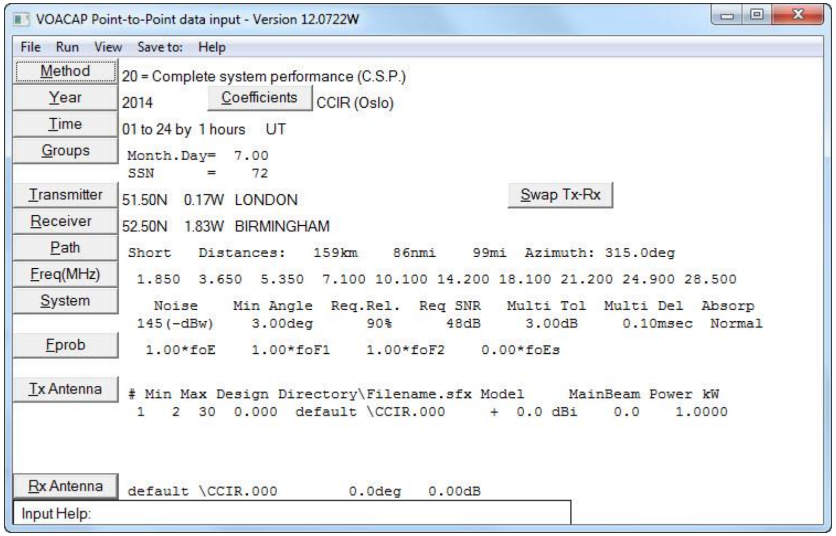
VOACAP NVIS Prediction (1)

- UK link
  - London-Birmingham
  - 159 km (99 miles)
- Method 20
  - Complete system performance
- July 2014
- SSN 72



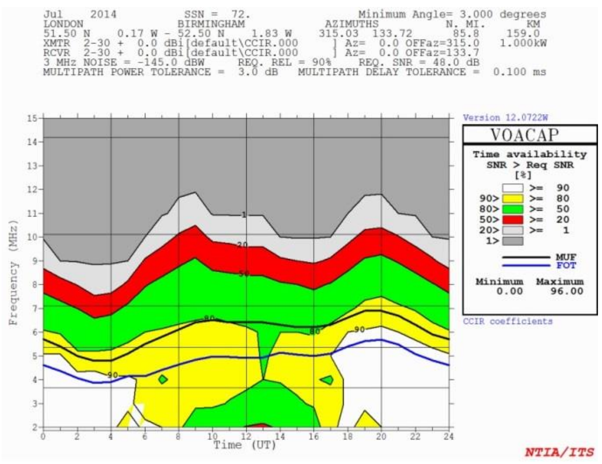
VOACAP NVIS Prediction (2)

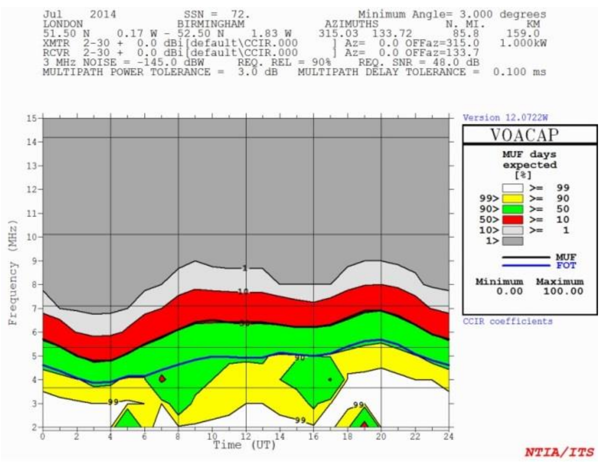
- Man-made noise level at 3 MHz
  - −145 dBW in 1 Hz (‘Residential’)
- Required SNR
  - 48 dBHz (SSB or J3E)
- Isotropic antennas
  - 0 dBi transmit and receive
- Transmit power
  - 1 kW



VOACAP NVIS Prediction (3)

- Predicted REL and MUFday
  - Looks ok but …
  - Reliability greater than zero when most reliable mode not supported (i.e. MUFday is zero)
  - Odd!   Investigate further





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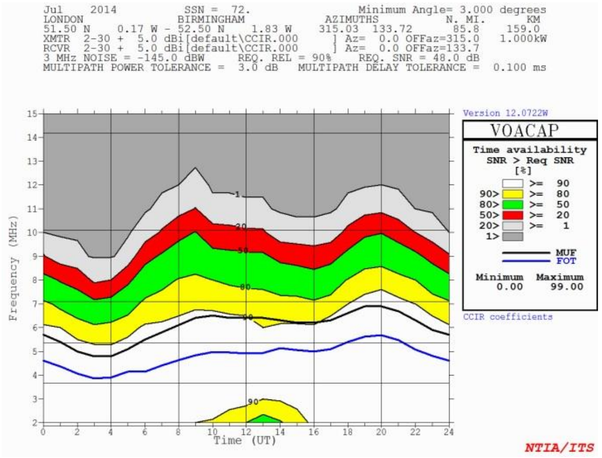
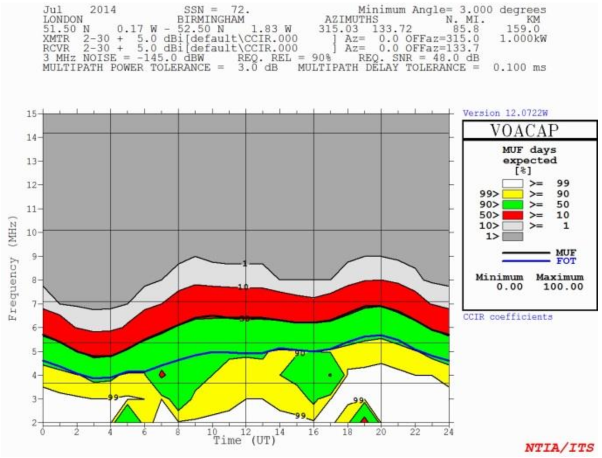
VOACAP NVIS Prediction (4)

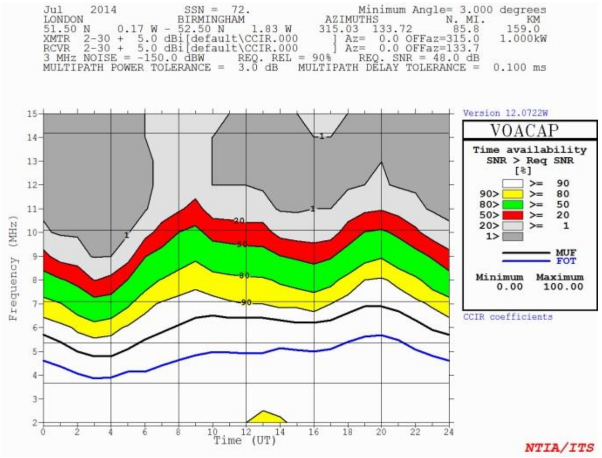
- Increase transmit and receive antenna gains
  - e.g. +5 dBi each (NVIS dipole over ‘average’ ground)
- No propagation predicted on certain frequencies but good reliability
  - e.g. 9 MHz at 0800 UTC, MUFday = 0% but REL ~64%

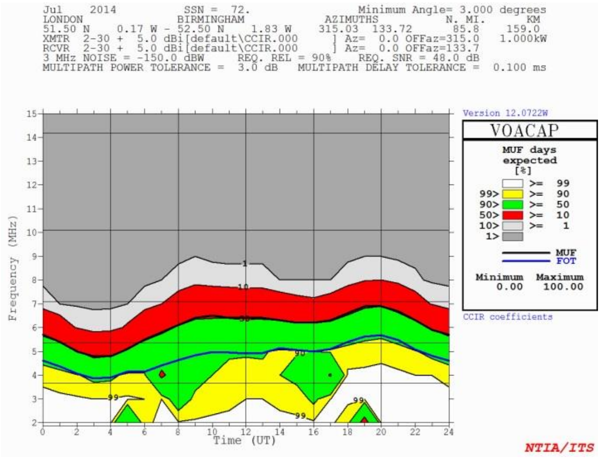




VOACAP NVIS Prediction (5)

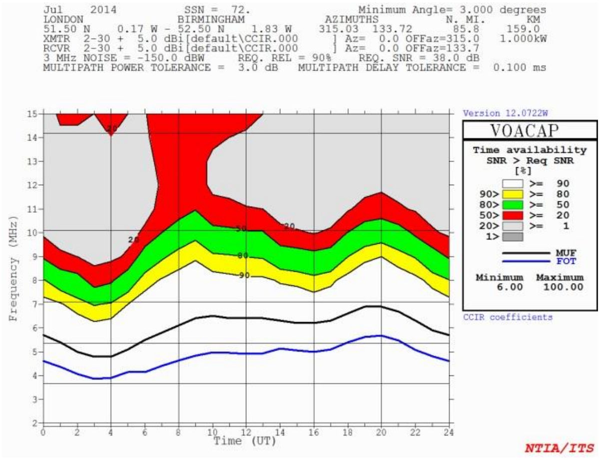
- Use lower man-made noise level
  - e.g. −150 dBW in 1 Hz at 3 MHz (ITU-R Rec. P.372 ‘Rural’)
- Still no propagation predicted on certain frequencies but reliability has improved
  - e.g. 9 MHz at 0800 UTC, MUFday = 0% but REL ~72%

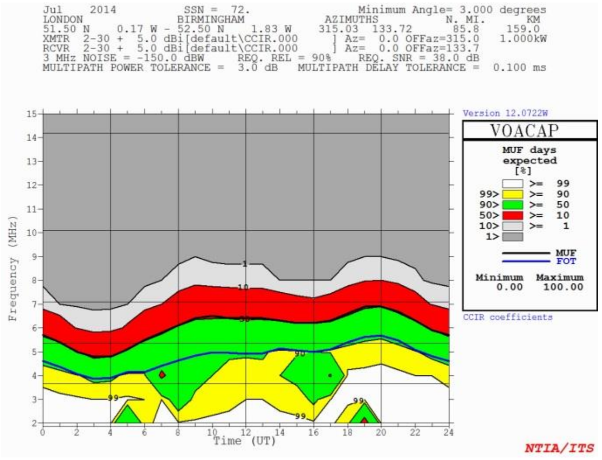




VOACAP NVIS Prediction (6)

- Use lower required SNR
  - e.g. 38 dBHz (ITU-R Rec. F.339 - A1A or 150 bps J2D in 3 kHz channel BER 10^{-5}, fading conditions)
- Reliability improves further but support still not predicted
  - e.g. 9 MHz at 0800 UTC, MUFday = 0% but REL ~85%





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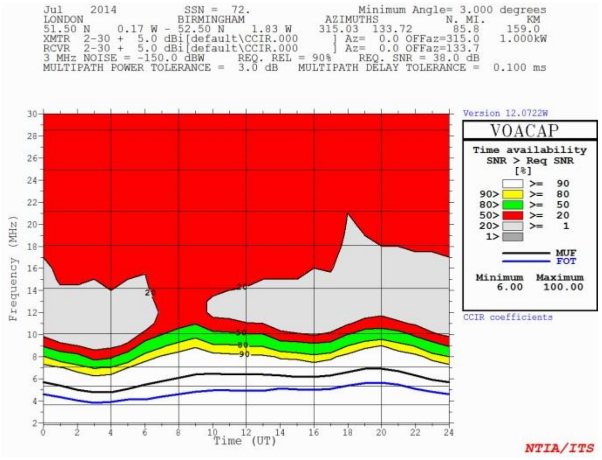
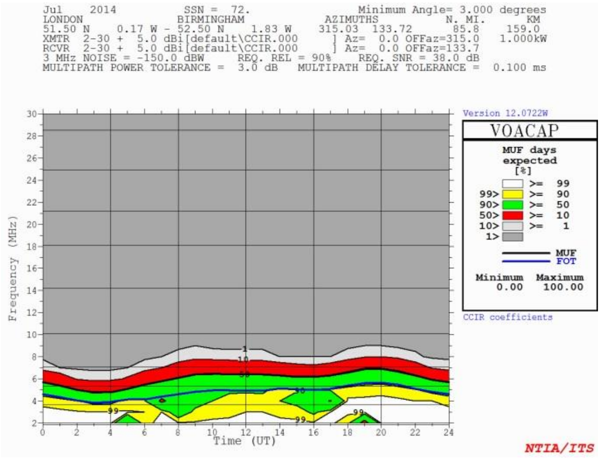
VOACAP NVIS Prediction (7)

- Look at REL and MUFday over complete HF band
  - e.g. 2-30 MHz
- NVIS predicted reliability falls to minimum at ~11-13 MHz but improves again with increasing frequency
  - e.g. 30 MHz at 1200 UTC, MUFday = 0% but REL ~46%





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Discussion

- What is going on?
  - Not ground wave!
- Look at Circuit text file for clues
  - Example at 1100 UTC

```
    CCIR Coefficients          METHOD 20   VOACAP 12.0722W  PAGE   6

 Jul    2014            SSN =  72.              Minimum Angle= 3.000 degrees
 LONDON                BIRMINGHAM          AZIMUTHS          N. MI.      KM
 51.50 N    0.17 W - 52.50 N    1.83 W    315.03  133.72       85.8     159.0
 XMTR  2-30 +  5.0 dBi[default\CCIR.000      ] Az=  0.0 OFFaz=315.0   1.000kW
 RCVR  2-30 +  5.0 dBi[default\CCIR.000      ] Az=  0.0 OFFaz=133.7
 3 MHz NOISE = -150.0 dBW     REQ. REL = 90%     REQ. SNR = 38.0 dB
 MULTIPATH POWER TOLERANCE =  3.0 dB   MULTIPATH DELAY TOLERANCE =  0.100 ms

 11.0  6.4  1.9  3.7  5.3  7.1 10.1 14.2 18.1 21.2 24.9 28.5  0.0 FREQ
       1F2  1 E  1 E  1F2  1F2  1F2  1F1  1F1  1F1  1F1  1F1   -  MODE
      78.9 49.8 55.3 75.6 78.8 78.8 70.9 70.9 70.9 70.9 70.9   -  TANGLE
       2.9  0.8  0.9  2.2  2.9  2.9  1.7  1.7  1.7  1.7  1.7   -  DELAY
       431   96  117  326  428  428  239  239  239  239  239   -  V HITE
      0.50 1.00 0.67 0.83 0.22 0.00 0.00 0.00 0.00 0.00 0.00   -  MUFday
       112  121  108  108  114  155  169  170  171  172  173   -  LOSS
        37   22   39   40   35   -2  -10   -9   -9   -9   -8   -  DBU
       -81  -91  -75  -77  -84 -125 -136 -137 -138 -139 -140   -  S DBW
      -159 -144 -152 -157 -160 -164 -168 -171 -173 -175 -177   -  N DBW
        78   53   78   80   76   39   32   34   36   36   37   -  SNR
       -15    0  -22  -23  -11   20   21   19   17   17   16   -  RPWRG
      0.98 0.90 1.00 1.00 0.96 0.53 0.20 0.31 0.36 0.41 0.45   -  REL
      0.00 0.00 1.00 0.00 0.00 0.00 0.05 0.09 0.12 0.15 0.17   -  MPROB
      0.68 0.50 0.81 0.82 0.63 0.23 0.13 0.16 0.17 0.18 0.19   -  S PRB
      22.5 11.5 14.8 15.9 25.0 18.5 11.5 11.5 11.5 11.5 11.5   -  SIG LW
       9.3  7.0  8.5  9.5 11.8 22.9  7.0  7.0  7.0  7.0  7.0   -  SIG UP
      24.5 15.1 17.7 18.6 26.8 20.8 14.9 15.0 15.0 15.0 15.0   -  SNR LW
      11.1  9.2 10.4 11.2 13.1 23.6  8.9  9.0  9.1  9.1  9.1   -  SNR UP
       5.0  0.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0   -  TGAIN
       5.0  0.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0   -  RGAIN
        53   38   60   61   49   18   17   19   21   21   22   -  SNRxx
```

Discussion – MUFday and REL

- MUFday is zero above 7.1 MHz but REL is non-zero
  - REL increases as 30 MHz approached from below
  - Confirms previous graphical outputs

```
     CCIR Coefficients          METHOD 20   VOACAP 12.0722W  PAGE   6

 Jul    2014            SSN =  72.              Minimum Angle= 3.000 degrees
 LONDON                BIRMINGHAM            AZIMUTHS          N. MI.      KM
 51.50 N    0.17 W - 52.50 N    1.83 W   315.03  133.72       85.8    159.0
 XMTR  2-30 +  5.0 dBi[default\CCIR.000     ] Az=  0.0 OFFaz=315.0  1.000kW
 RCVR  2-30 +  5.0 dBi[default\CCIR.000     ] Az=  0.0 OFFaz=133.7
 3 MHz NOISE = -150.0 dBW     REQ. REL = 90%    REQ. SNR = 38.0 dB
 MULTIPATH POWER TOLERANCE =  3.0 dB   MULTIPATH DELAY TOLERANCE =  0.100 ms

 11.0   6.4   1.9   3.7   5.3   7.1  10.1  14.2  18.1  21.2  24.9  28.5   0.0 FREQ
        1F2   1 E   1 E   1F2   1F2   1F2   1F1   1F1   1F1   1F1   1F1    -  MODE
       78.9  49.8  55.3  75.6  78.8  78.8  70.9  70.9  70.9  70.9  70.9    -  TANGLE
        2.9   0.8   0.9   2.2   2.9   2.9   1.7   1.7   1.7   1.7   1.7    -  DELAY
        431    96   117   326   428   428   239   239   239   239   239    -  V HITE
       0.50  1.00  0.67  0.83  0.22  0.00  0.00  0.00  0.00  0.00  0.00    -  MUFday
        112   121   108   108   114   155   169   170   171   172   173    -  LOSS
         37    22    39    40    35    -2   -10    -9    -9    -9    -8    -  DBU
        -81   -91   -75   -77   -84  -125  -136  -137  -138  -139  -140    -  S DBW
       -159  -144  -152  -157  -160  -164  -168  -171  -173  -175  -177    -  N DBW
         78    53    78    80    76    39    32    34    36    36    37    -  SNR
        -15     0   -22   -23   -11    20    21    19    17    17    16    -  RPWRG
       0.98  0.90  1.00  1.00  0.96  0.53  0.20  0.31  0.36  0.41  0.45    -  REL
       0.00  0.00  1.00  0.00  0.00  0.00  0.05  0.09  0.12  0.15  0.17    -  MPROB
       0.68  0.50  0.81  0.82  0.63  0.23  0.13  0.16  0.17  0.18  0.19    -  S PRB
       22.5  11.5  14.8  15.9  25.0  18.5  11.5  11.5  11.5  11.5  11.5    -  SIG LW
        9.3   7.0   8.5   9.5  11.8  22.9   7.0   7.0   7.0   7.0   7.0    -  SIG UP
       24.5  15.1  17.7  18.6  26.8  20.8  14.9  15.0  15.0  15.0  15.0    -  SNR LW
       11.1   9.2  10.4  11.2  13.1  23.6   8.9   9.0   9.1   9.1   9.1    -  SNR UP
        5.0   0.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0    -  TGAIN
        5.0   0.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0    -  RGAIN
         53    38    60    61    49    18    17    19    21    21    22    -  SNRxx
```

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Discussion – REL Calculation (1)

- Reliability prediction uses either SNR LW or SNR UP

- SNR LW is lower decile offset from median SNR
  - Lower decile SNR given by SNR90
  - SNR90 = SNR − SNR LW

- SNR UP is upper decile offset from median SNR
  - Upper decile SNR given by SNR10
  - SNR10 = SNR + SNR UP

Discussion – REL Calculation (2)

- When your required SNR (REQ.SNR) is equal to or less than the predicted SNR, use the following:

  (1) z = (SNR − REQ.SNR) / (ABS(SNR LW) / 1.28)

- When your required SNR (REQ.SNR) is greater than the predicted SNR, use the following:

  (2) z = ABS(SNR − REQ.SNR) / (ABS(SNR UP) / 1.28)

- Use look-up table to convert z to percentage reliability

- Artificially low SNR LW or SNR UP leads to prediction errors

Discussion – SIG LW and SIG UP

- SIG LW and SIG UP used to calculate SNR LW and SNR UP
  - Lower and upper decile offset from median signal (S DBW)
- At higher frequencies, SIG LW and SIG UP appear to take values predicted for lowest frequency
  - Artificially low values for SIG LW and SIG UP
  - Correspondingly low values for SNR LW and SNR UP

```
     CCIR Coefficients          METHOD 20   VOACAP 12.0722W  PAGE   6

 Jul    2014          SSN =  72.               Minimum Angle= 3.000 degrees
 LONDON               BIRMINGHAM          AZIMUTHS          N. MI.      KM
 51.50 N   0.17 W - 52.50 N    1.83 W    315.03  133.72      85.8    159.0
 XMTR  2-30 +  5.0 dBi[default\CCIR.000     ] Az=  0.0 OFFaz=315.0  1.000kW
 RCVR  2-30 +  5.0 dBi[default\CCIR.000     ] Az=  0.0 OFFaz=133.7
 3 MHz NOISE = -150.0 dBW     REQ. REL = 90%    REQ. SNR = 38.0 dB
 MULTIPATH POWER TOLERANCE =  3.0 dB   MULTIPATH DELAY TOLERANCE =  0.100 ms

 11.0  6.4  1.9  3.7  5.3  7.1 10.1 14.2 18.1 21.2 24.9 28.5  0.0 FREQ
       1F2  1 E  1 E  1F2  1F2  1F2  1F1  1F1  1F1  1F1  1F1   -  MODE
      78.9 49.8 55.3 75.6 78.8 78.8 70.9 70.9 70.9 70.9 70.9   -  TANGLE
       2.9  0.8  0.9  2.2  2.9  2.9  1.7  1.7  1.7  1.7  1.7   -  DELAY
       431   96  117  326  428  428  239  239  239  239  239   -  V HITE
      0.50 1.00 0.67 0.83 0.22 0.00 0.00 0.00 0.00 0.00 0.00   -  MUFday
       112  121  108  108  114  155  169  170  171  172  173   -  LOSS
        37   22   39   40   35   -2  -10   -9   -9   -9   -8   -  DBU
       -81  -91  -75  -77  -84 -125 -136 -137 -138 -139 -140   -  S DBW
      -159 -144 -152 -157 -160 -164 -168 -171 -173 -175 -177   -  N DBW
        78   53   78   80   76   39   32   34   36   36   37   -  SNR
       -15    0  -22  -23  -11   20   21   19   17   17   16   -  RPWRG
      0.98 0.90 1.00 1.00 0.96 0.53 0.20 0.31 0.36 0.41 0.45   -  REL
      0.00 0.00 1.00 0.00 0.00 0.00 0.05 0.09 0.12 0.15 0.17   -  MPROB
      0.68 0.50 0.81 0.82 0.63 0.23 0.13 0.16 0.17 0.18 0.19   -  S PRB
      22.5 11.5 14.8 15.9 25.0 18.5 11.5 11.5 11.5 11.5 11.5   -  SIG LW
       9.3  7.0  8.5  9.5 11.8 22.9  7.0  7.0  7.0  7.0  7.0   -  SIG UP
      24.5 15.1 17.7 18.6 26.8 20.8 14.9 15.0 15.0 15.0 15.0   -  SNR LW
      11.1  9.2 10.4 11.2 13.1 23.6  8.9  9.0  9.1  9.1  9.1   -  SNR UP
       5.0  0.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0   -  TGAIN
       5.0  0.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0   -  RGAIN
        53   38   60   61   49   18   17   19   21   21   22   -  SNRxx
```

Discussion – SIG LW

- SIG LW gradually increases to maximum 25.0 dB at 7.1 MHz
  - Then decreases to minimum 11.5 dB
- ‘Above-the-MUF’ loss in VOACAP limited to 25 dB

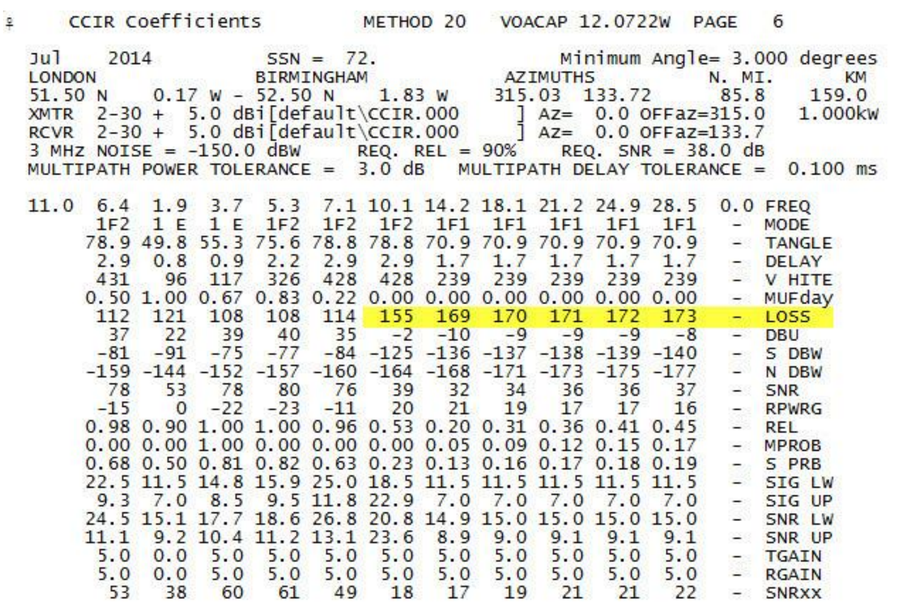
```
     CCIR Coefficients          METHOD 20   VOACAP 12.0722W  PAGE   6

 Jul    2014            SSN =  72.                 Minimum Angle= 3.000 degrees
 LONDON                BIRMINGHAM             AZIMUTHS            N. MI.      KM
 51.50 N    0.17 W - 52.50 N    1.83 W   315.03  133.72          85.8     159.0
 XMTR  2-30 +  5.0 dBi[default\CCIR.000        ] Az=  0.0 OFFaz=315.0   1.000kW
 RCVR  2-30 +  5.0 dBi[default\CCIR.000        ] Az=  0.0 OFFaz=133.7
 3 MHz NOISE = -150.0 dBW      REQ. REL = 90%     REQ. SNR = 38.0 dB
 MULTIPATH POWER TOLERANCE =  3.0 dB   MULTIPATH DELAY TOLERANCE =  0.100 ms

 11.0  6.4  1.9  3.7  5.3  7.1 10.1 14.2 18.1 21.2 24.9 28.5  0.0 FREQ
       1F2  1 E  1 E  1F2  1F2  1F2  1F1  1F1  1F1  1F1  1F1   -  MODE
      78.9 49.8 55.3 75.6 78.8 78.8 70.9 70.9 70.9 70.9 70.9   -  TANGLE
       2.9  0.8  0.9  2.2  2.9  2.9  1.7  1.7  1.7  1.7  1.7   -  DELAY
       431   96  117  326  428  428  239  239  239  239  239   -  V HITE
      0.50 1.00 0.67 0.83 0.22 0.00 0.00 0.00 0.00 0.00 0.00   -  MUFday
       112  121  108  108  114  155  169  170  171  172  173   -  LOSS
        37   22   39   40   35   -2  -10   -9   -9   -9   -8   -  DBU
       -81  -91  -75  -77  -84 -125 -136 -137 -138 -139 -140   -  S DBW
      -159 -144 -152 -157 -160 -164 -168 -171 -173 -175 -177   -  N DBW
        78   53   78   80   76   39   32   34   36   36   37   -  SNR
       -15    0  -22  -23  -11   20   21   19   17   17   16   -  RPWRG
      0.98 0.90 1.00 1.00 0.96 0.53 0.20 0.31 0.36 0.41 0.45   -  REL
      0.00 0.00 1.00 0.00 0.00 0.00 0.05 0.09 0.12 0.15 0.17   -  MPROB
      0.68 0.50 0.81 0.82 0.63 0.23 0.13 0.16 0.17 0.18 0.19   -  S PRB
      22.5 11.5 14.8 15.9 25.0 18.5 11.5 11.5 11.5 11.5 11.5   -  SIG LW
       9.3  7.0  8.5  9.5 11.8 22.9  7.0  7.0  7.0  7.0  7.0   -  SIG UP
      24.5 15.1 17.7 18.6 26.8 20.8 14.9 15.0 15.0 15.0 15.0   -  SNR LW
      11.1  9.2 10.4 11.2 13.1 23.6  8.9  9.0  9.1  9.1  9.1   -  SNR UP
       5.0  0.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0   -  TGAIN
       5.0  0.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0   -  RGAIN
        53   38   60   61   49   18   17   19   21   21   22   -  SNRxx
```

Discussion – ‘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 will give predictions even when it has no idea what is going to happen”
  - “If the program could talk, it would tell you that it doesn't have any idea what is going to happen on XX MHz”

Discussion – LOSS

- LOSS appears fairly stable above 7.1 MHz
  - Little variation with frequency
  - Under-predicting loss?
  - Artificially high S DBW?



```
        CCIR Coefficients          METHOD 20   VOACAP 12.0722W   PAGE    6

  Jul     2014              SSN =  72.                Minimum Angle= 3.000 degrees
  LONDON                   BIRMINGHAM             AZIMUTHS             N. MI.      KM
  51.50 N    0.17 W - 52.50 N    1.83 W    315.03  133.72          85.8     159.0
  XMTR  2-30 +  5.0 dBi[default\CCIR.000          ] Az=  0.0 OFFaz=315.0   1.000kW
  RCVR  2-30 +  5.0 dBi[default\CCIR.000          ] Az=  0.0 OFFaz=133.7
  3 MHz NOISE = -150.0 dBW       REQ. REL = 90%     REQ. SNR = 38.0 dB
  MULTIPATH POWER TOLERANCE =  3.0 dB   MULTIPATH DELAY TOLERANCE =  0.100 ms

  11.0   6.4  1.9  3.7  5.3  7.1 10.1 14.2 18.1 21.2 24.9 28.5   0.0 FREQ
         1F2  1 E  1 E  1F2  1F2  1F2  1F1  1F1  1F1  1F1  1F1    -  MODE
        78.9 49.8 55.3 75.6 78.8 78.8 70.9 70.9 70.9 70.9 70.9    -  TANGLE
         2.9  0.8  0.9  2.2  2.9  2.9  1.7  1.7  1.7  1.7  1.7    -  DELAY
         431   96  117  326  428  428  239  239  239  239  239    -  V HITE
        0.50 1.00 0.67 0.83 0.22 0.00 0.00 0.00 0.00 0.00 0.00    -  MUFday
         112  121  108  108  114  155  169  170  171  172  173    -  LOSS
          37   22   39   40   35   -2  -10   -9   -9   -9   -8    -  DBU
         -81  -91  -75  -77  -84 -125 -136 -137 -138 -139 -140    -  S DBW
        -159 -144 -152 -157 -160 -164 -168 -171 -173 -175 -177    -  N DBW
          78   53   78   80   76   39   32   34   36   36   37    -  SNR
         -15    0  -22  -23  -11   20   21   19   17   17   16    -  RPWRG
        0.98 0.90 1.00 1.00 0.96 0.53 0.20 0.31 0.36 0.41 0.45    -  REL
        0.00 0.00 1.00 0.00 0.00 0.00 0.05 0.09 0.12 0.15 0.17    -  MPROB
        0.68 0.50 0.81 0.82 0.63 0.23 0.13 0.16 0.17 0.18 0.19    -  S PRB
        22.5 11.5 14.8 15.9 25.0 18.5 11.5 11.5 11.5 11.5 11.5    -  SIG LW
         9.3  7.0  8.5  9.5 11.8 22.9  7.0  7.0  7.0  7.0  7.0    -  SIG UP
        24.5 15.1 17.7 18.6 26.8 20.8 14.9 15.0 15.0 15.0 15.0    -  SNR LW
        11.1  9.2 10.4 11.2 13.1 23.6  8.9  9.0  9.1  9.1  9.1    -  SNR UP
         5.0  0.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0    -  TGAIN
         5.0  0.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0    -  RGAIN
          53   38   60   61   49   18   17   19   21   21   22    -  SNRXX
```

Plextek Consulting

Discussion – Method 25

- Use Method 25 for more detail on predictions
- Example at 1100 UTC on 10.1 MHz
  - MODE PROB is zero for all possible modes at this time and frequency (1E, 1F1 and 1F2)
  - 'Most reliable mode' is 1F2 even if MODE PROB is zero
  - SNR calculation includes 'contributions' from other modes even if MODE PROB values are zero
  - Artificially high reliability

```
   CCIR Coefficients           METHOD 25   VOACAP 12.0722W  PAGE 115

  Jul    2014           SSN =  72.               Minimum Angle= 3.000 degrees
  LONDON               BIRMINGHAM          AZIMUTHS          N. MI.      KM
  51.50 N    0.17 W - 52.50 N    1.83 W   315.03  133.72       85.8    159.0
  XMTR  2-30 +  5.0 dBi[default\CCIR.000      ] Az=  0.0 OFFaz=315.0   1.000kW
  RCVR  2-30 +  5.0 dBi[default\CCIR.000      ] Az=  0.0 OFFaz=133.7
  3 MHz NOISE = -150.0 dBW      REQ. REL = 90%    REQ. SNR = 38.0 dB

 SUMMARY    3 MODES   FREQ =  10.1 MHZ  UT =  11.0
                                                 Most REL
                   1. E       1.F1       1.F2       1.F2
  TIME DEL.        0.99       1.68       2.91       2.91
  ANGLE           57.00      70.92      78.78      78.78
  VIR. HITE      125.30     238.98     427.94     427.94
  TRAN.LOSS      171.49     167.73     155.00     155.00
  T. GAIN          5.00       5.00       5.00       5.00
  R. GAIN          5.00       5.00       5.00       5.00
  ABSORB           5.33       4.75       4.58
  FS. LOSS       102.01     106.60     111.34
  FIELD ST.      -19.20     -15.44      -2.71      -2.39
  SIG. POW.     -141.49    -137.73    -125.00    -124.68
  SNR             22.38      26.14      38.87      39.19
  MODE PROB        0.00       0.00       0.00       0.00
  R. PWRG       1000.00    1000.00    1000.00      19.62
  RELIABIL         0.01       0.04       0.52       0.53
  SERV PROB        0.08       0.10       0.23       0.23
  SIG LOW         11.52      11.52      20.13      18.55
  SIG  UP          7.04       7.04      23.22      22.91
  NOISE =   -164        S. POWER = -124.7
  SIGNAL =   11.5     1.3     7.0  /      2.1      3.5      1.0
  NOISE =     9.4  -163.9     5.5  /      1.4      4.6      1.5
  RELIAB =   23.6    39.2    20.8
  SPROB =    28.6    16.6    28.6
```

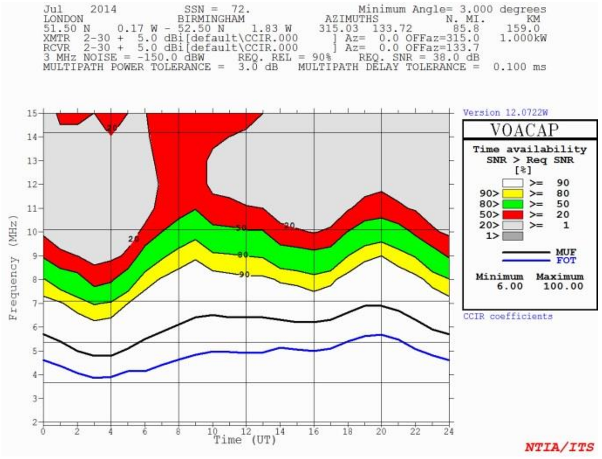
Discussion – Effects

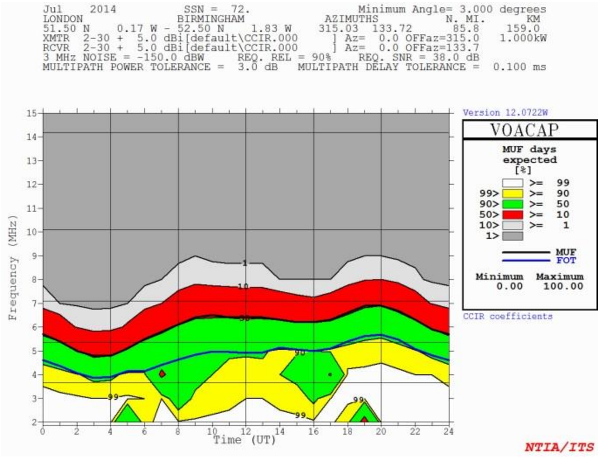
- Affects short links most (i.e. NVIS links)
  - Simulations appear better behaved for links > ~1000 km
- REL and MUFday contradictions more likely when allowable path loss is large
  - High transmit power levels (e.g 1 kW)
  - Modest or high antenna gains (e.g. NVIS dipole above ground ~4-6 dBi)
  - Low man-made noise levels (e.g. less than ‘Rural’)
  - Low required SNR (e.g. narrow bandwidth modes and/or not accounting for fading conditions)

Recommendations (1)

- User validation of VOACAP NVIS predictions necessary
  - Check predictions for longer distances up to ~1000 km

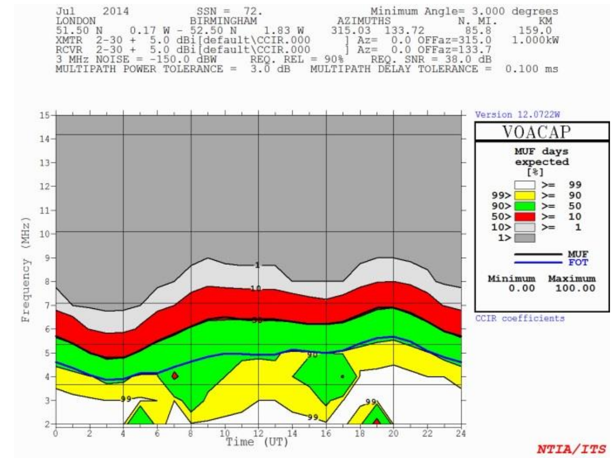
- Do not rely on REL parameter alone
  - REL can be non-zero when MUFday is zero (contradiction)



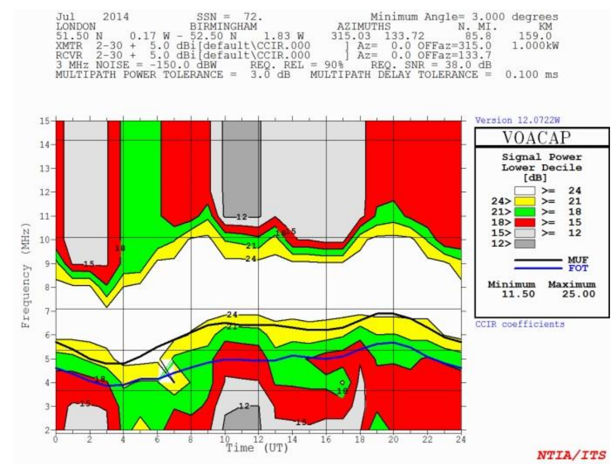


Recommendations (2)

- Check MUFday parameter
  - Is ionospheric support predicted at frequency of interest?
  - Check Method 9 frequencies



- Check SIG LW parameter
  - Has SIG LW reached 25 dB at some frequency?
  - Indication that VOACAP is having difficulties



VOACAP – Unfinished Business?

- Correct VOACAP to prevent false signal, noise and reliability predictions when ionospheric propagation not supported

- Other loose ends?
  - George Lane
    - “*By the way, the IONCAP family of programs does have a multipath probability calculation which is supposed to give an estimate of the probability that the presence of other modes will cause serious multipath conditions. Sadly, this calculation is in error. However, funding ran out before I could get the corrections into VOACAP*”
    - “*After that are 3 numbers which deal with prediction errors and are included in the service probability [S PROB calculation which is not recommended for use at this time*”

Summary

- VOACAP reliability predictions can be in error for short-range links
  - e.g. Good reliability predicted when no ionospheric support predicted
  - Affects predictions for NVIS links and links < ~1000 km
- 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

References

- G. Lane, *Signal-to-Noise Predictions Using VOACAP – A User's Guide*, Rockwell Collins, Cedar Rapids, IA, USA, 2001.
- www.voacap.com

Online VOACAP Parameters

- Low man-made noise levels (−155 dBW in 1 Hz at 3 MHz)
  - Lower than ITU-R Rec. P.372-11 ‘Rural’
    - ‘Rural’ −150 dBW in 1 Hz at 3 MHz
    - ‘Quiet rural’ −164 dBW in 1 Hz at 3 MHz
- Low required SNR (CW 24 dBHz and SSB 38 dBHz)
  - Lower than ITU-R Rec. F.339-8 for fading conditions
    - CW 38 dBHz
    - SSB 48/61/72 dBHz depending on grade of service