Australian Government
Department of Defence
Defence Science and Technology Organisation

The DSTO Ionospheric Sounder Replacement for JORN

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14th Ionospheric Effects Symposium 2015

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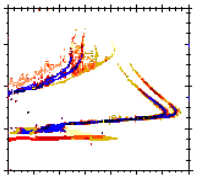
Background

JORN = Jindalee Over-the-horizon Radar Network



- 3 Radars
- The Northern approaches to Australia
- High-Frequency (HF) band, 3-30MHz
- A national defence capability for Australia.

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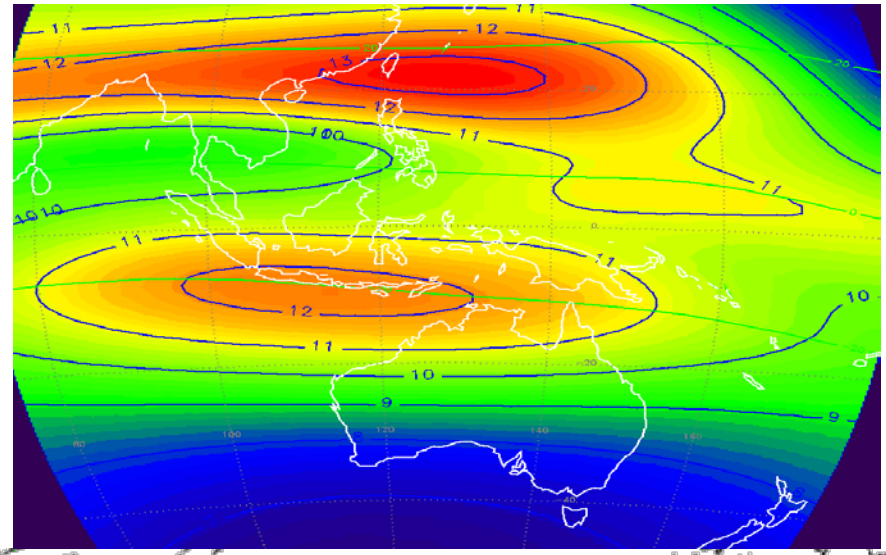
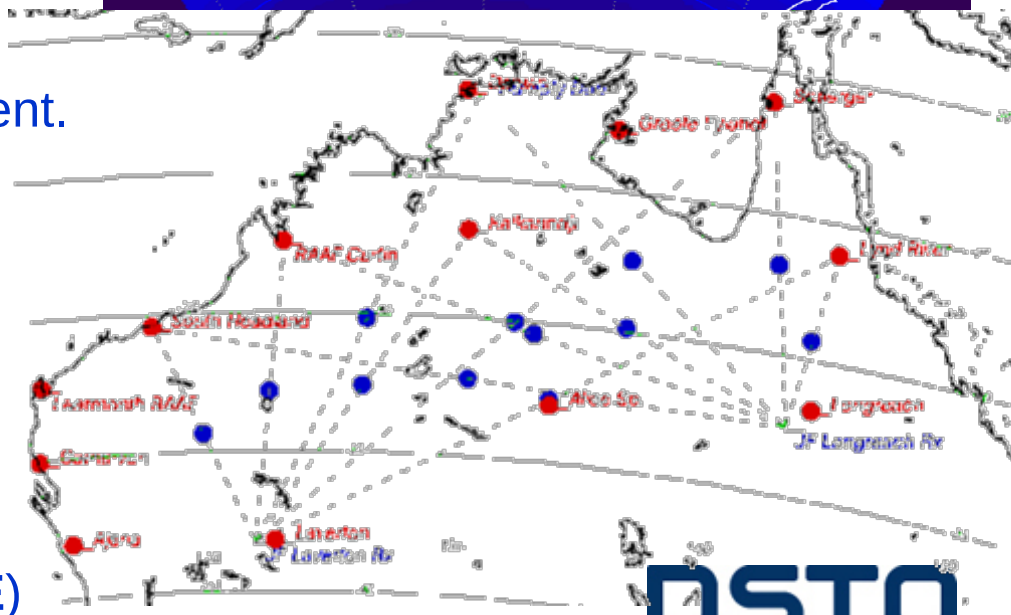
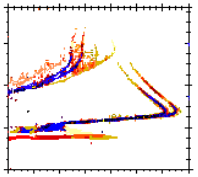
The Requirement

- JORN requires a real-time model of the ionosphere.
- Primary source of data is
  - 2x DPS-4 and 11x DPS-1.
- DPS-1 at end of maintainable life.
- JORN ongoing sustainment program
  - Upgrade of VIS network
  - form/fit/function VIS replacement.
- HFRB of DSTO developed VI solution
  - based on its radar hardware technology
  - HFRB solution is the **P**ortable **R**emote **I**onospheric **M**onitoring **E**quipment (**PRIME**)





Criteria for the PRIME development



- form/fit/function replacement of old Lowell DPS-1
- NOT trying to compete or reproduce latest Lowell or other VIS
- accurate + resilient TRACE output over wide variety of ionospheres
- Robust hardware/software to handle varied local conditions
- easy and convenient advancement path for future development
- Flexibility in design
  - allow for scientific R&D
  - JORN operational usage
- commonality with other JORN products to ease through-life maintenance (*eg*. Common hardware with OIS)

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Timeline of PRIME development

2006-2007 – DINIS ➔ DORS – Digital Oblique Receiver System

- A HFRB OIS Rx and Tx system
- Using HFRB MkIID drx + HFRB dwfg hardware,software

2007-2009 – SpICE – Spatial Ionospheric Correlation Experiment

- Evaluated DORS as a QVIS (NVIS), then as a VIS.
- **Demonstrated a DSTO VIS capability**

2x digital Rx →

2x digital wfg →

2010-2015 – VISRep – The JORN VIS Replacement Project

- Aug 2010 – PRIME concept demo
- Dec 2014 – PRIME validation
- 2015 – JORN integrations

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PRIME

25W fwd
<1W rev

- All DSTO created and developed
- ~20W CW system; 100% duty cycle;
- Operates with close but separate Tx & Rx antenna;
- Has overcome issues with Rx in the near-field of CW Tx;
- The Tx direct-wave is the largest signal at the Rx;
- Uses 2x orthogonal Rx antenna
  - to obtain 2x analogue signal channels
  - which are digitised at RF to give 2x complex timeseries
  - which then give 2x complex ionograms
- O/X discrimination based on phases of 2x complex ionograms
- Realtime Trace extraction of both O and X mode signals
- Realtime Ionospheric parameters

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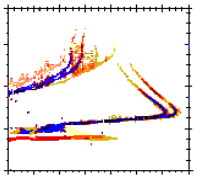
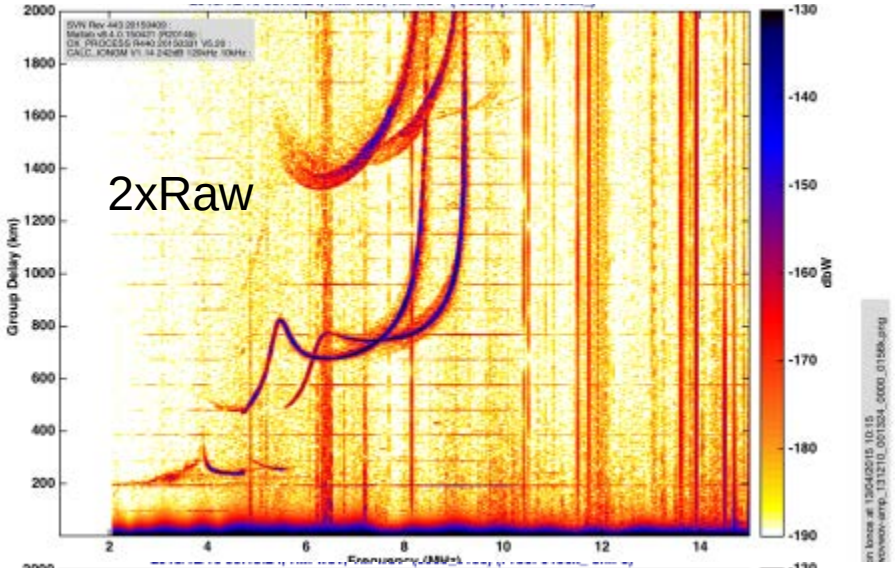
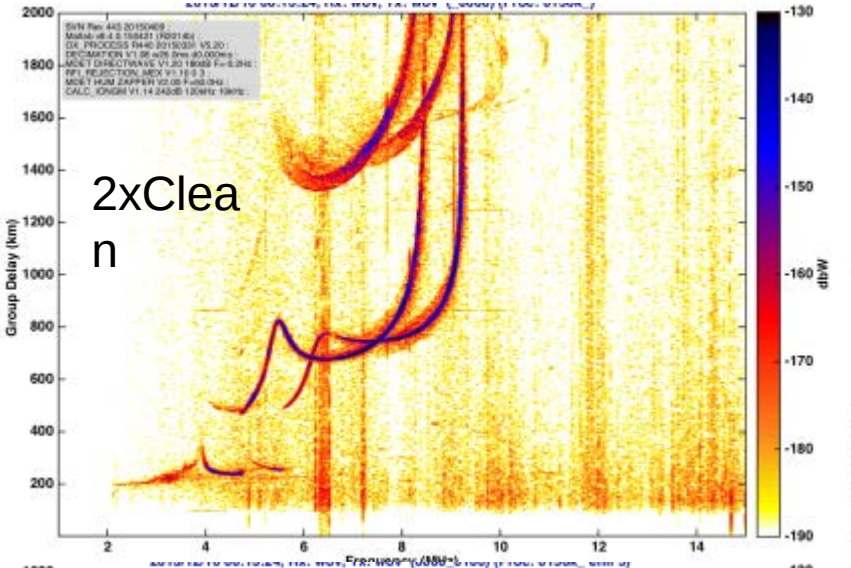
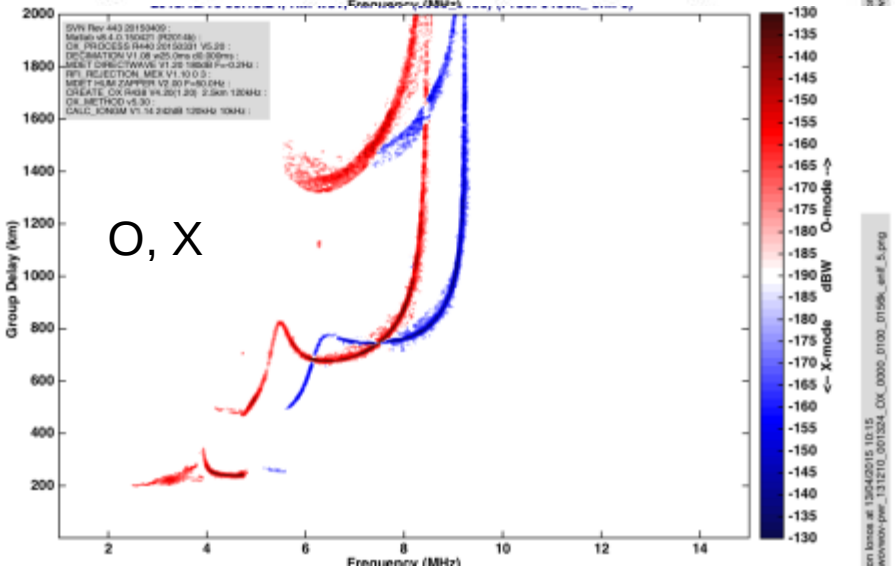
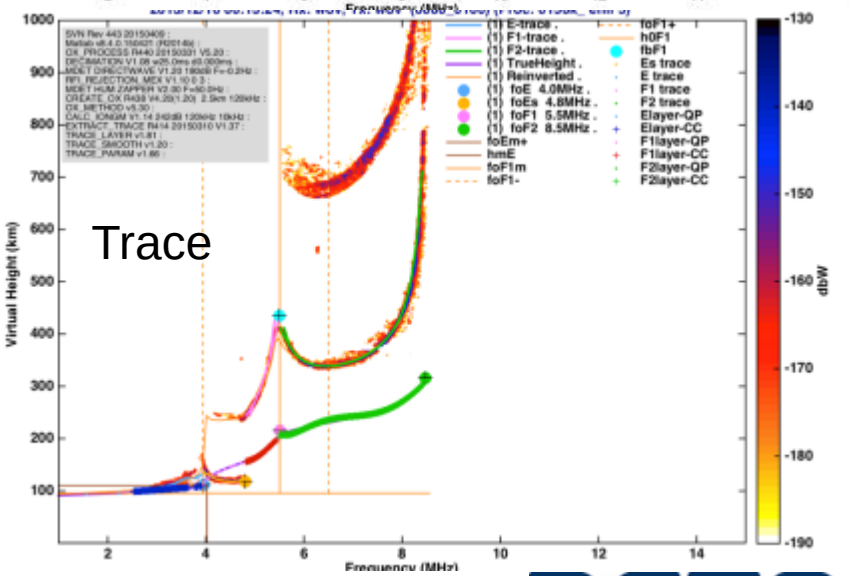
Raw -> Clean -> O/X-> Trace









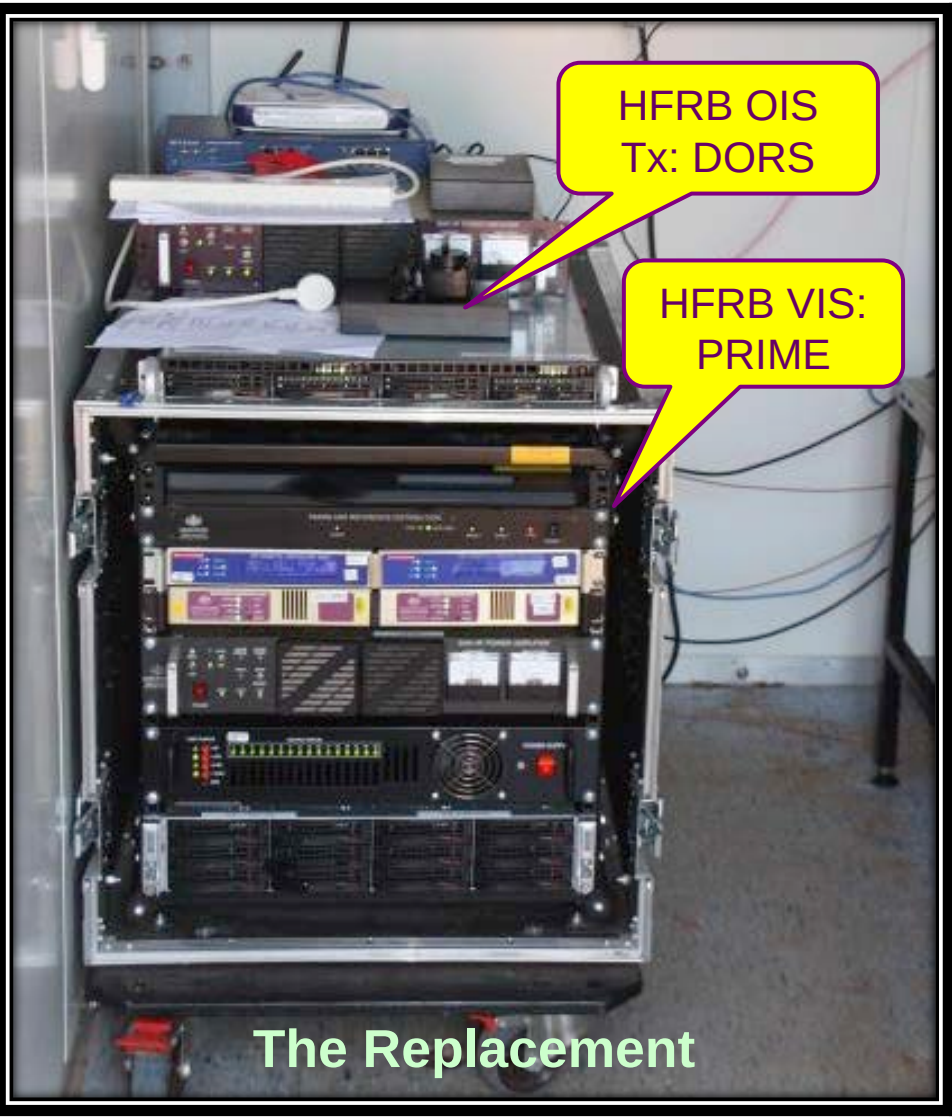


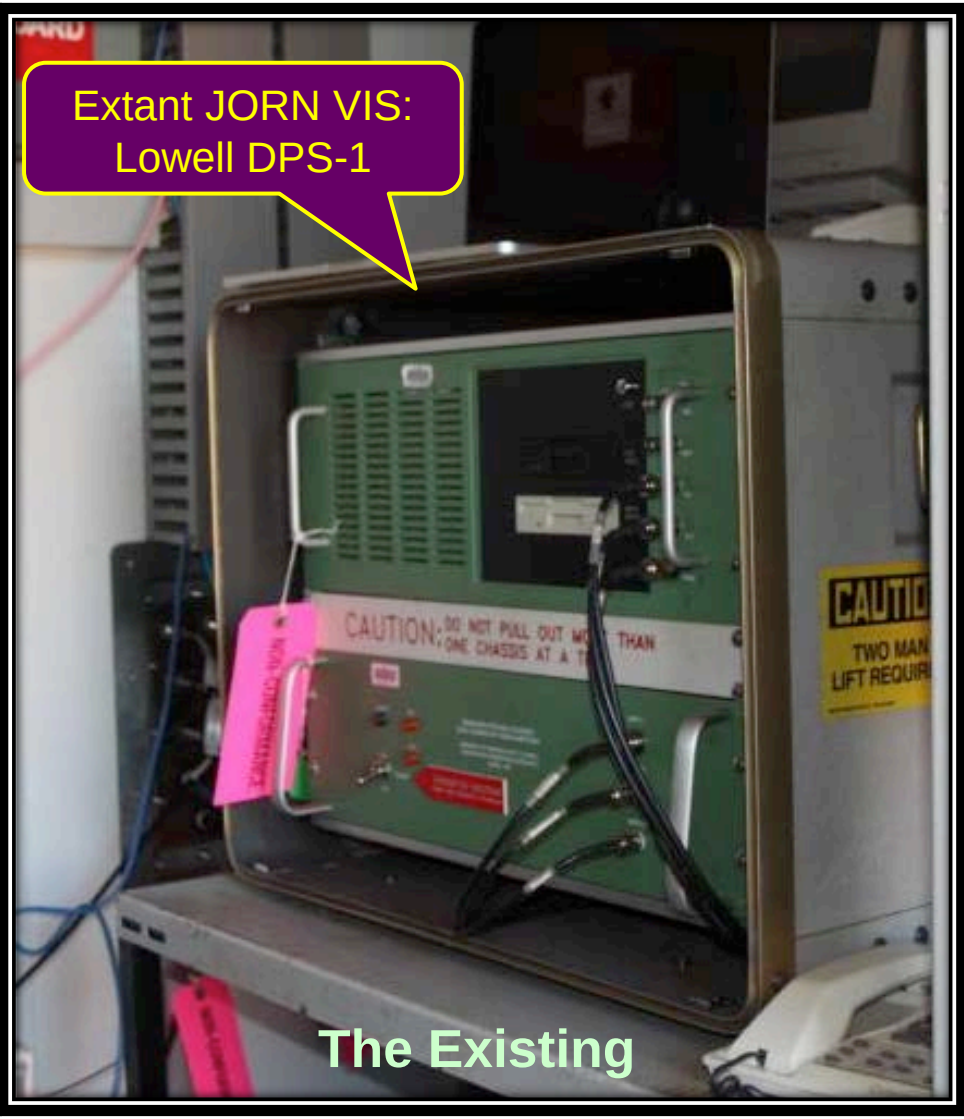
Side-x-Side trial Dec2014

~100m Tx - Rx HERB VIS

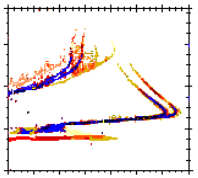
JORN VIS

The Two VIS

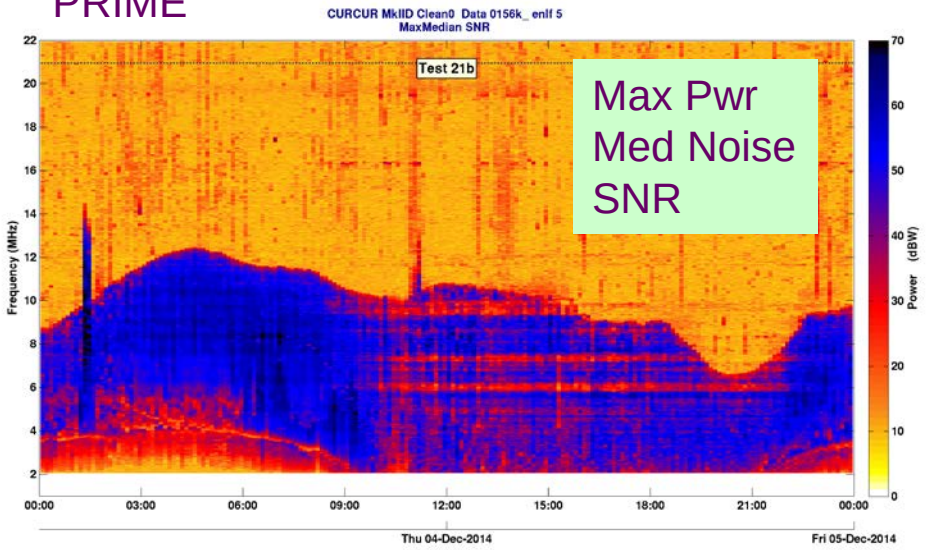

HFRB OIS
Tx: DORS
HFRB VIS:
PRIME
The Replacement


Extant JORN VIS:
Lowell DPS-1
CAUTION:
The Existing

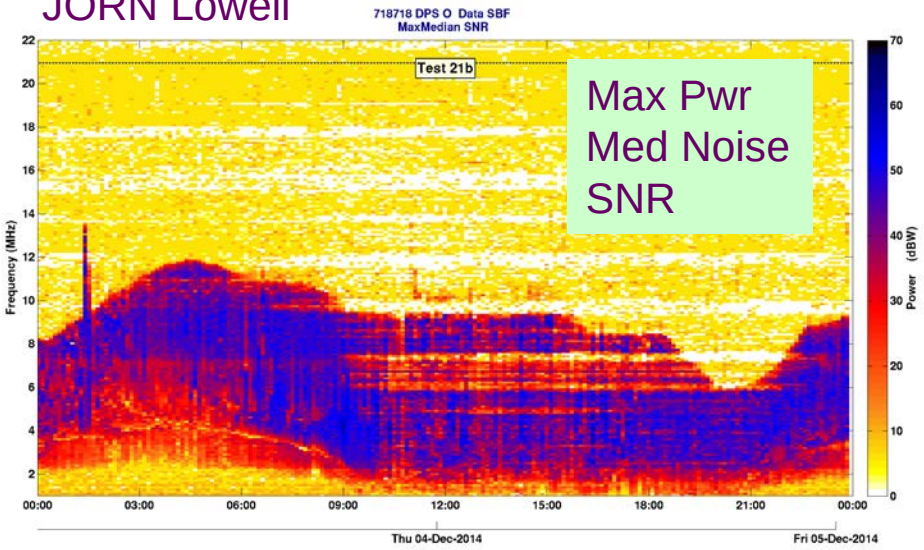
HFRB VIS – Lowell DPS-1 SNR Comparison

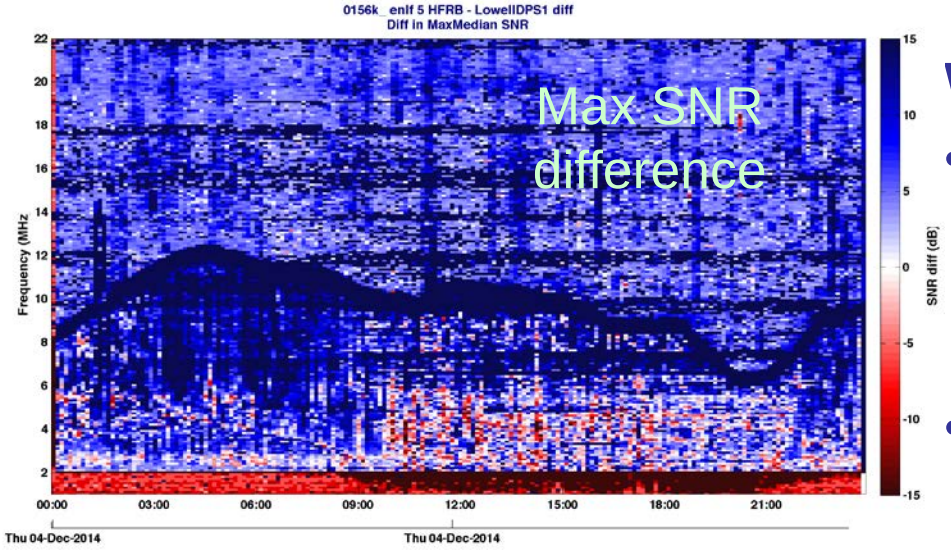


PRIME



JORN Lowell





Where there is signal

- **On average, Max SNR**
  - PRIME ~10dB > DPS1 (F-region)
  - PRIME ~5dB > DPS1 (E-region)
- **On average, Median SNR**
  - PRIME ~10-15dB > DPS1

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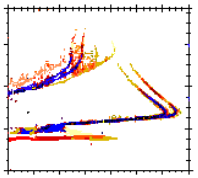
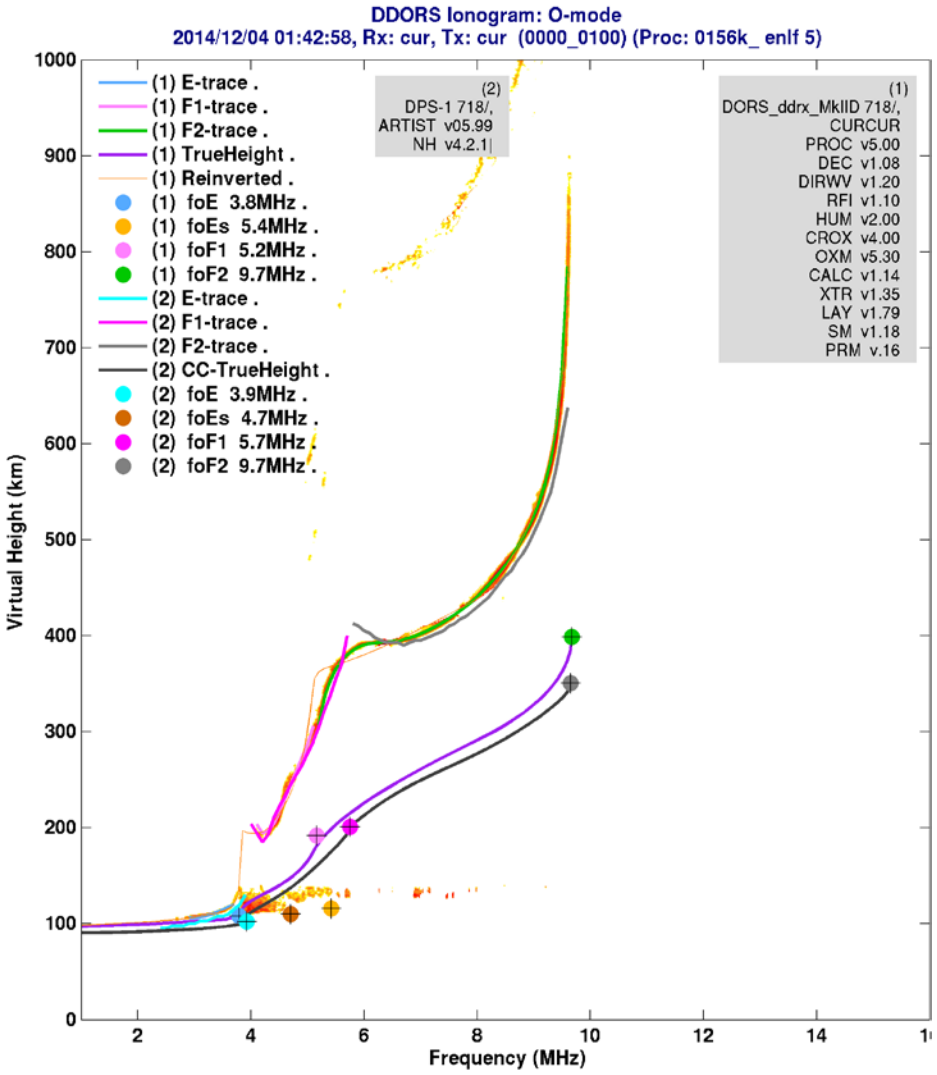
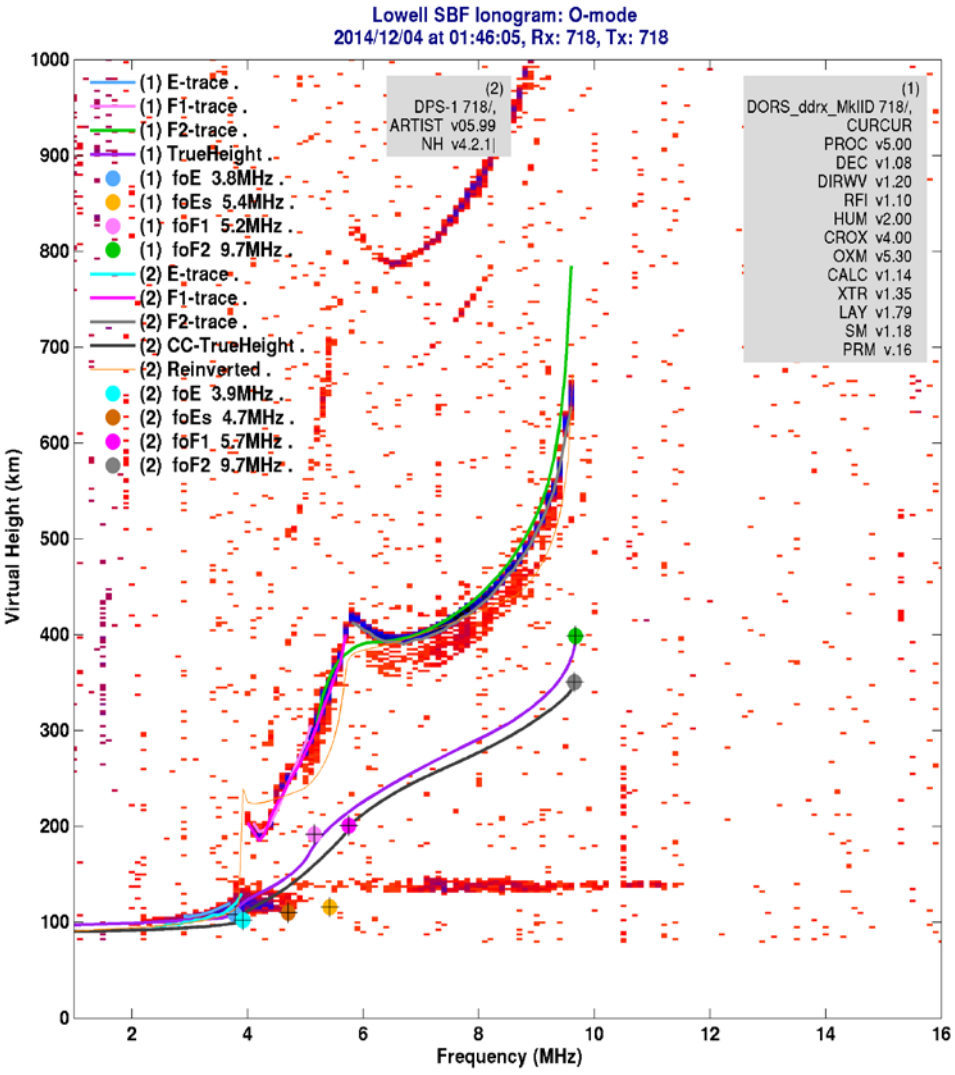


Ionogram / Trace comparison

PRIME HRI



DPS1 SBT



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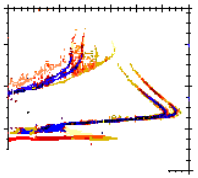
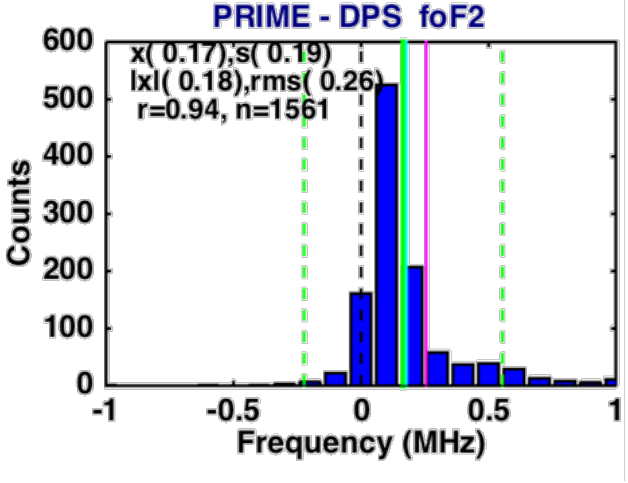
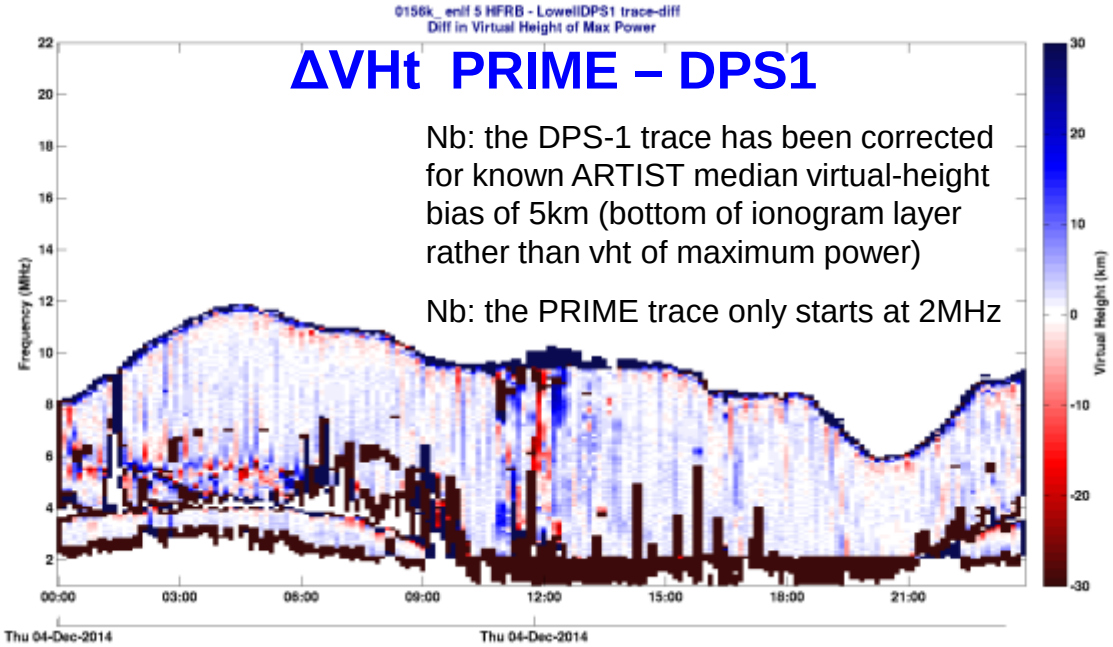
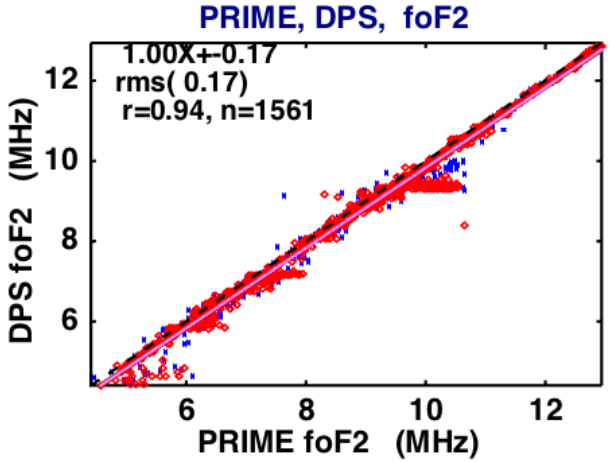
Comparison of Traces and Parameters









PRIME v DPS comparison

- Ionograms – PRIME cleaner
- Trace accuracy– much the same
- Trace robustness – PRIME superior
- Parameter accuracy – much the same
- Parameter robustness – PRIME superior

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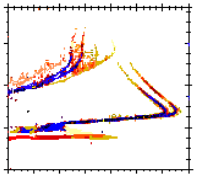
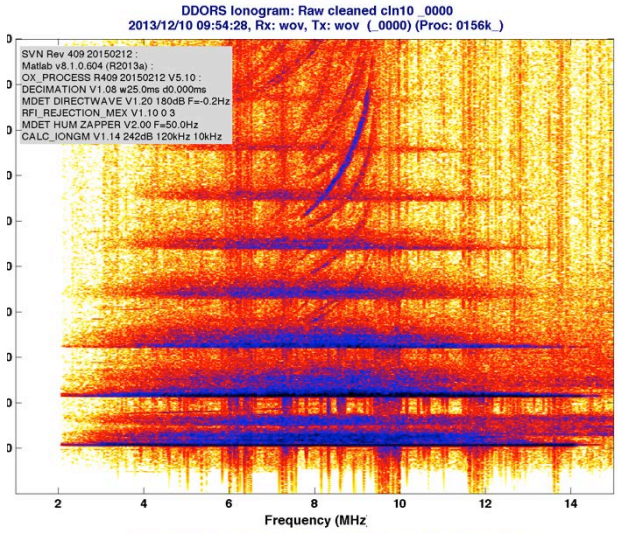
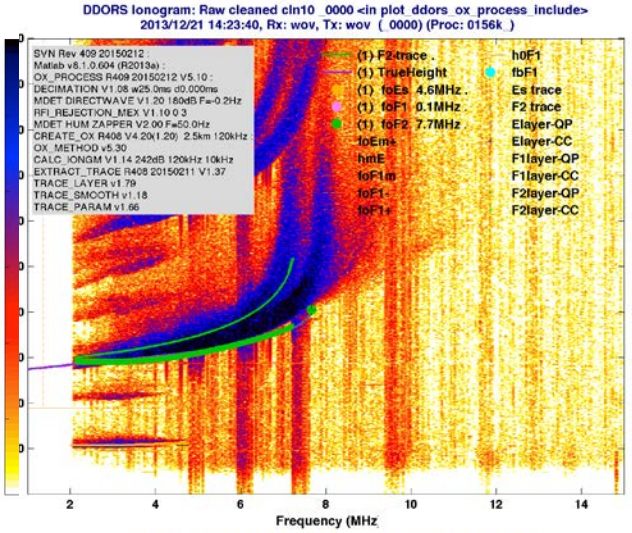
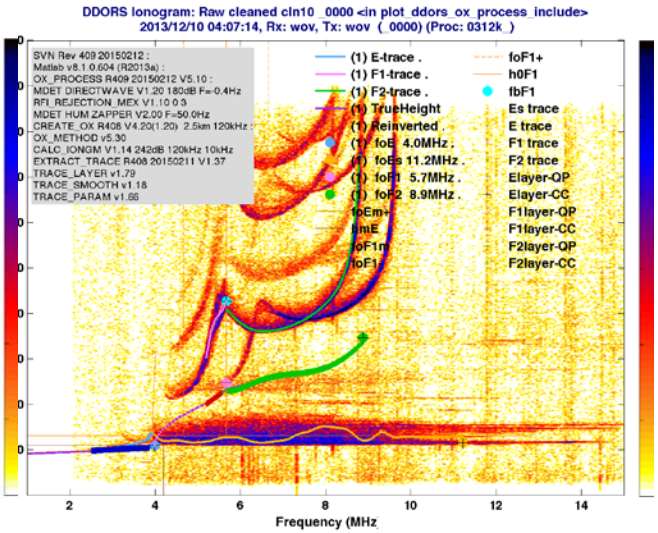
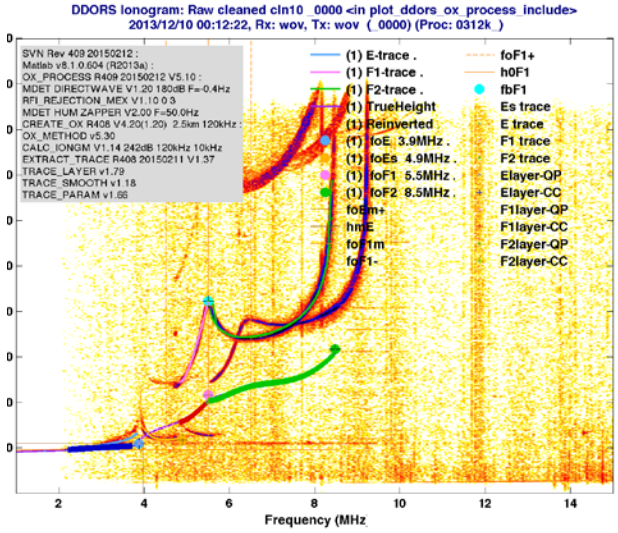
Ionograms: the Good, Bad & Ugly

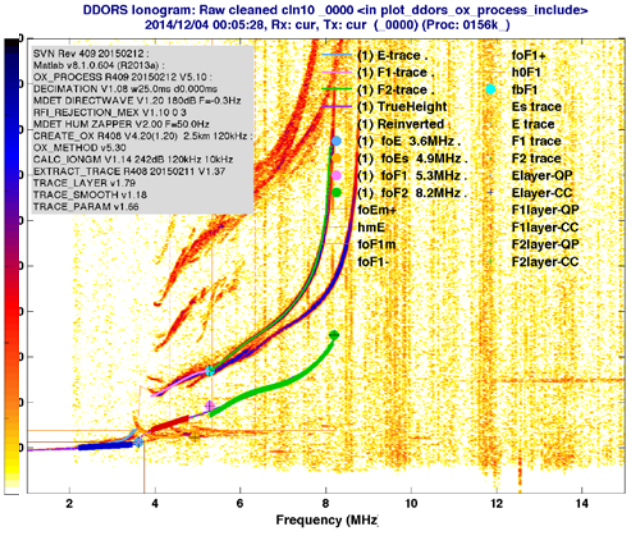


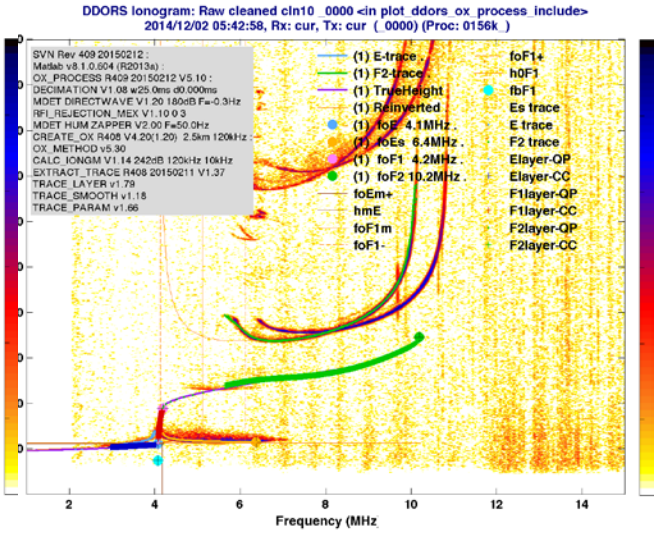












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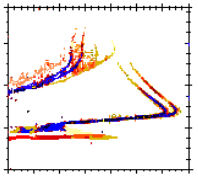
TIMING AND REFERENCE DISTRIBUTION
HF DIGITAL RECEIVER MK2
VIS DWG
DIS TX
DWG
50W HF POWER AMPLIFIER
TEST POINTS
OUTPUT STATUS
POWER SUPPLY
PRIME

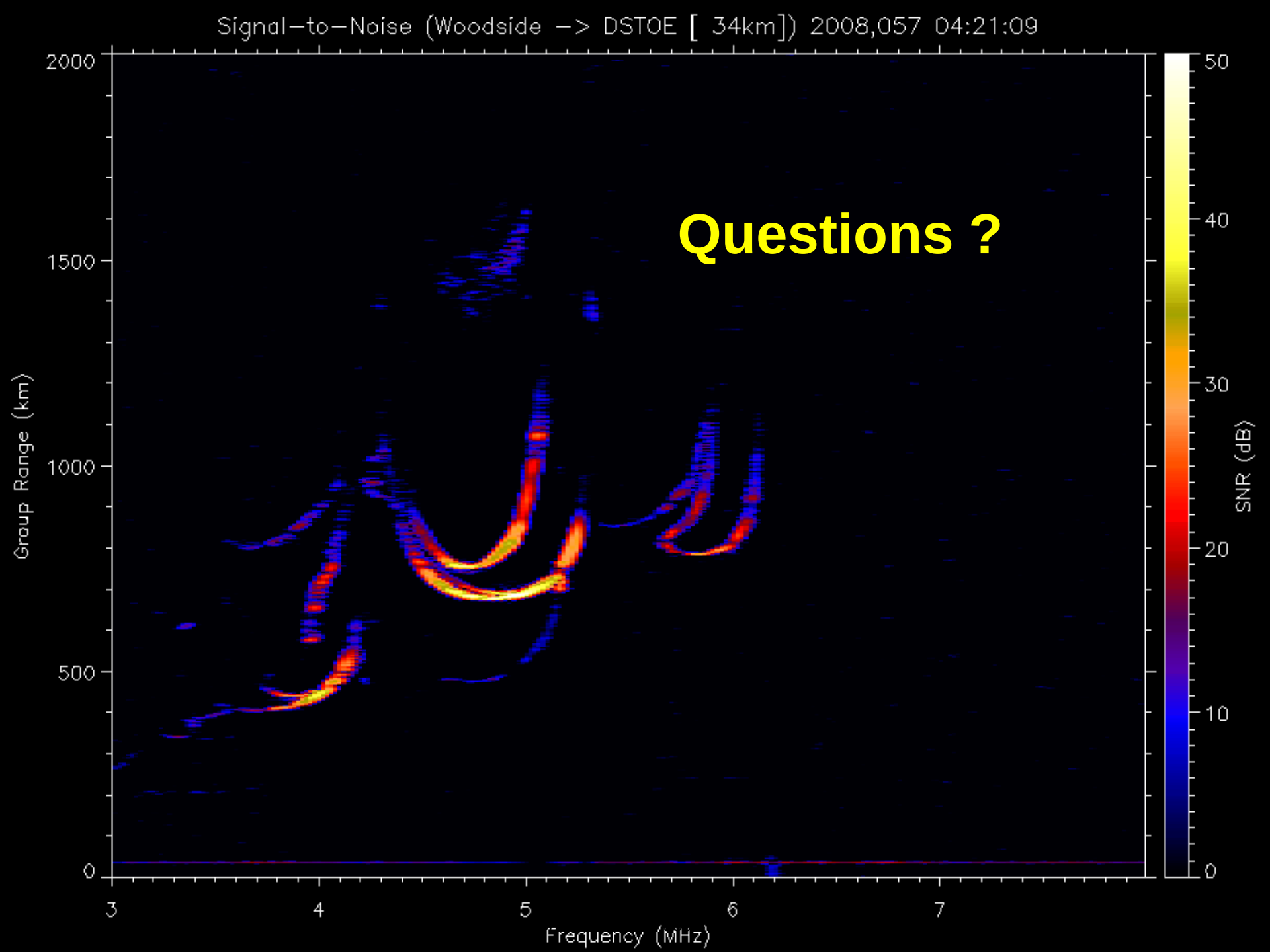
Conclusion

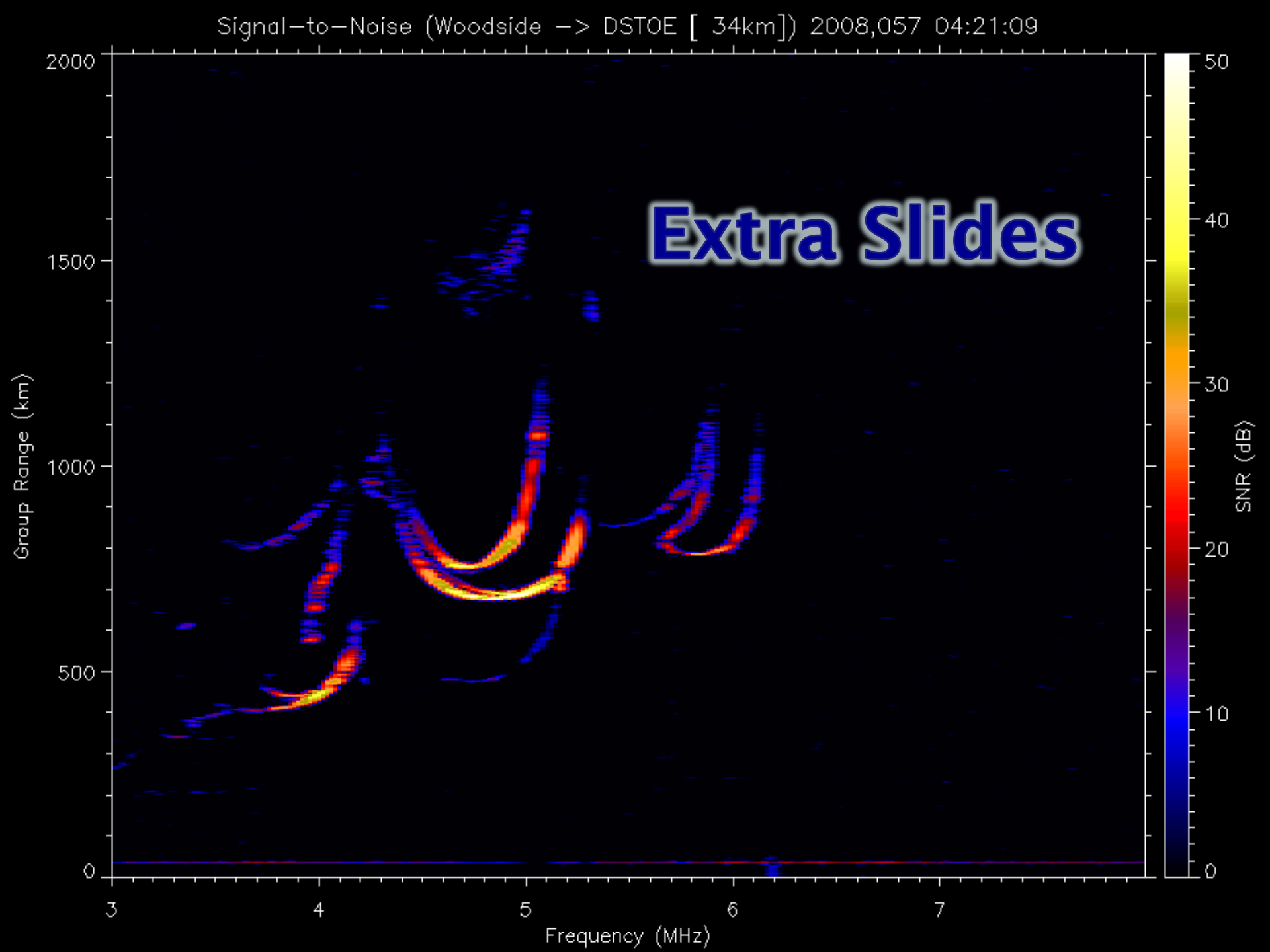
Issues investigated and solved



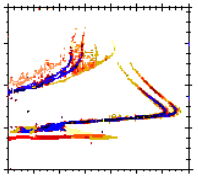
- **Receiving Ionograms in the near field of VIS transmitter**
  - **Isolation – electrical, RF, spatial (≥100m and position in the null)**
  - **signal processing**
- Self-generated noise sources
  - Direct wave leakage and phase noise
  - other equipment on site (generators, comms antenna, …)
  - coupling via common power-lines, timing sources (TRDU, GPS), switched power supplies, power-packs, RF leakage (PA, WFG, GPS), earth-current loops
- Rx choices: Monitor drx vs MkIID drx
  - Monitor Rx sufficient for F-layer signals.
  - MkIID required for better sensitivity in E-region (avge of 9dB better SNR)
- Improving the SNR at E-layer frequencies
  - Alternate Rx Antenna, Signal processing options
- **Visual inspections of Raw, cleaned, processed ionograms and Trace extraction**
  - When the ionosphere is good, all fits and extractions are good
  - Many unusual ionospheric conditions produced many poor results
  - Tuning and algorithmic development for a more robust system
- **Operational viability**
  - **Running at an existing JORN VIS site, using existing JORN VIS antenna,**
  - **in presence of OIS Tx**
  - **Connected to JORN sounder data network, being received and displayed at JCC**

DSTO


Signal−to−Noise (Woodside −> DSTOE [34km]) 2008,057 04:21:09
Questions ?
Group Range (km)
2000
1500
1000
500
0
3
4
5
6
7
Frequency (MHz)
SNR (dB)
50
40
30
20
10
0


Signal−to−Noise (Woodside −> DSTOE [34km]) 2008,057 04:21:09
Extra Slides
Group Range (km)
2000
1500
1000
500
0
3
4
5
6
7
Frequency (MHz)
SNR (dB)
50
40
30
20
10
0

In Progress



- Soak-test of PRIME at an operational JORN sounder site – full feed into RTIM etc…
- Align high-res output with OIS high-res files
- Transition the PRIME solution to a JORN supportable, configured, operational system
- Build and field more systems
- Transition Build and Maintenance to Industry

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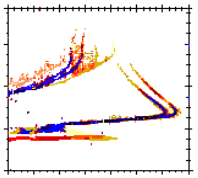
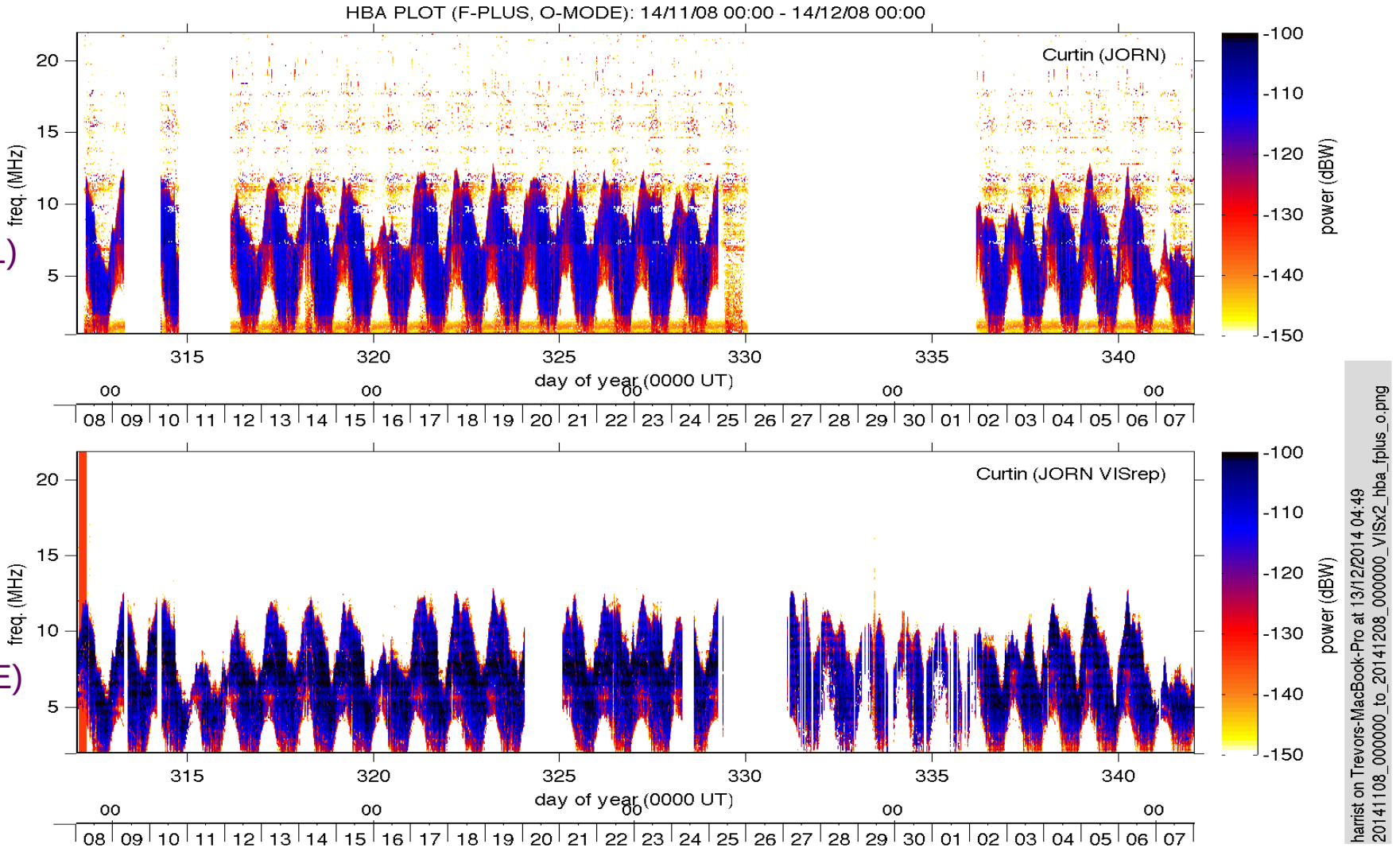
VIS Replacement Trial: Curtin 2014
"Simultaneous" DPS-1 and PRIME data collect



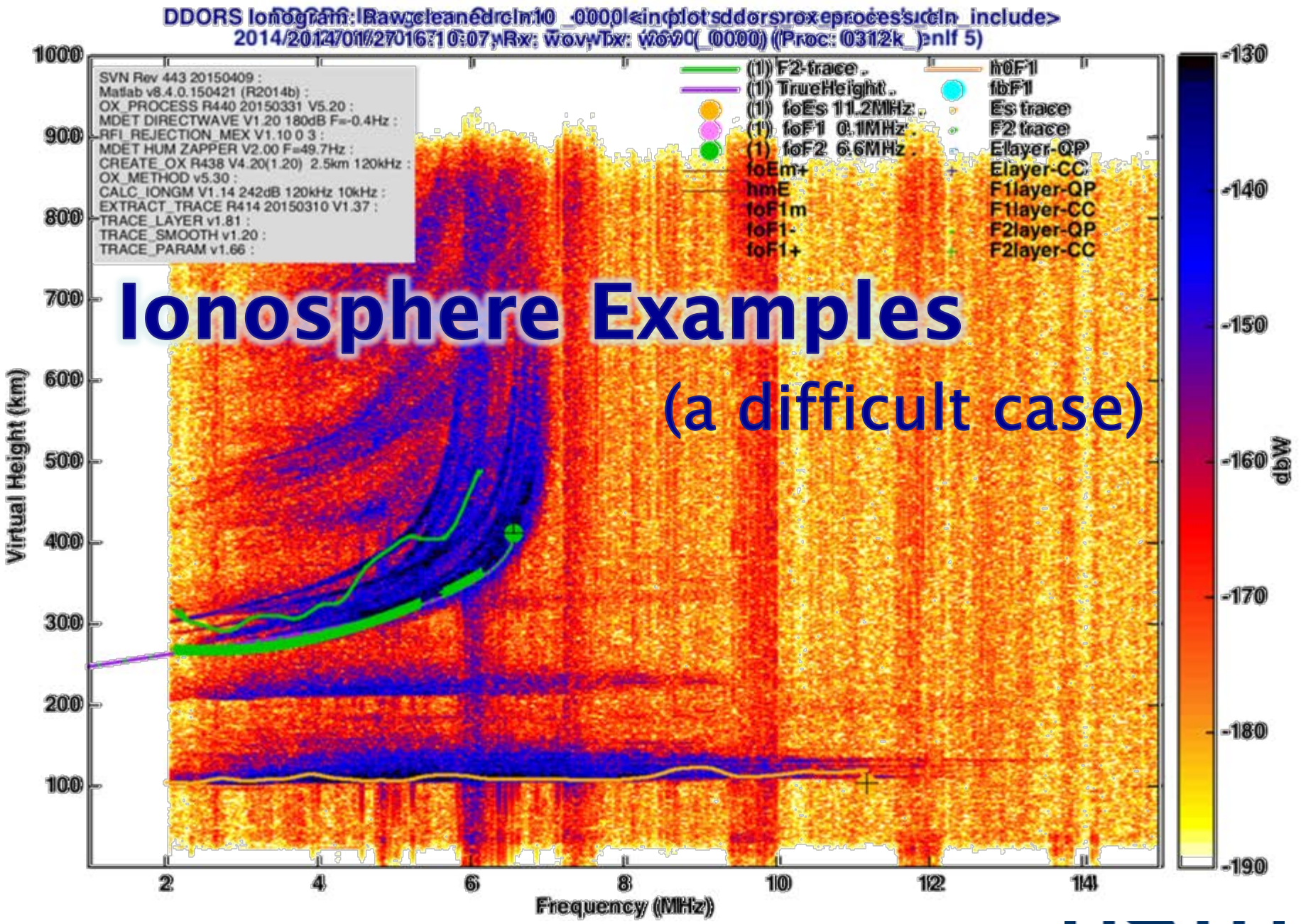
Extant JORN VIS (DPS-1)

HFRB VIS (PRIME)

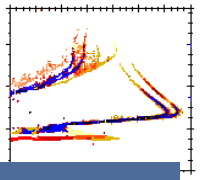


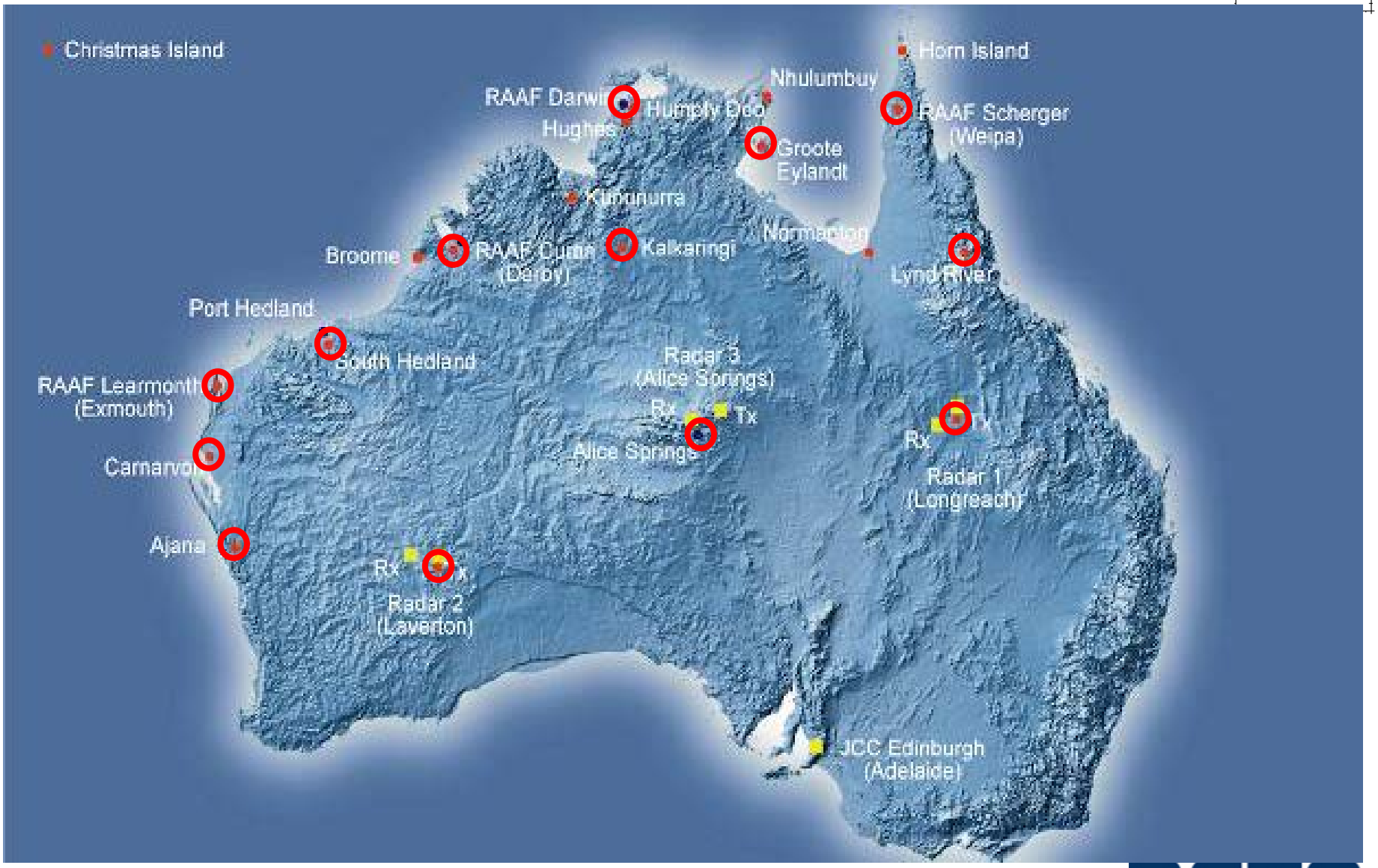
Nb: features same in general, some difference in detail

DSTO


DDORS Ionogram: RawCleanedCln10_0000[<in:plot:ddors>roxeprocess:cln_include>
2014/2014/01/27016:10:07, Rx: Wov, Tx: Wov0(_0000) ((Proc: 0312k_)nlf 5)
SVN Rev 443 20150409 :
Matlab v8.4.0.150421 (R2014b) :
OX_PROCESS R440 20150331 V5.20 :
MDET DIRECTWAVE V1.20 180dB F=-0.4Hz :
RFI_REJECTION_MEX V1.10 0 3 :
MDET HUM ZAPPER V2.00 F=49.7Hz :
CREATE_OX R438 V4.20(1.20) 2.5km 120kHz :
OX_METHOD v5.30 :
CALC_IONGM V1.14 242dB 120kHz 10kHz :
EXTRACT_TRACE R414 20150310 V1.37 :
TRACE_LAYER v1.81 :
TRACE_SMOOTH v1.20 :
TRACE_PARAM v1.66 :
(1) F2-trace .
(1) TrueHeight .
(1) foEs 11.2MHz .
(1) foF1 0.1MHz .
(1) foF2 6.6MHz .
foEm+
hmE
foF1m
foF1-
foF1+
h0F1
fbF1
Es trace
F2 trace
Elayer-QP
Elayer-CC
F1layer-QP
F1layer-CC
F2layer-QP
F2layer-CC
Ionosphere Examples
(a difficult case)
Virtual Height (km)
Frequency (MHz)
dbW

JORN Sounder Locations





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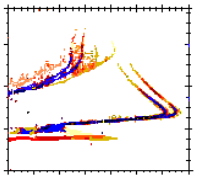
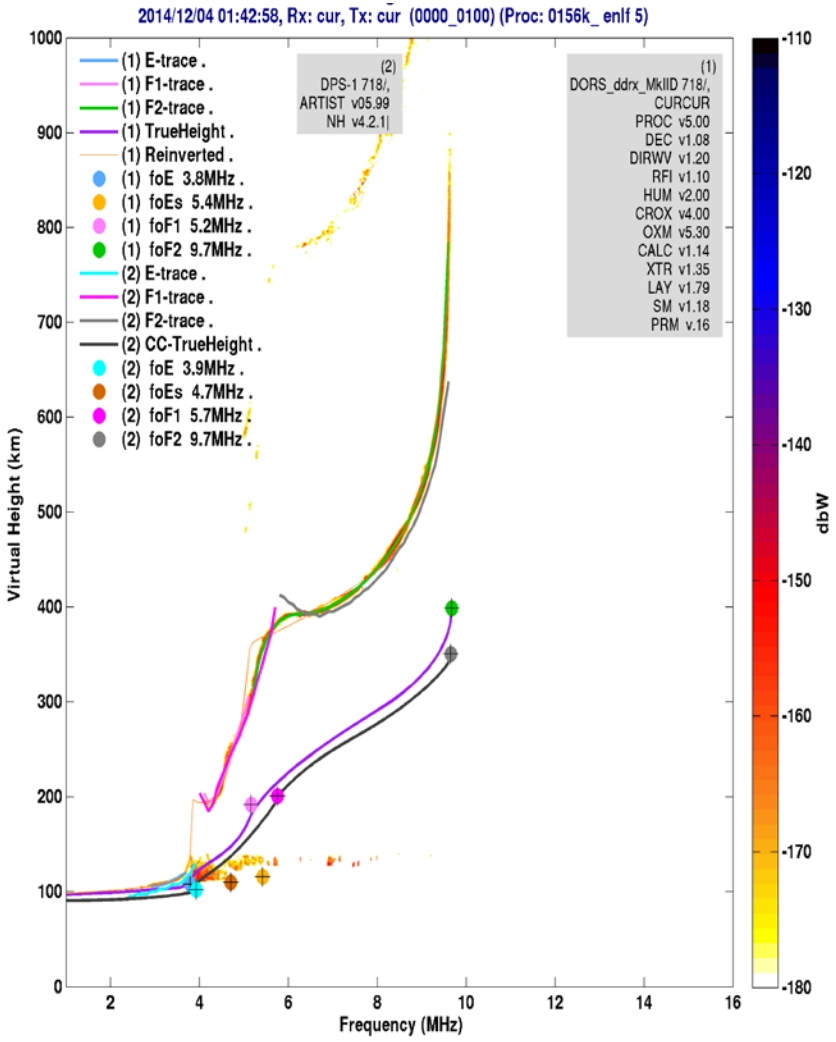
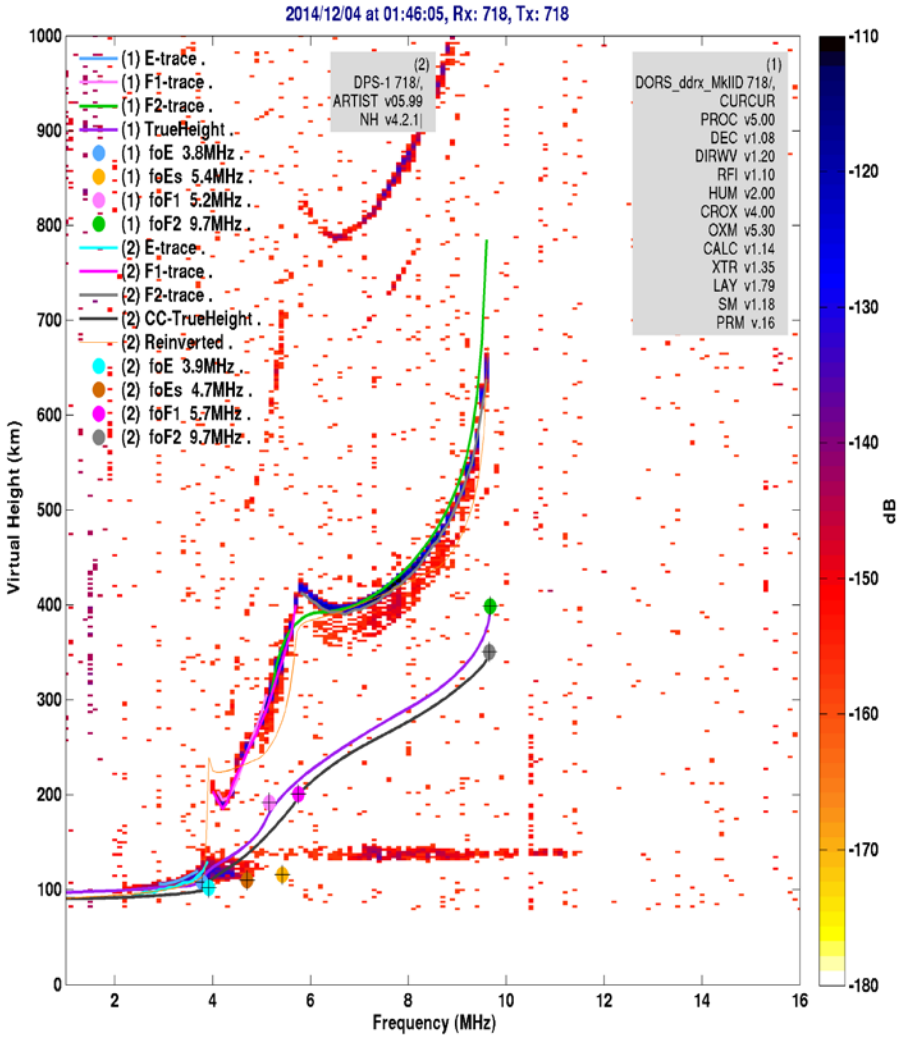
Ionogram / Trace comparison



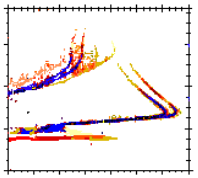
PRIME HRI



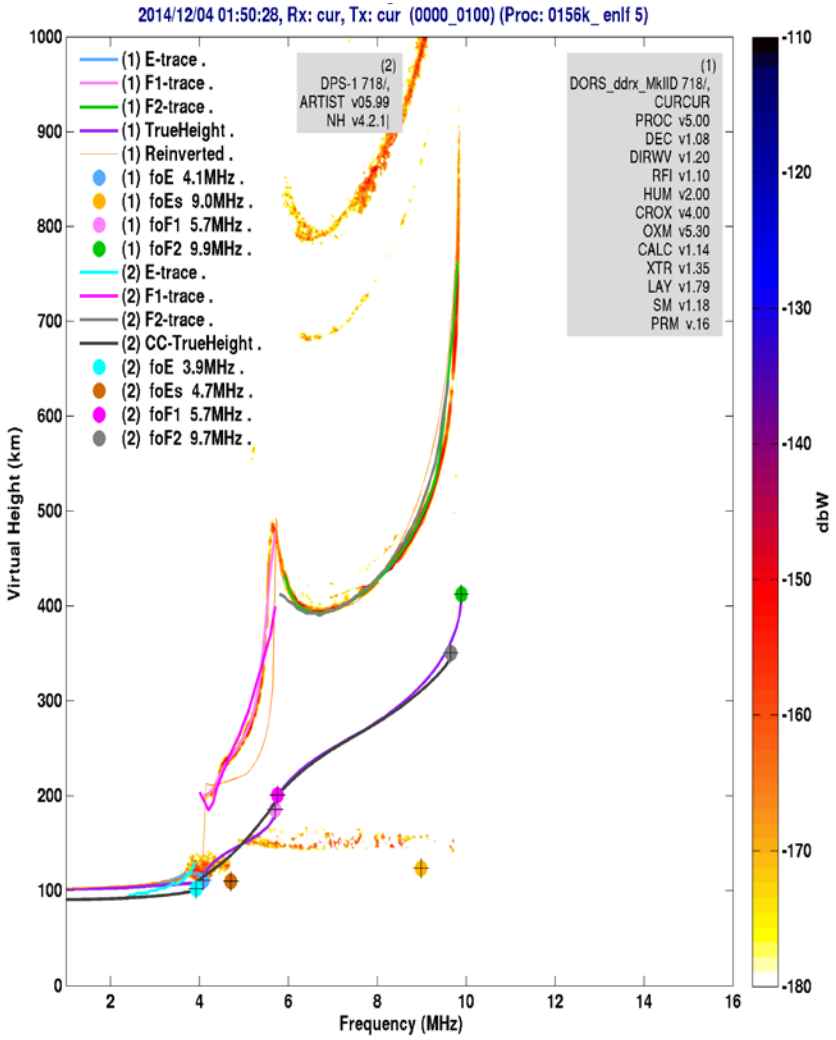
DPS1 SBT



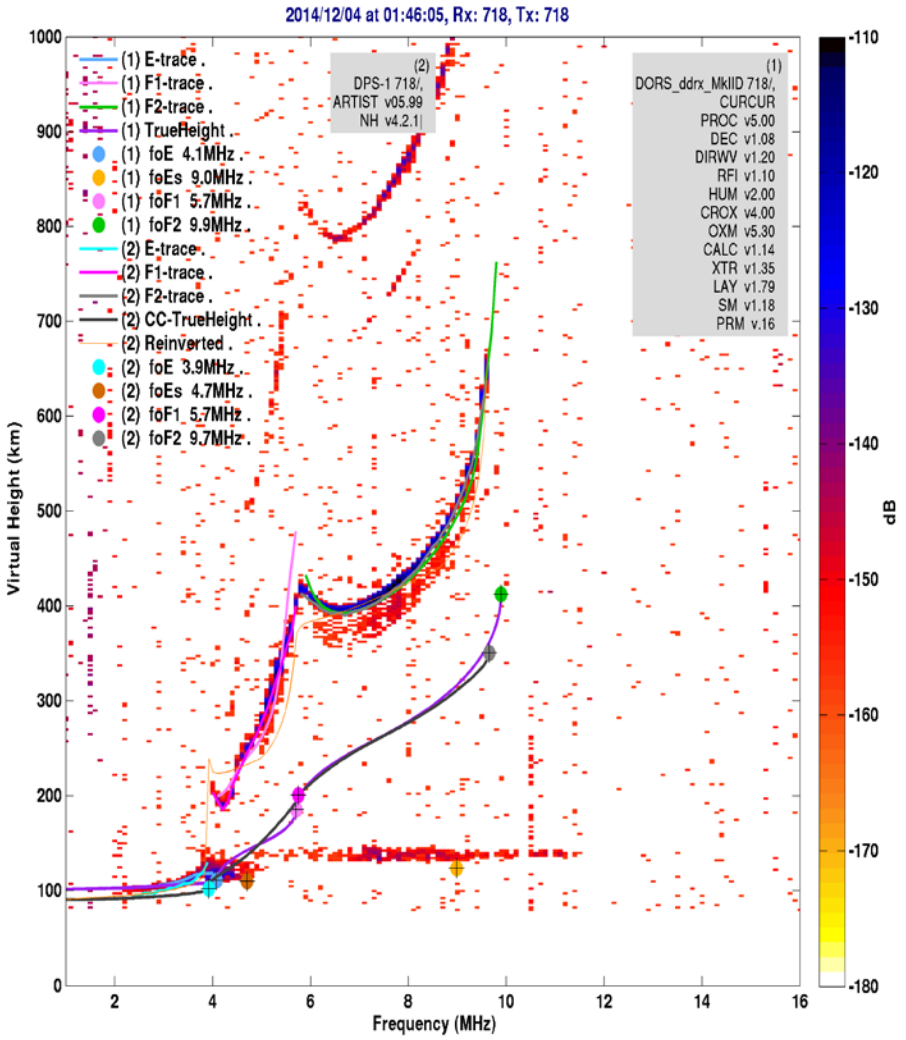
Ionogram / Trace comparison



PRIME HRI

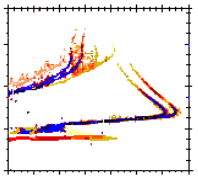


DPS1 SBT

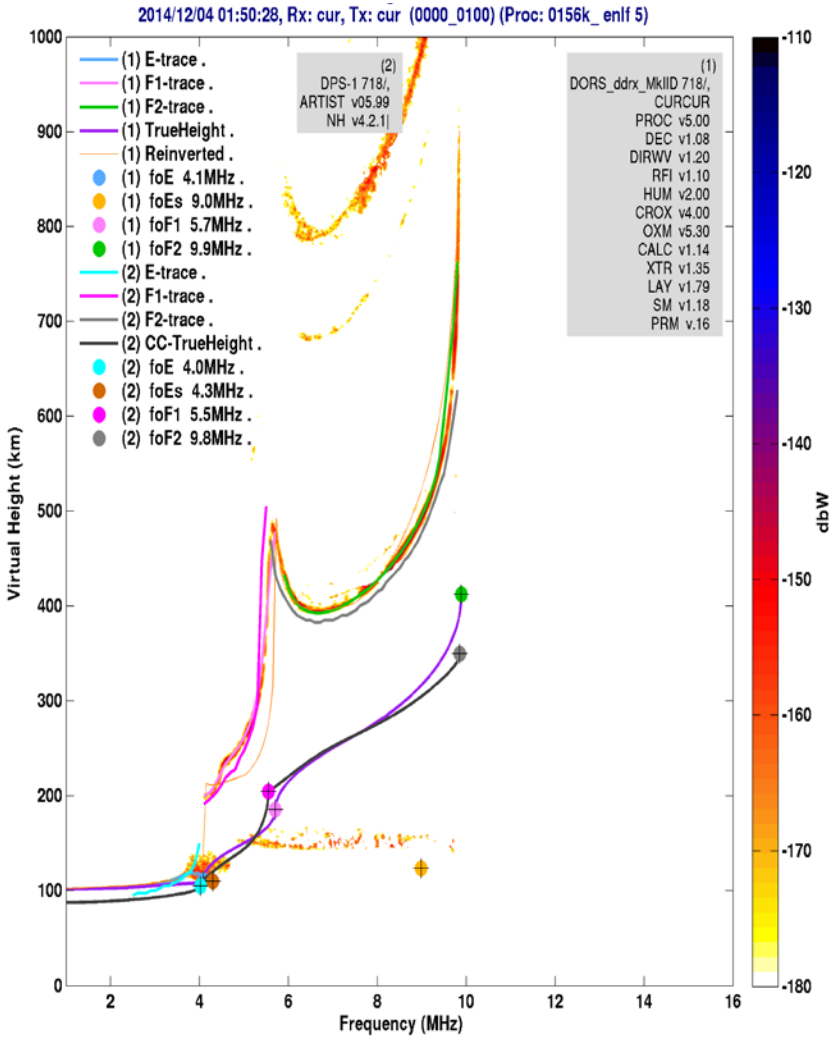


DSTO

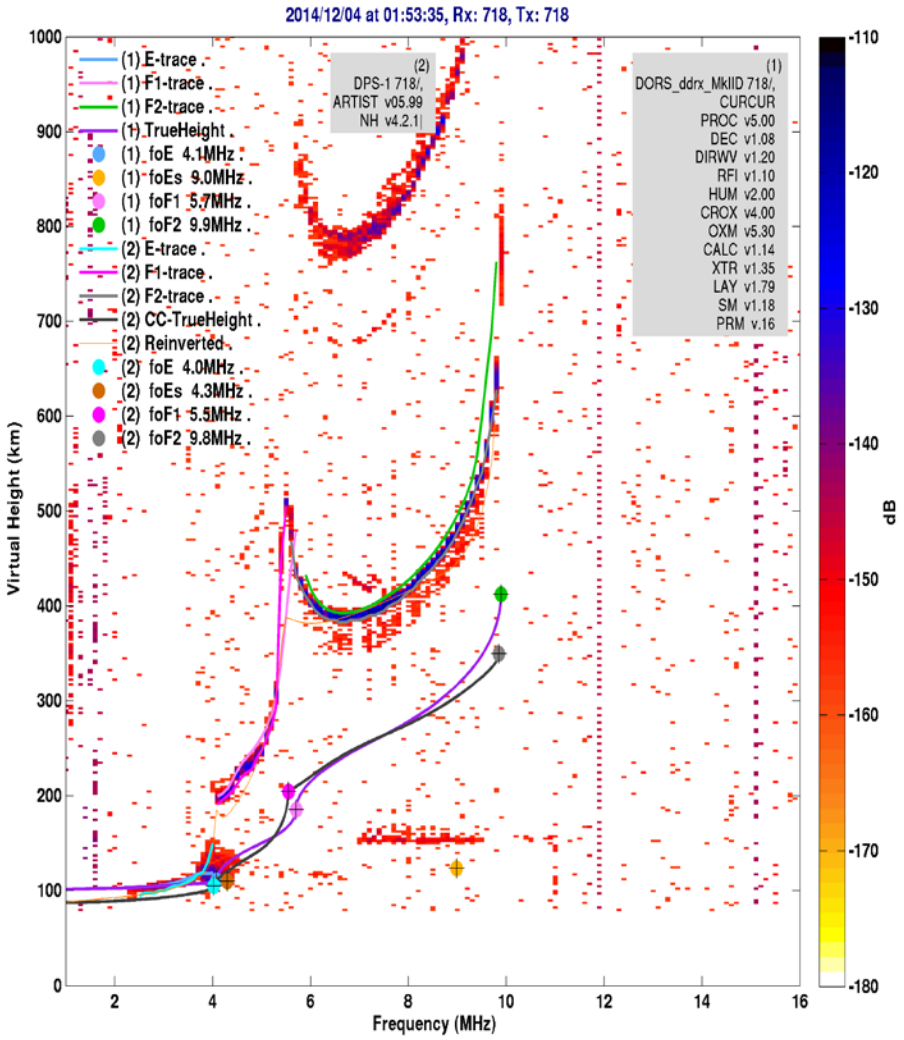
Ionogram / Trace comparison



PRIME HRI



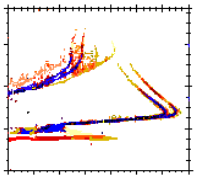
DPS1 SBT

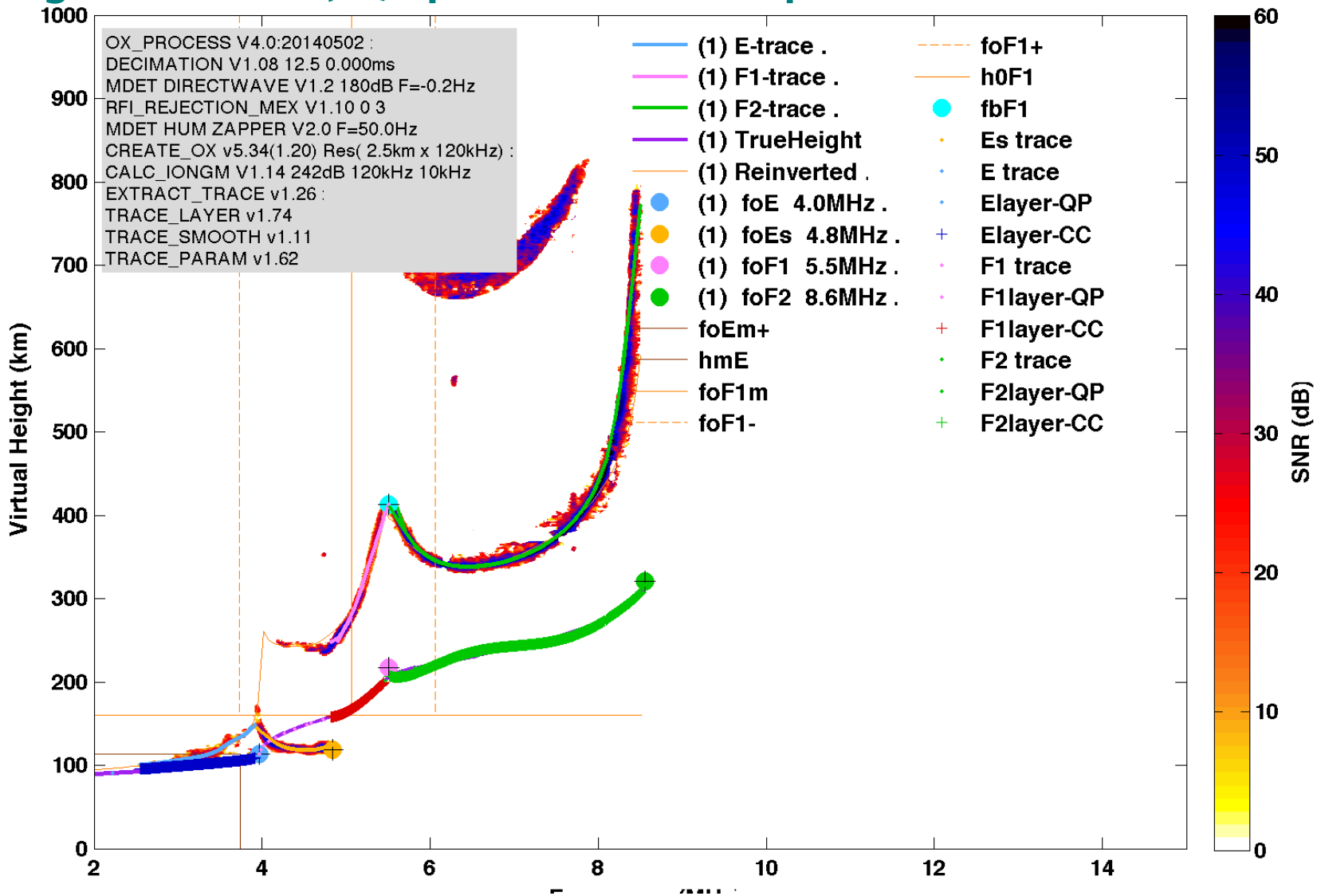


DSTO

Final Results: O-Mode Ionogram

Image with trace, QP parameters and profile



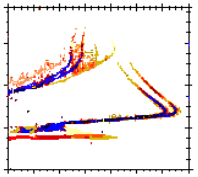


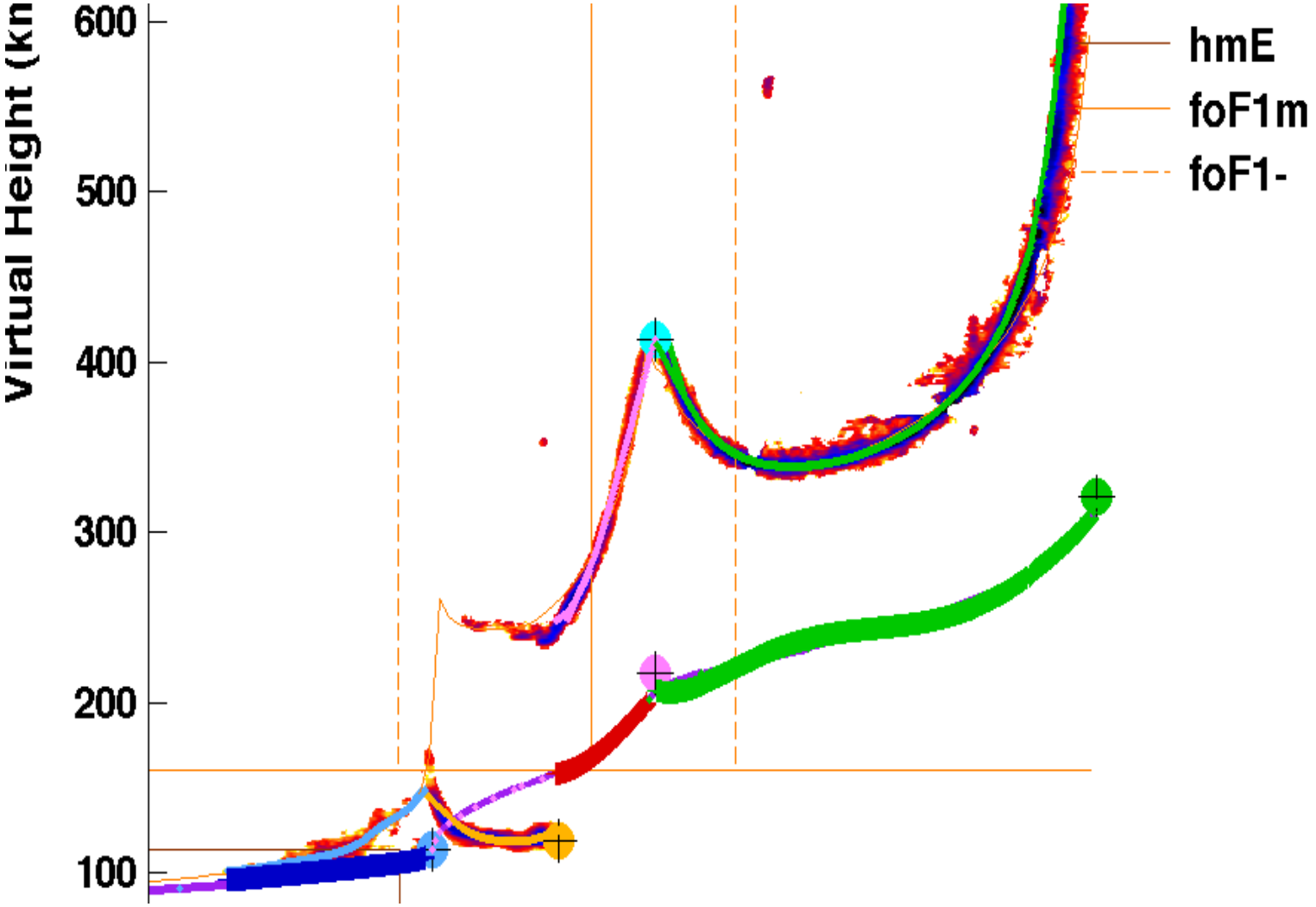
on Ionos at 12/06/2014 15:01
wovwov-sntr_131210_001324_trace-O_0000_0100_0156k_5.png

DSTO

Final Results: O-Mode Ionogram

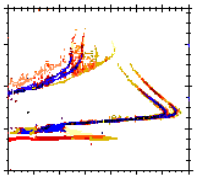
Image with trace, QP parameters and profile

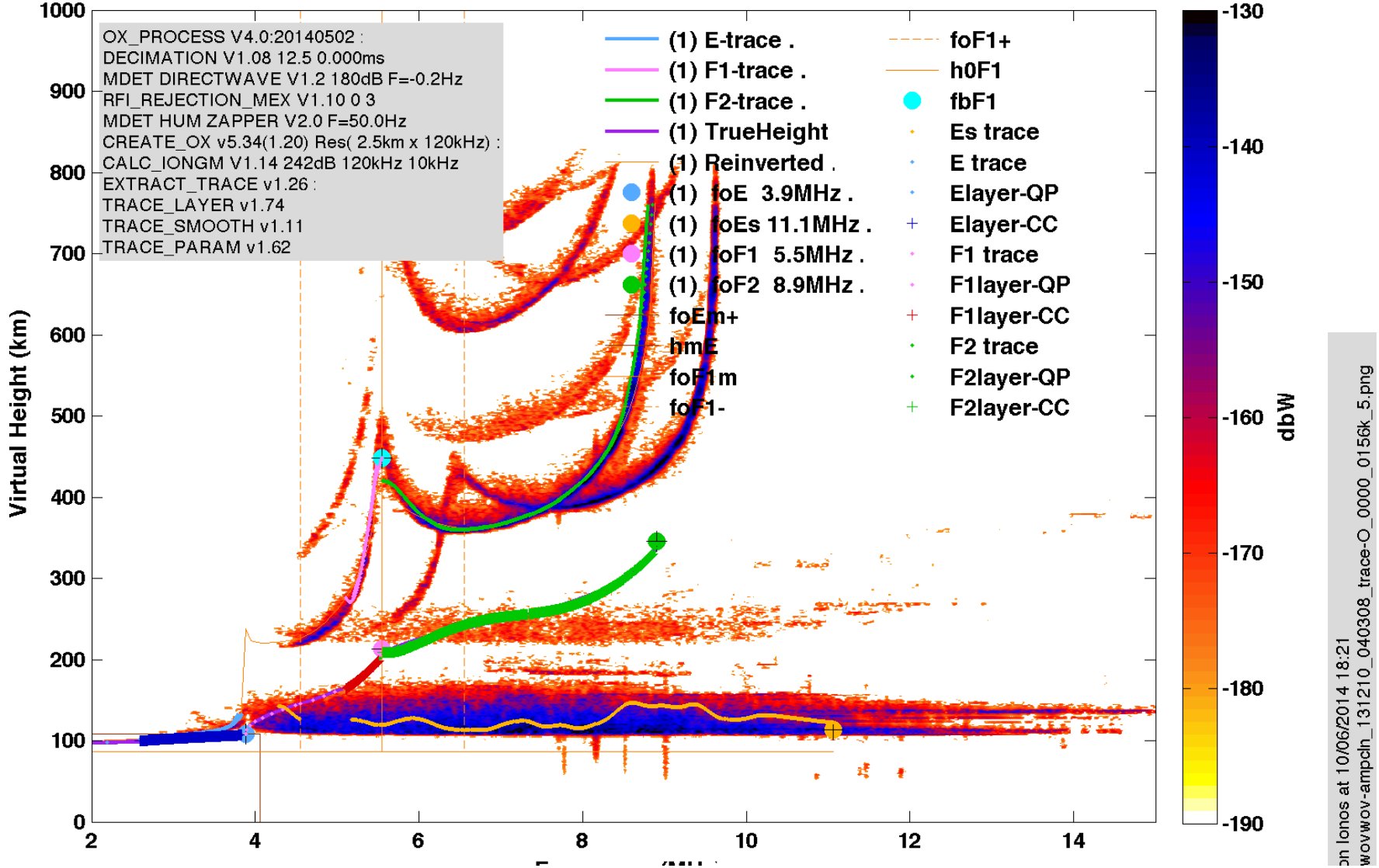




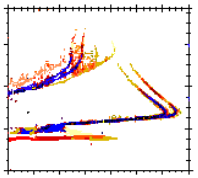
DSTO

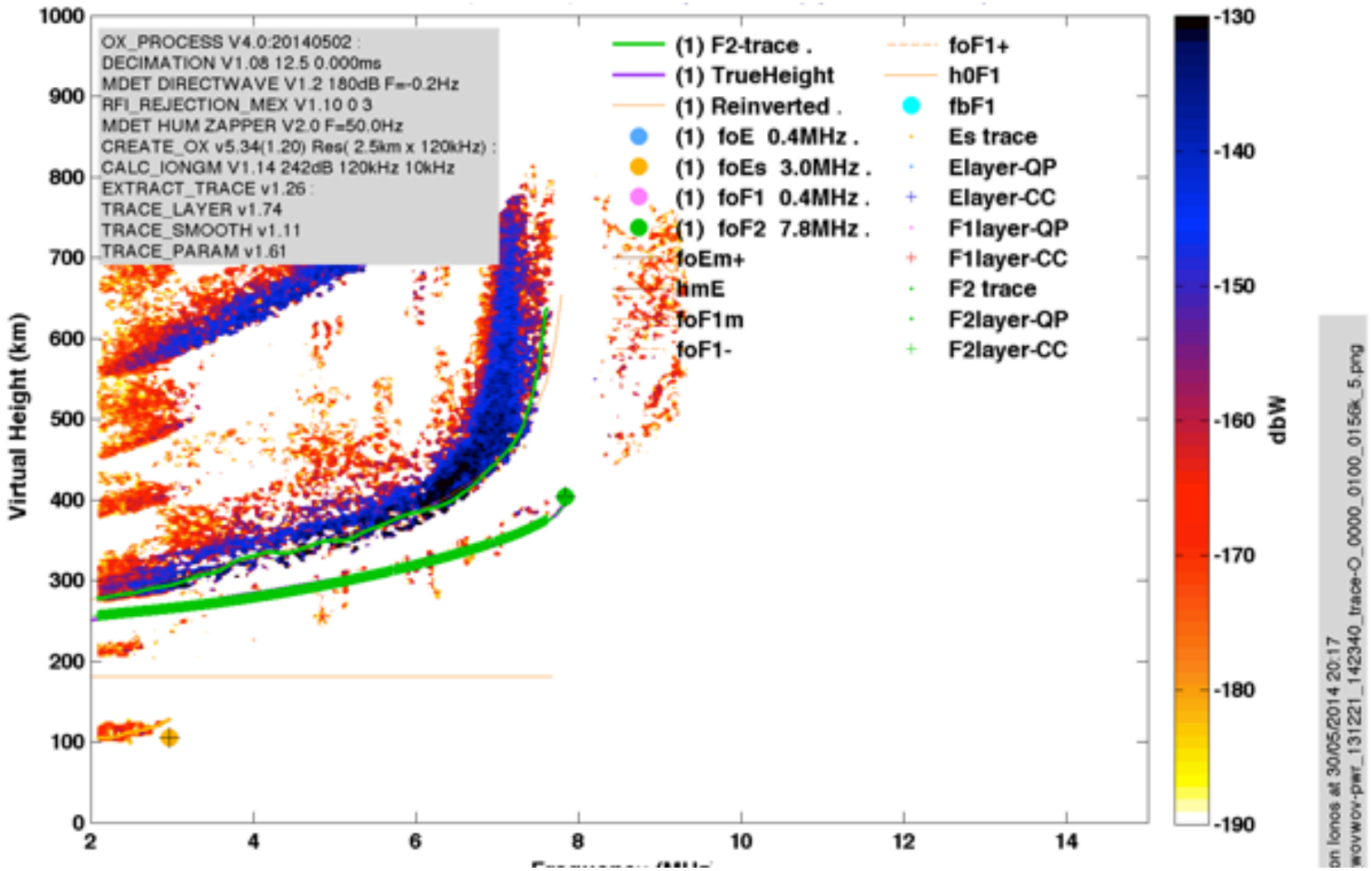
Final Results: Example-2 Raw Ionogram Image with trace, QP parameters and profile





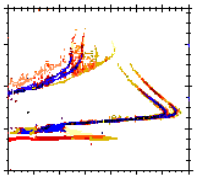
Example Ionogram

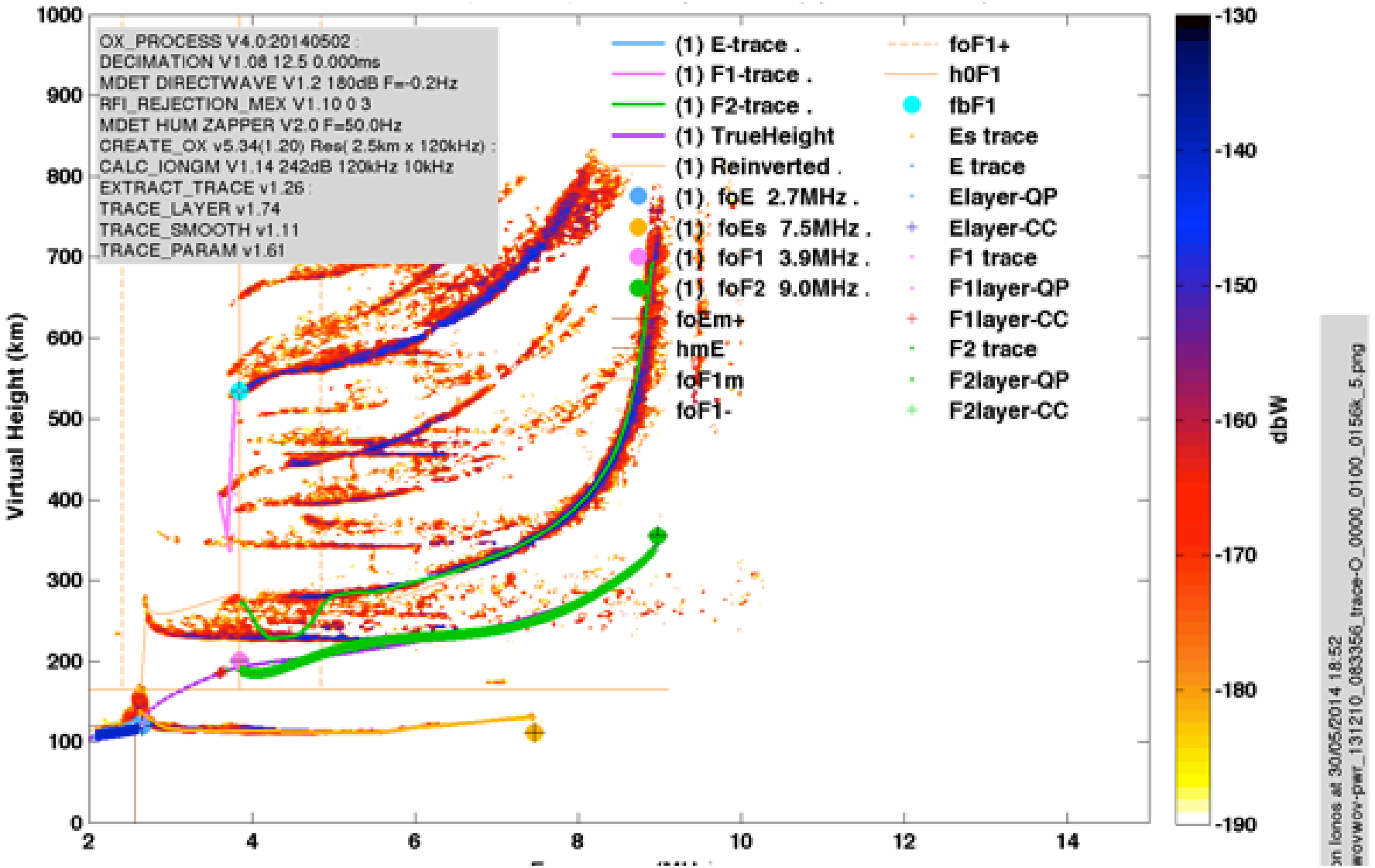




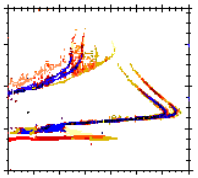
DSTO

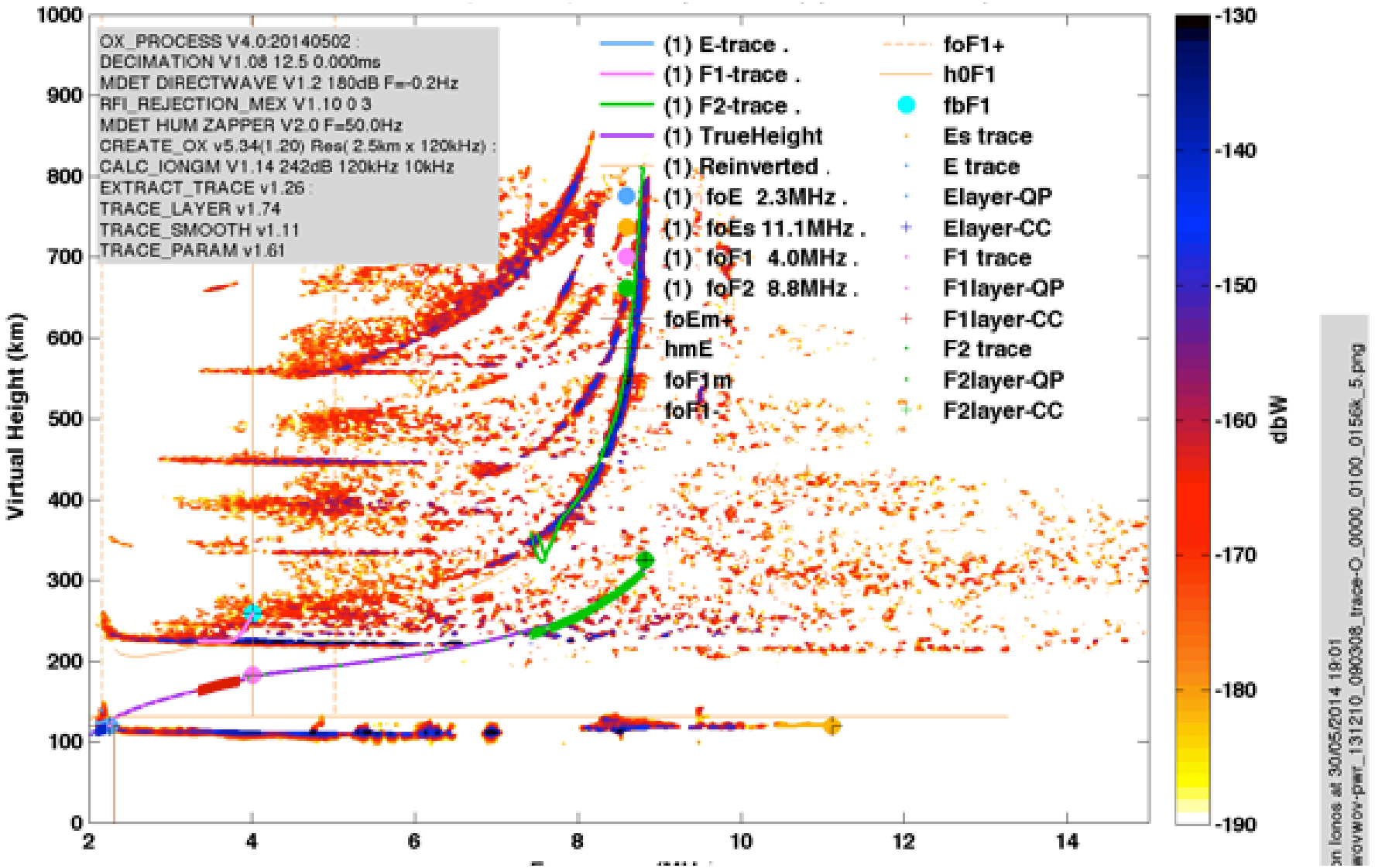
Example Ionogram



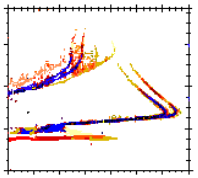


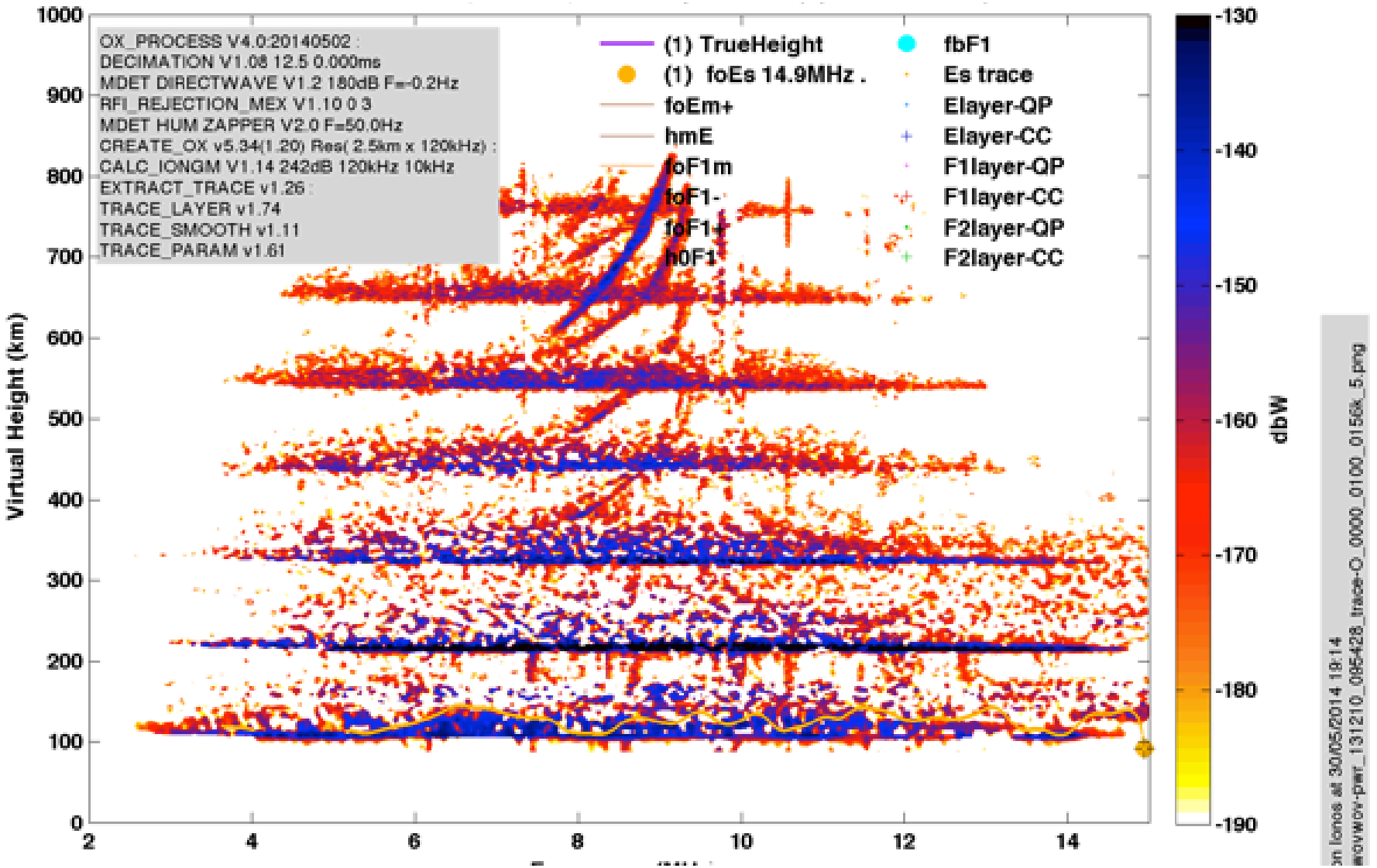
Difficult Ionosphere …





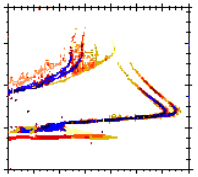
Difficult ionosphere…





DSTO

Manual validation of the trace fitting to GOOD and AVERAGE ionospheres.



Validators: Lenard Pederick, Manuel Cervera

VISRep algorithms of Apr2014

6 days of Data from Woodside VIS for
- 12,17,27,30 Dec2013, 1,2 Jan2014

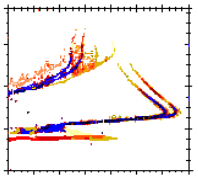
GOOD ionosphere:
- lack of spread-F, spread-Es and multihop Es;
- Observability of E, F1, F2 layers (hence must daytime data)

Trace	Pass	Fail	comment	Total	Pass %
E	475	22	6 fail due to spread E	497	**96 %**
F1	378	110	101 fail due to bad F1/F2 cusp	488	**77 %**
F2	492	17	All provided a good foF2	509	**97 %**

This table represents the accuracy of the trace extraction process for those ionograms that an *expert* could scale

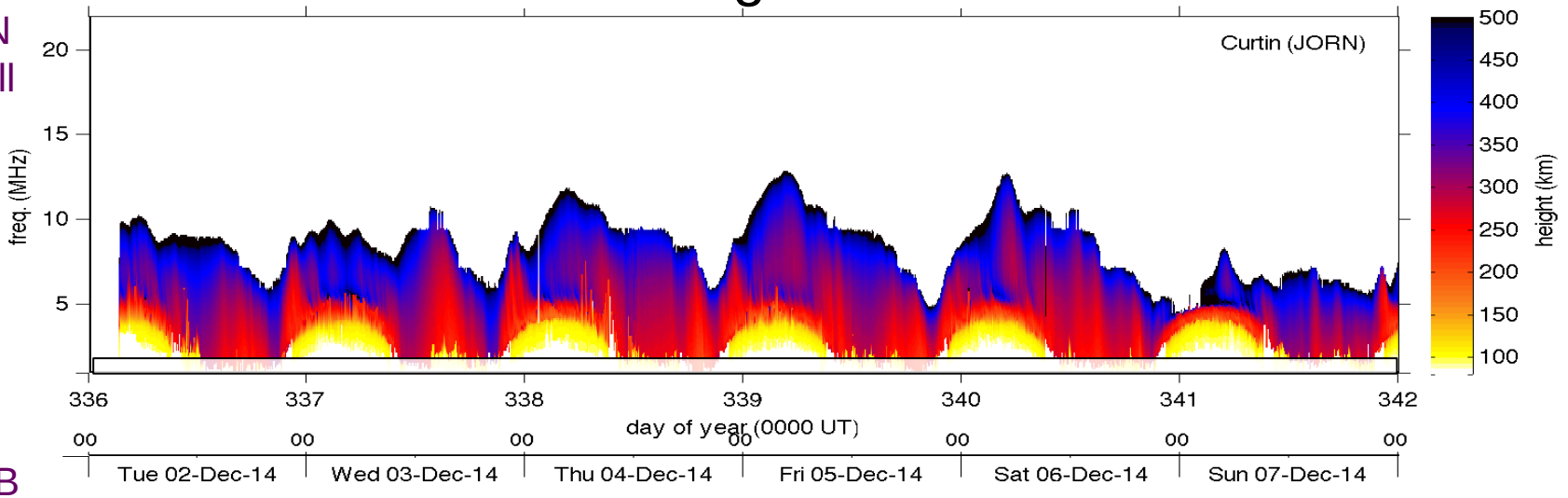
DSTO

Test-21: VIS Side-by-Side Comparison

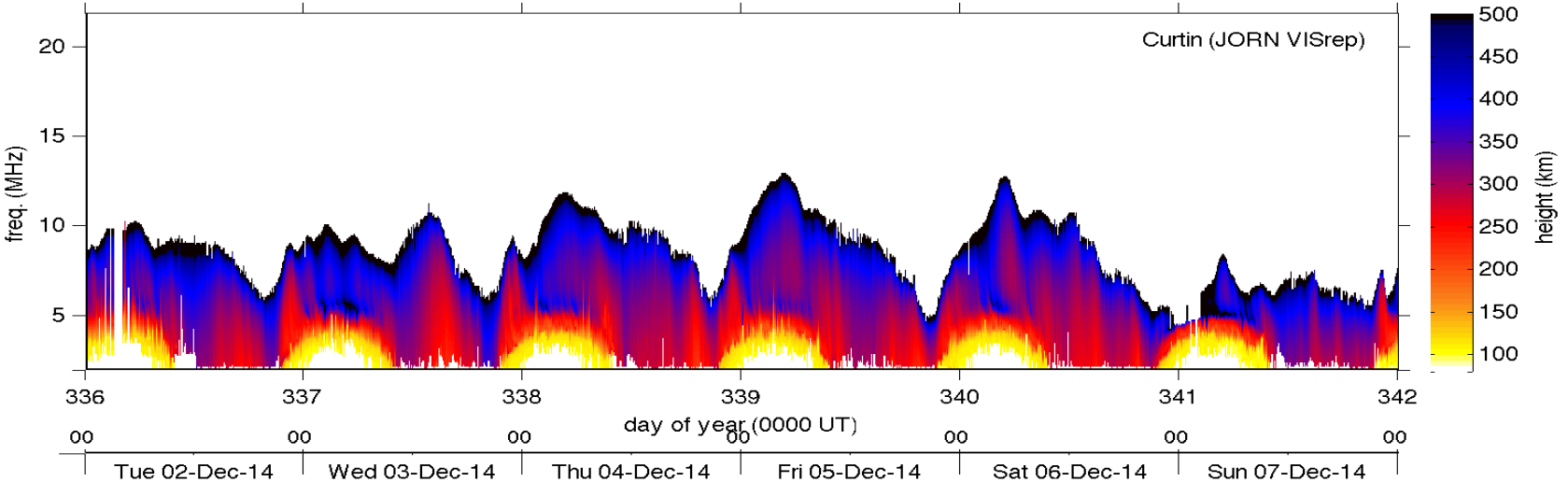


Virtual-Height of Trace

JORN
Lowell
VIS



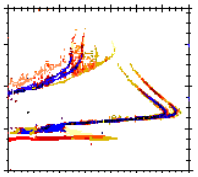
HFRB
VIS



harrist on Trevors-MacBook-Pro at 13/12/2014 04:57
20141202_000000_to_20141208_000000_VISx2_peak_vh_trace.png

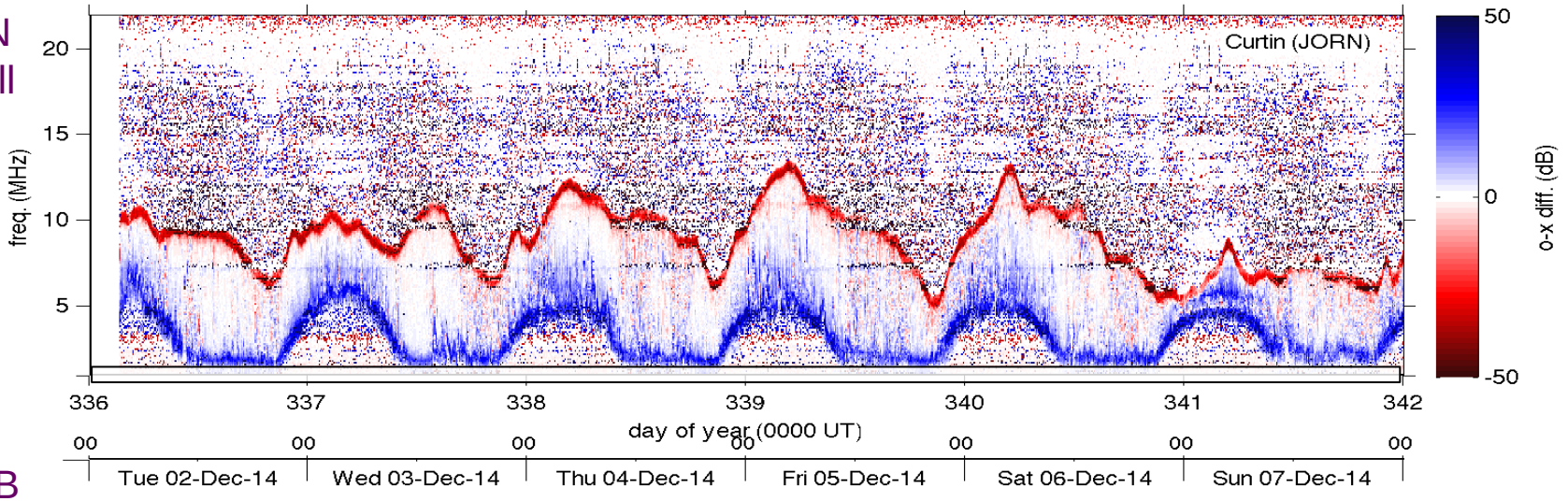
DSTO

Test-21: VIS Side-by-Side Comparison

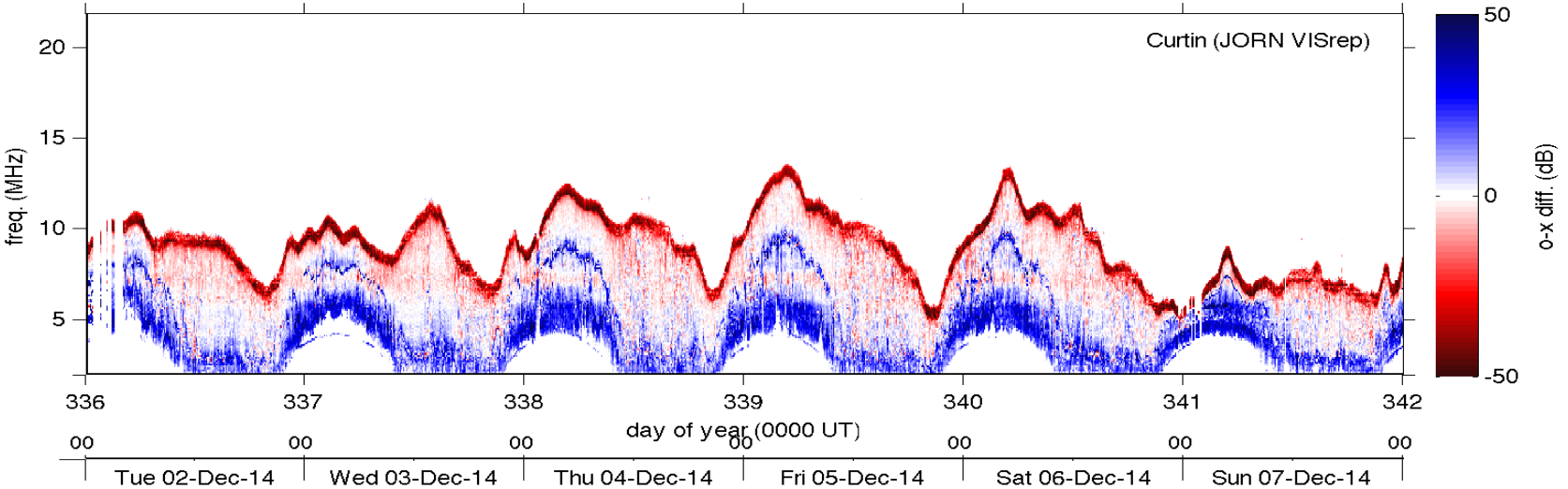


O-X Power

JORN Lowell VIS



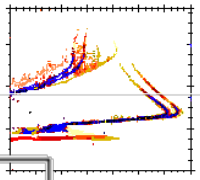
HFRB VIS



harrist on Trevors-MacBook-Pro at 13/12/2014 04:57
20141202_000000_to_20141208_000000_VISx2_hba_fplus_diff.png

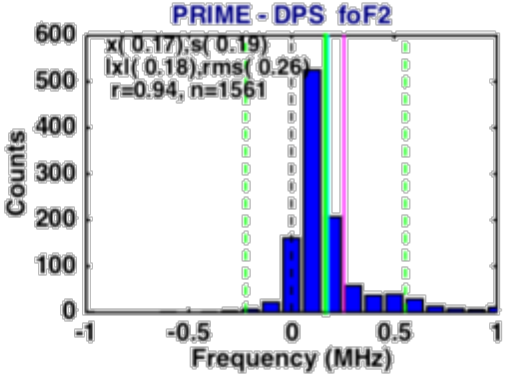
DSTO

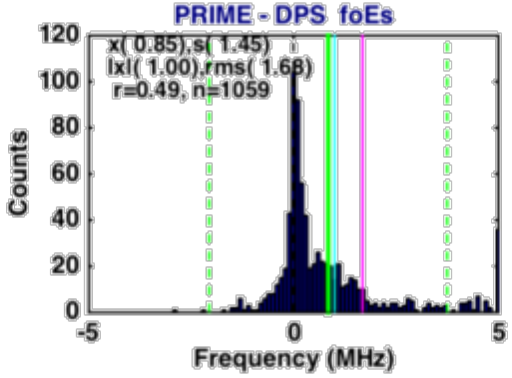
Comparison with Sounder derived Parameters

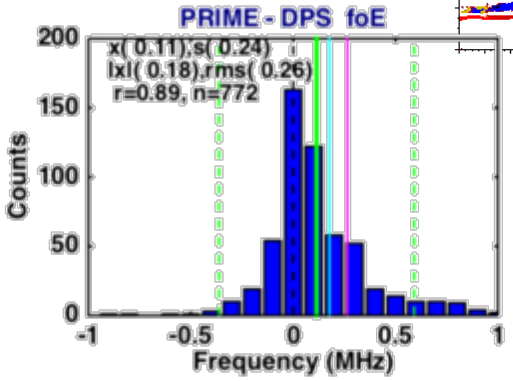


(μ, σ)
(|μ|,
rms)
ρ, n

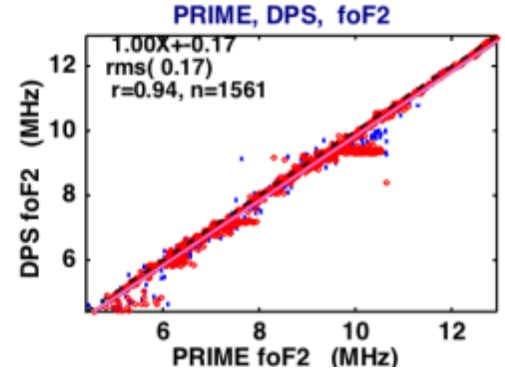
Critical freq.

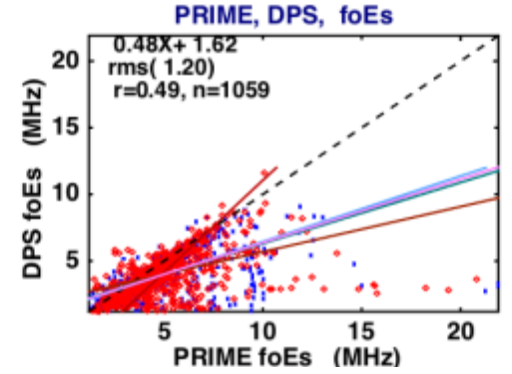


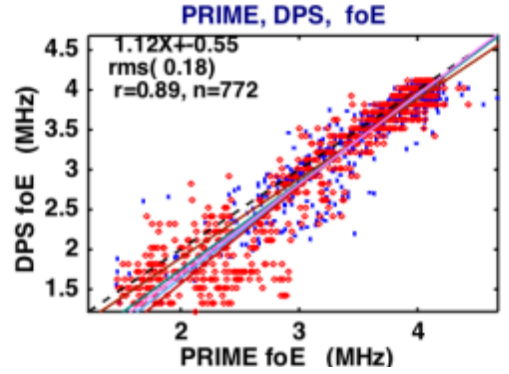




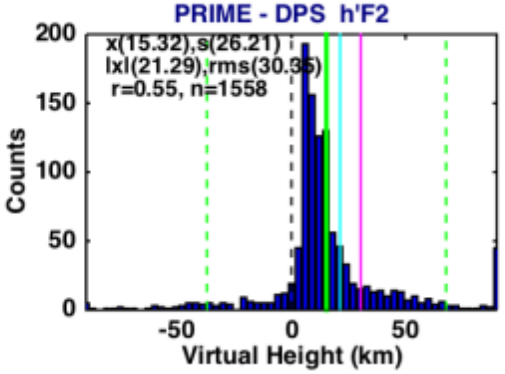
Freq.

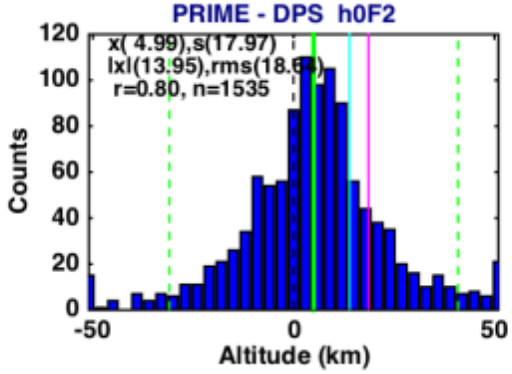


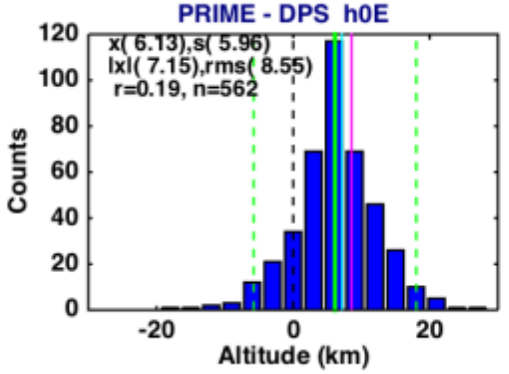




Base Heights



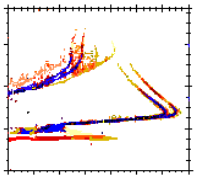




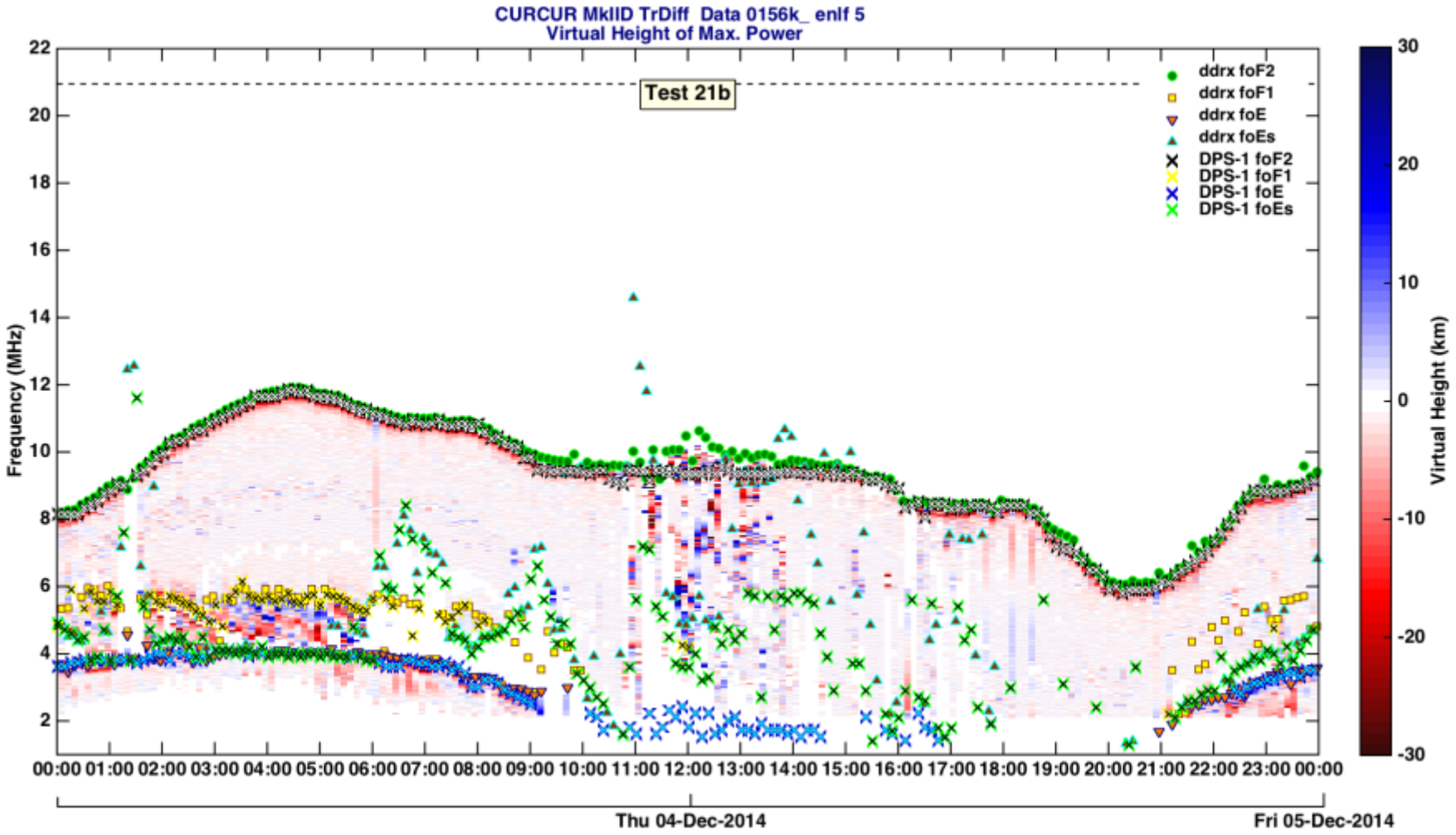
(all data for 02-07 Dec 2014)

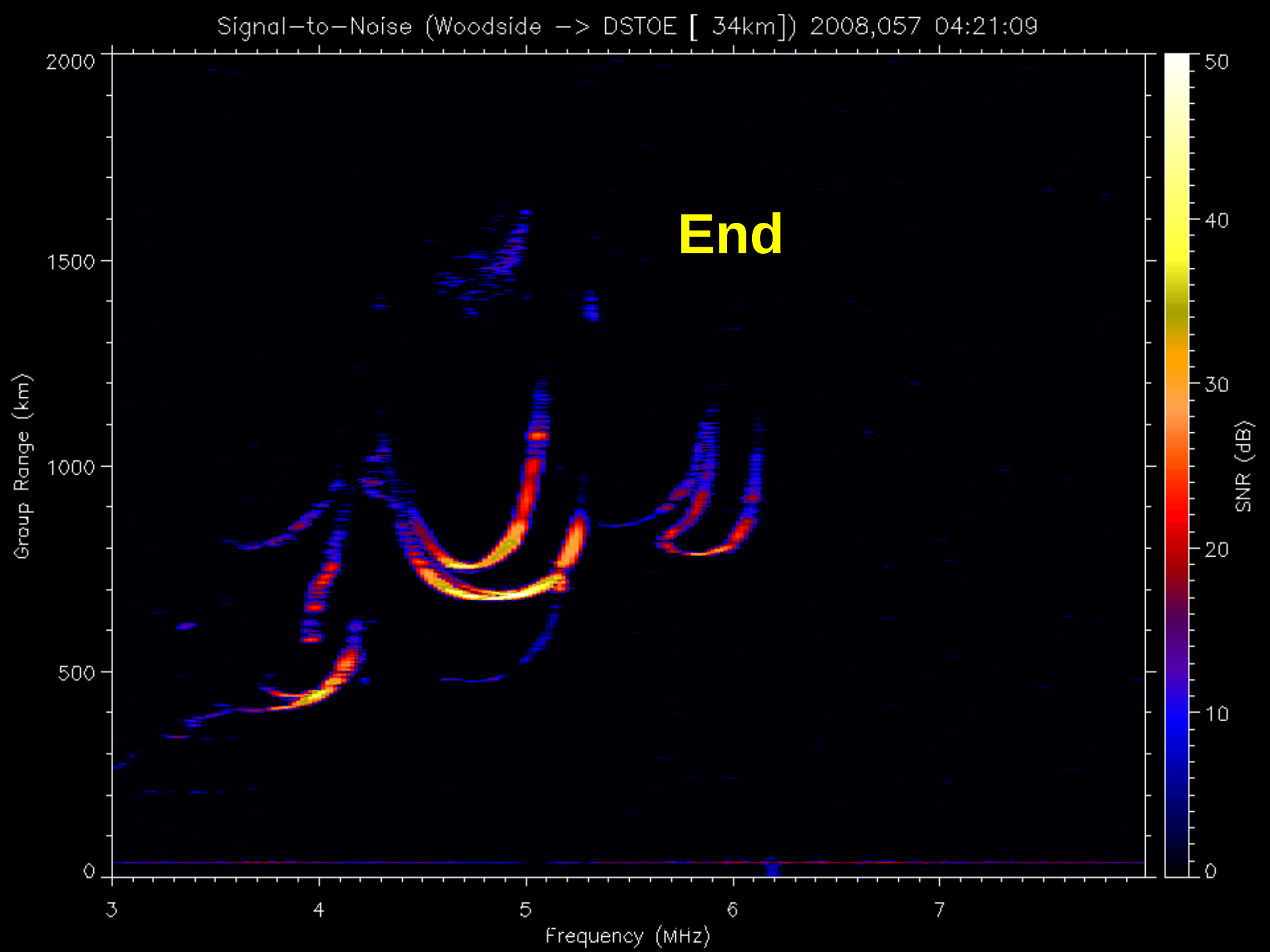
DSTO

Difference in Virtual-Heights (F-region only)



Trace – MaxPower (PRIME)




Signal−to−Noise (Woodside −> DSTOE [34km]) 2008,057 04:21:09
End
2000
1500
1000
500
0
Group Range (km)
3
4
5
6
7
Frequency (MHz)
50
40
30
20
10
0
SNR (dB)