Recreating the effects of Artificial Ionospheric Modification observed in the HF environment; an application of numerical ray tracing

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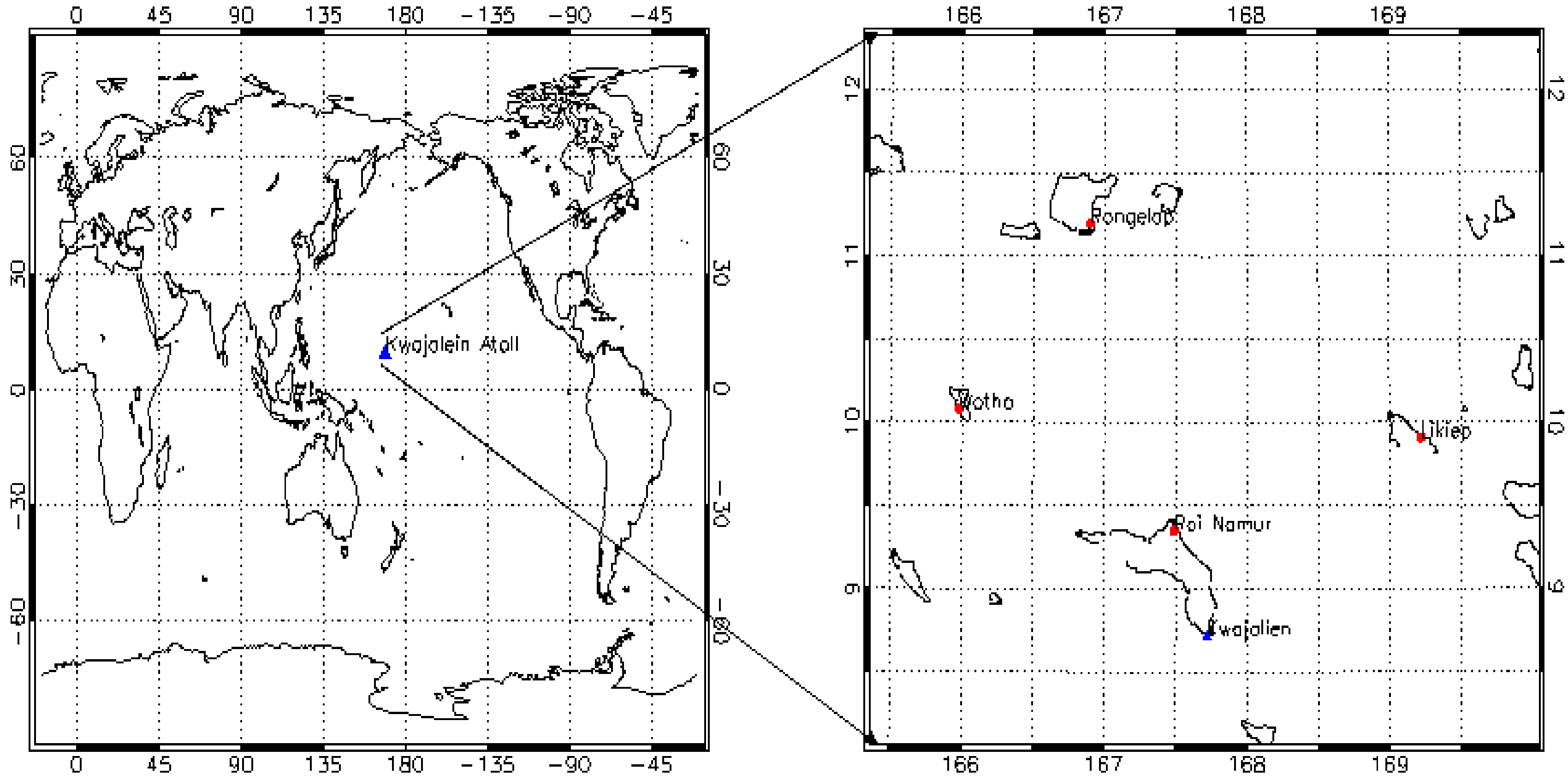
Introduction

Introduction

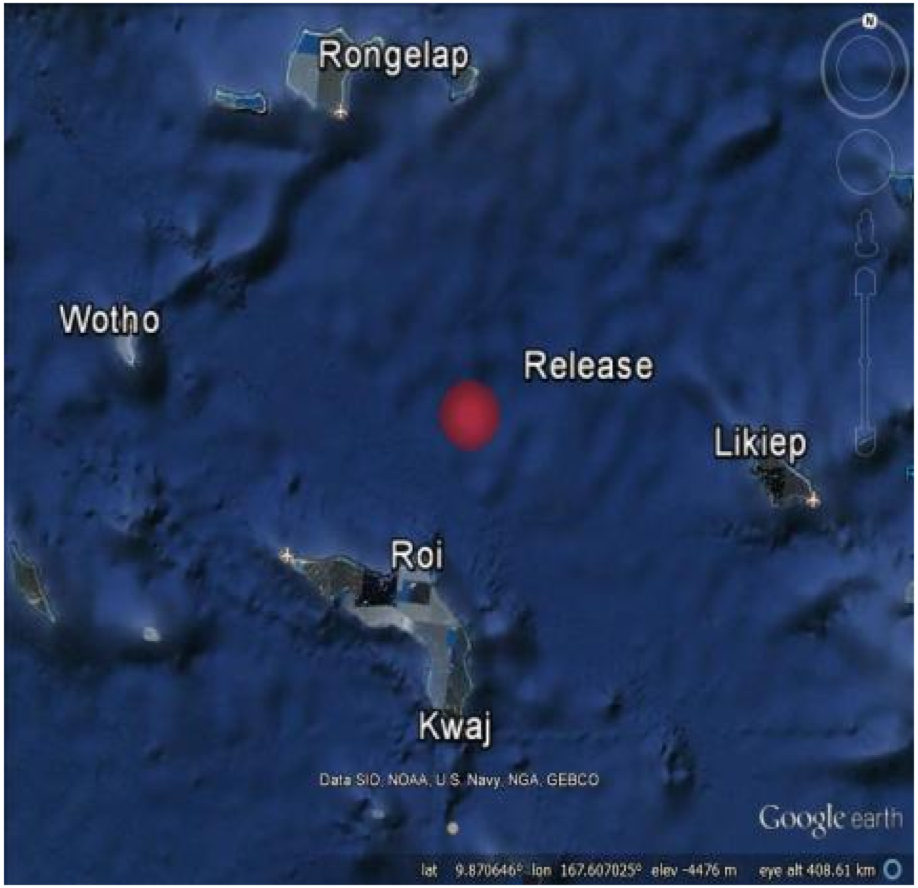
- Artificial Ionospheric Modification (AIM) involves the exploitation of the ionosphere through injections of aerosols, chemicals or RF signals
- MOSC was a US experiment which released samarium into the ionosphere to:
  – Create new layers and explore affects on scintillation
- In May 2013 two sounding rockets were launched from Kwajalein Atoll in the Marshall Islands
  – Each rocket released two canisters of samarium
  – UK contributed an High Frequency (HF) sounding experiment to characterise evolution of cloud and how it moved

MOSC launch location



System overview

Deployment Sites



	Kwajalein	Roi	Likiep	Rongelap	Wotho
Kwajalein		83 km 340°	204 km 48.5°	297 km 339°	301 km 320.5°
Roi	83 km 160°		190 km 72°	215 km 338.5°	225 km 313.5°
Likiep	204 km 229°	190 km 253°		296 km 299°	358 km 287°
Rongelap	297 km 160°	215 km 158°	296 km 118.5°		96 km 242°
Wotho	301 km 140°	225 km 133°	358 km 105.5°	96 km 62°	

Equipment overview

Roi

- IRIS receive system
- HF chirp transmitter
- AFRL USRP beacon receiver
- NRL beacon receiver
- AFRL Digisonde
- ALTAIR radar
- Illinois Radar
- AFRL optics
- Clemson University optics
- Speedball launch site

Rongelap

- IRIS2 receiver
- Chirp transmitter
- Delay-Doppler transmitter
- AFRL USRP beacon receiver
- NRL beacon receiver
- AFRL GPS experiment
- AFRL Digisonde
- AFRL optics
- Clemson University optics

Likiep

- IRIS2 receiver
- Delay-Doppler transmitter
- MIT LL chirp transmitter
- AFRL USRP beacon receiver
- AFRL GPS experiment
- Clemson University optics

Wotho

- IRIS2 receiver
- MIT LL receiver (chirp and delay-Doppler)
- AFRL USRP beacon receiver
- AFRL GPS receiver

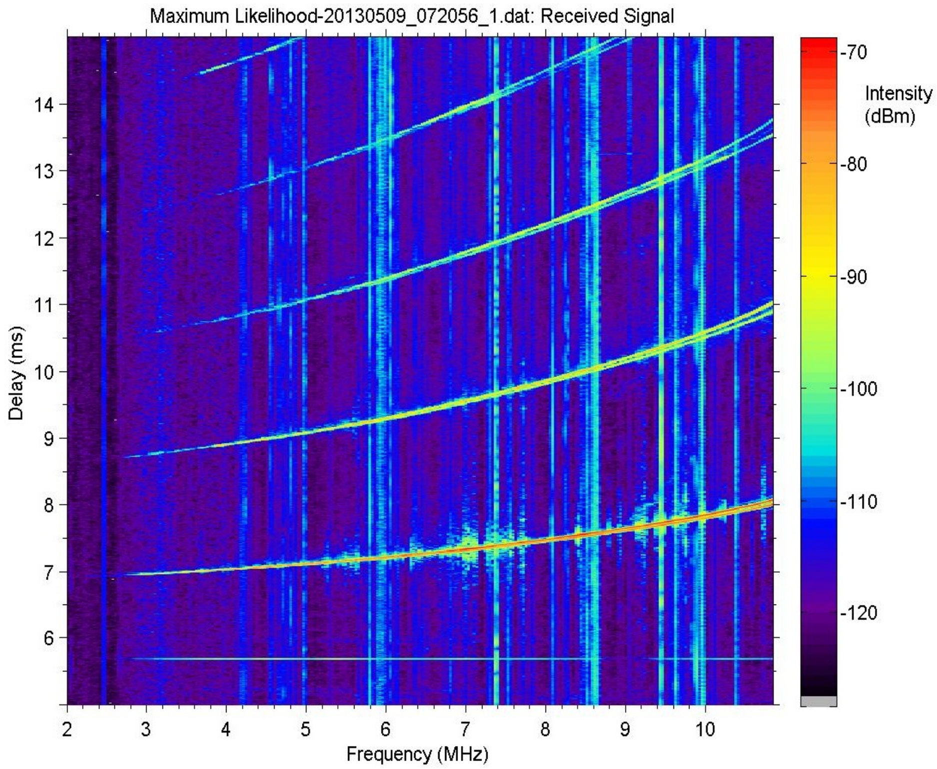
Kwajalein

- 18 channel N-IRIS (including 18 antenna array)
- AFRL USRP beacon receiver
- NRL beacon receiver
- AFRL GPS receiver

QinetiQ experiment in blue

Chirp Transmissions

- Chirp transmitters installed on Rongelap and Likiep
- A FM-CW chirp waveform transmitted
  - Sweep rate 100 kHz/s
  - Frequency range 2-30 MHz (blanking at distress frequencies)
  - Generate conventional oblique ionograms
- NIRIS
  - 18-channel digital wideband receiver (based on Roke MCDWR) installed on Kwajalein
  - Phase coherent across rx cards
- Ionogram Mode
  - Recorded chirps between 2-28 MHz from Likiep and Rongelap
  - Start time 1:04.015

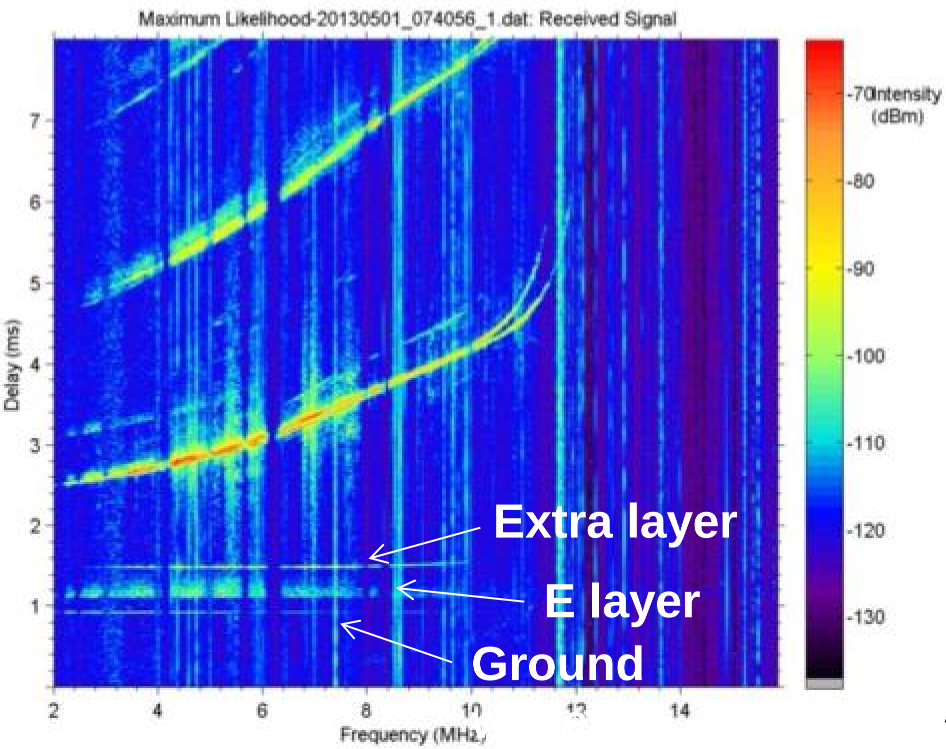


Preliminary Results

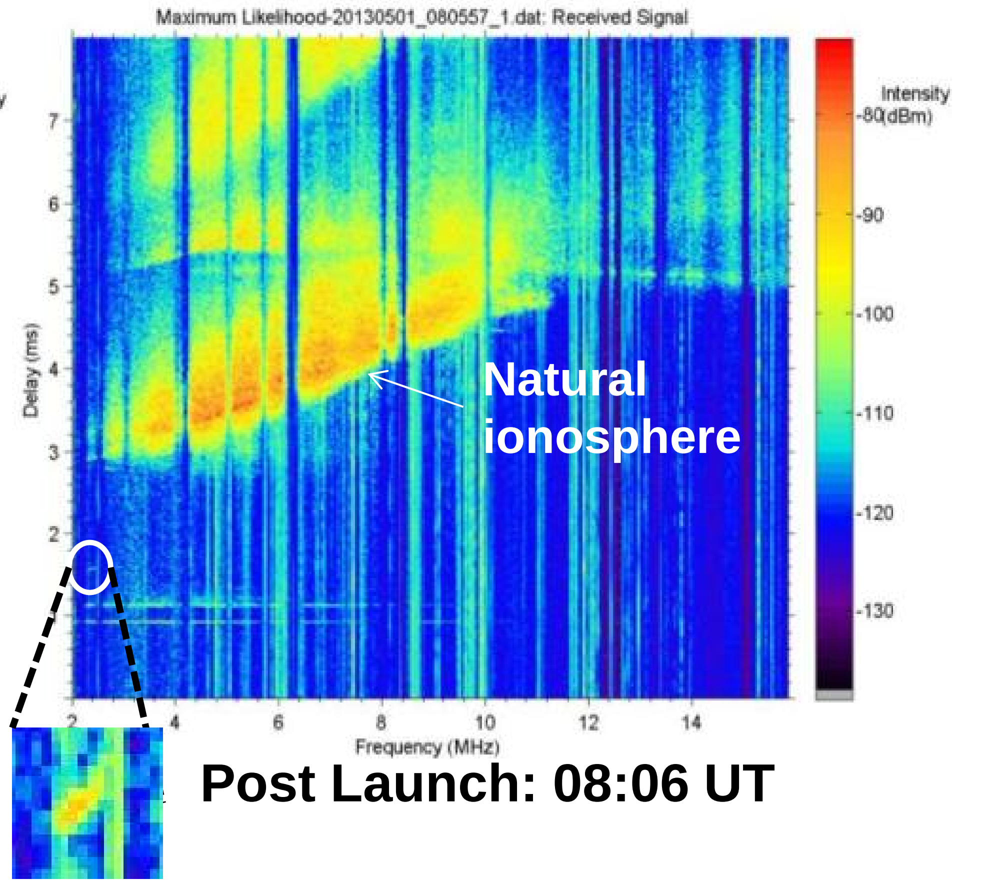
MOSC Launches

- MOSC launch 1 occurred on 1st May 2013
  - Launch at 07:38 UT
  - Release at 07:40:40 UT
  - Release height of 170.1 km
  - Only 10% of samarium ionised
- MOSC launch 2 occurred on 9th May 2013
  - Launch at 07:23 UT
  - Release at 07:25:40 UT
  - Release height of ~ 180 km
  - Again only 10% of samarium ionised
- Results for both launches very similar

Launch 1: Rongelap - Kwajalein path (1st May 2013)



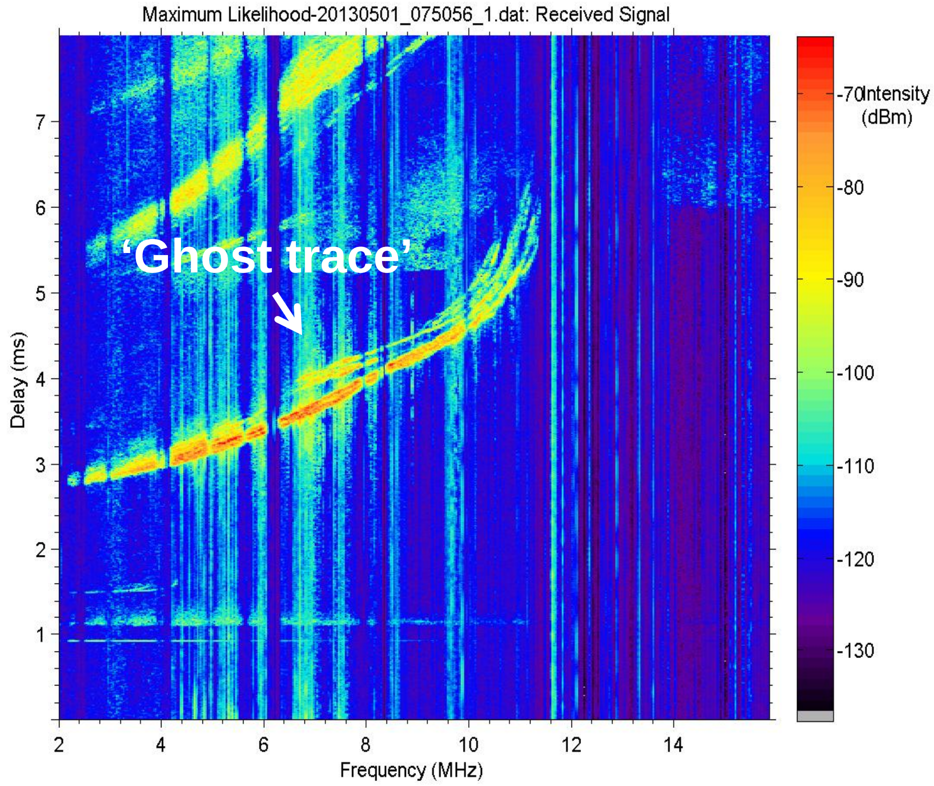
Post Launch: 07:41 UT



Post Launch: 08:06 UT

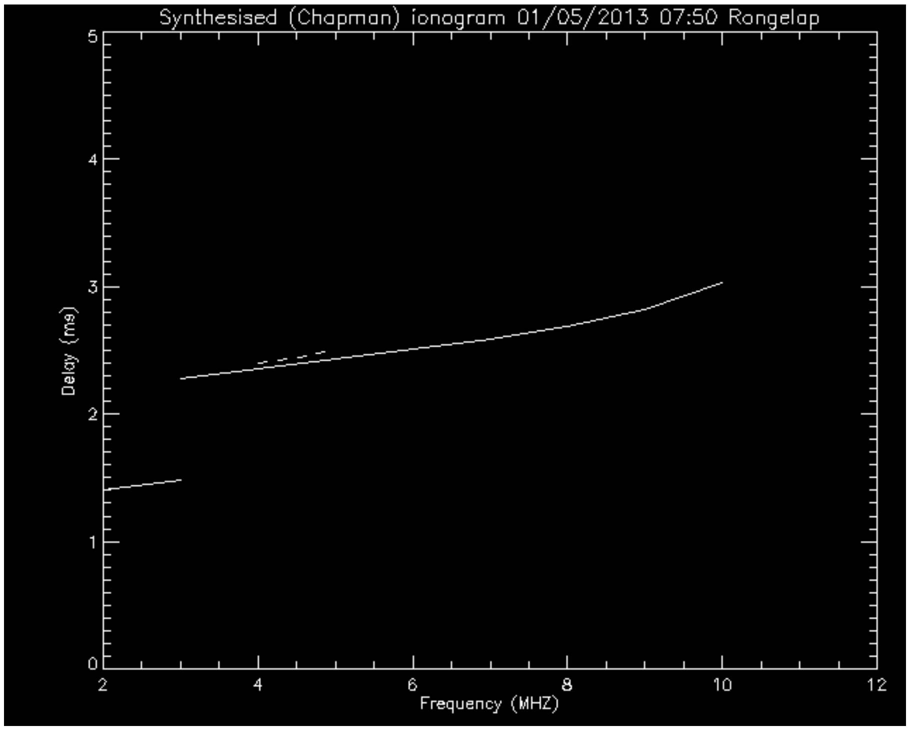
- On Rongelap path the extra layer can be seen for 25 minutes after release

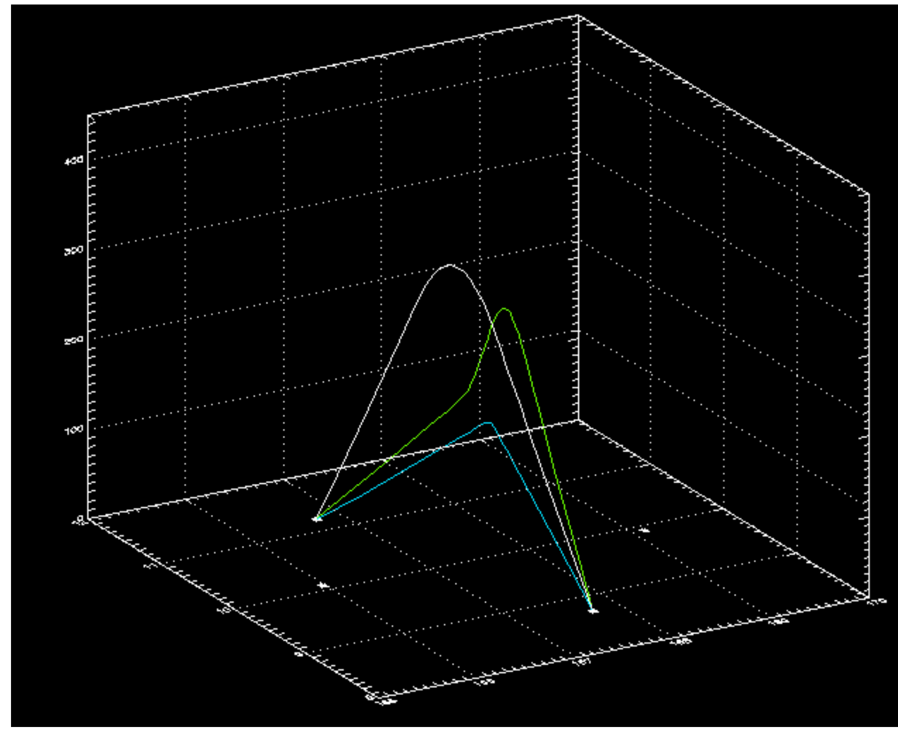
Launch 1: ‘Ghost trace’



- During the initial analysis a trace was seen just above the F-layer on ionograms recorded on the Rongelap to Kwajalein path
- Their existence was confirmed on the Rongelap to Wotho path
- Combined with the AoA information it is seen that these so called ‘ghost traces’ had a slightly longer delay than the F-layer, but had the same AoA
- The ‘ghost traces’ were seen in the first ionogram after release, but appeared to get stronger with time

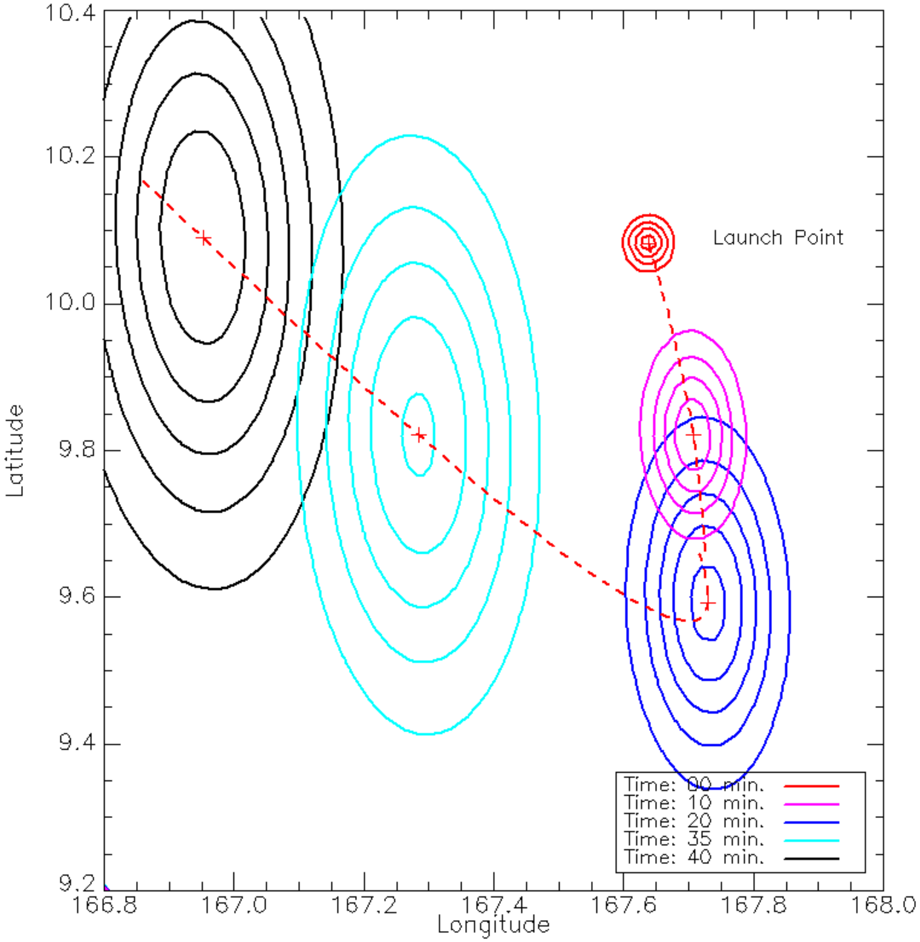
Gaussian perturbation and Chapman layer: ‘Ghost trace’

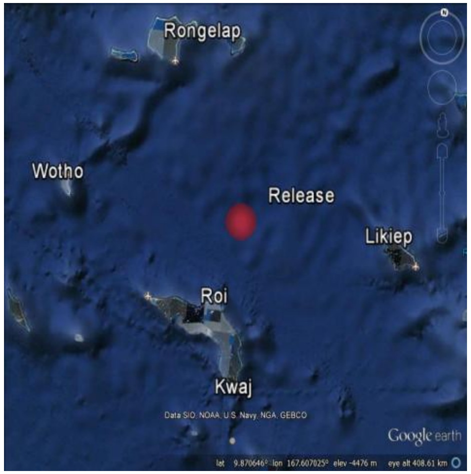




Ionogram reconstruction: Launch 2 *Rongelap to Kwajalein path*

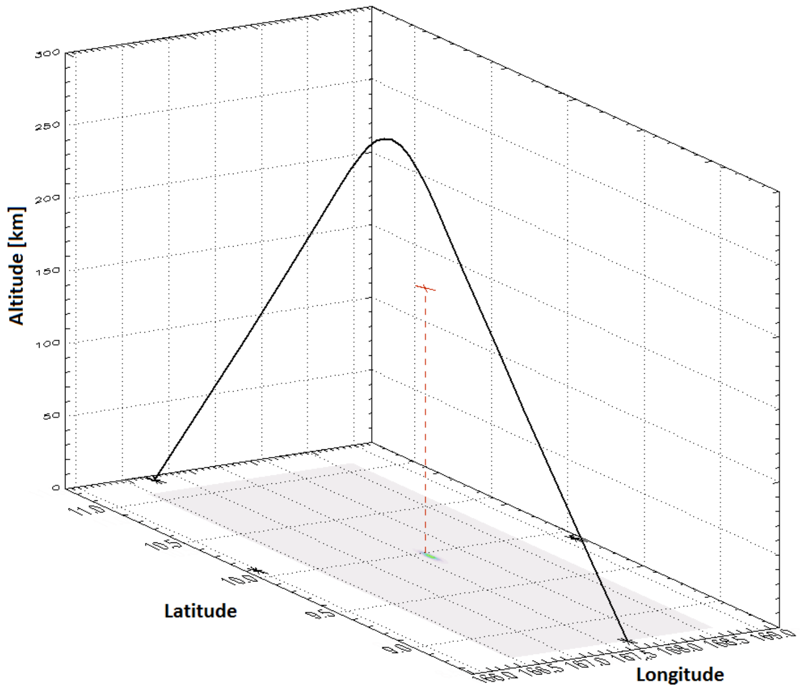
AFRL Cloud Model





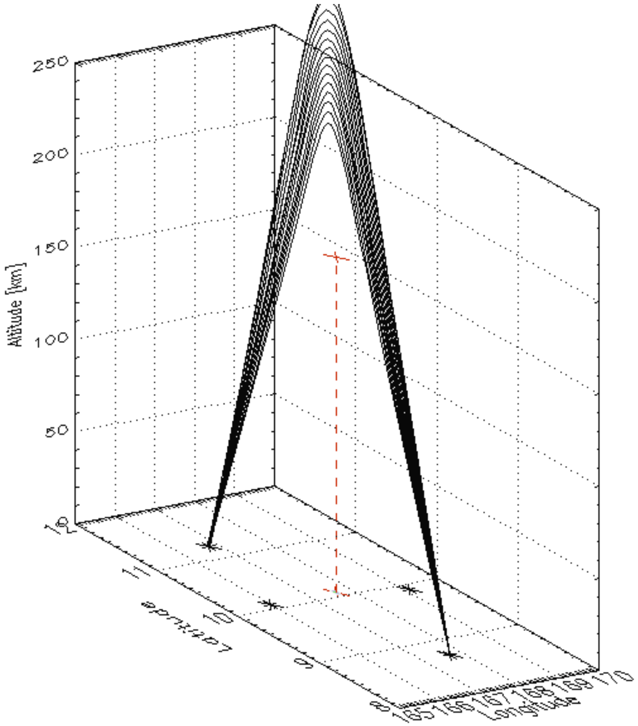
- The AFRL model was based on optical and ALTAIR data recorded during release.
- The model is time dependent and parametric.
- The cloud asymmetrically disperses with time.
- Its centroid position drifts with time.

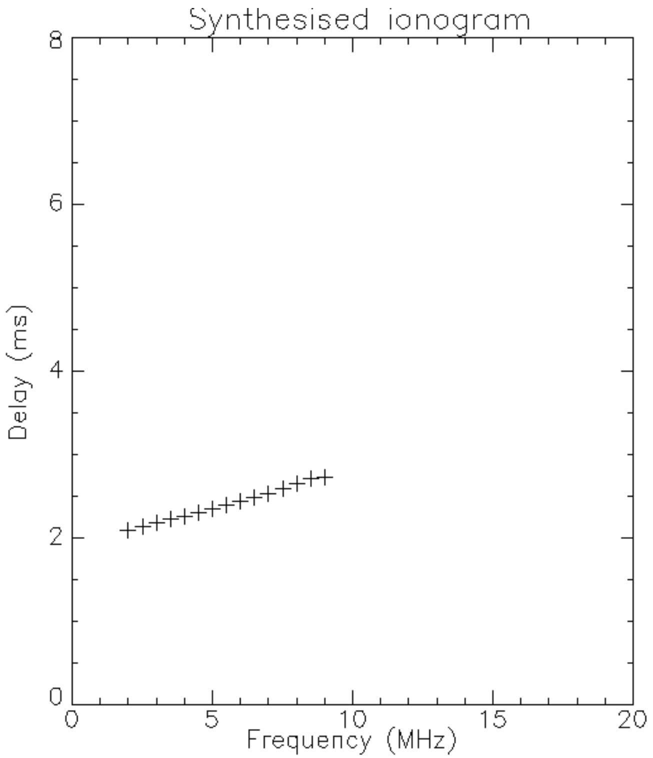
Home Ray Trace



- A 3D ray tracing procedure in spherical co-ordinates.
- Implements the Runge-Kutta ODE solver.
- Solves the Haselgrove equation set.
- Computes the:
  - Group path.
  - Phase path.
  - Reflection height.
  - Divergent power loss.
- Produces a ray between the input transmitter and receiver ground locations which are assumed to be stationary.

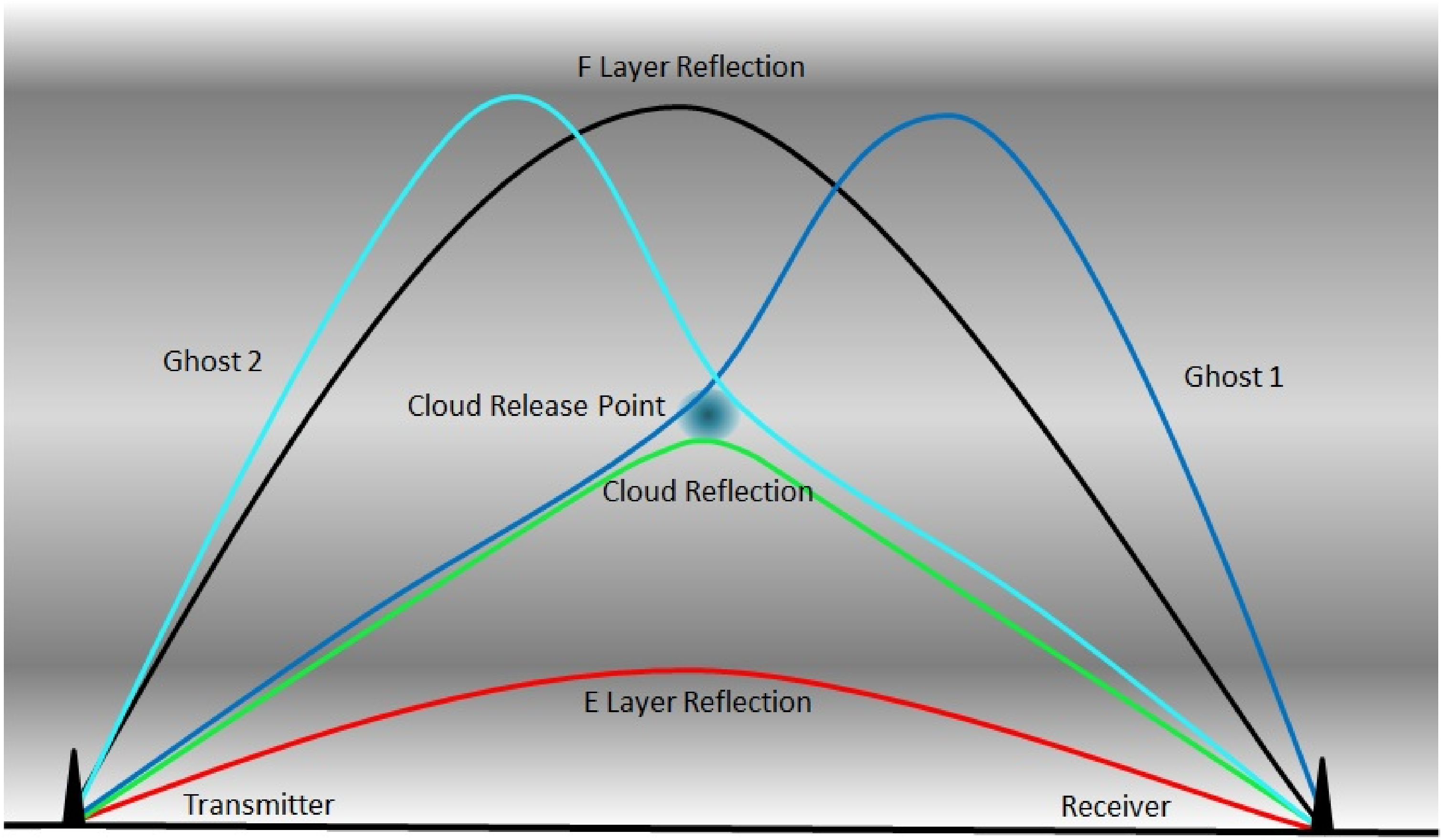
F Layer Simulations



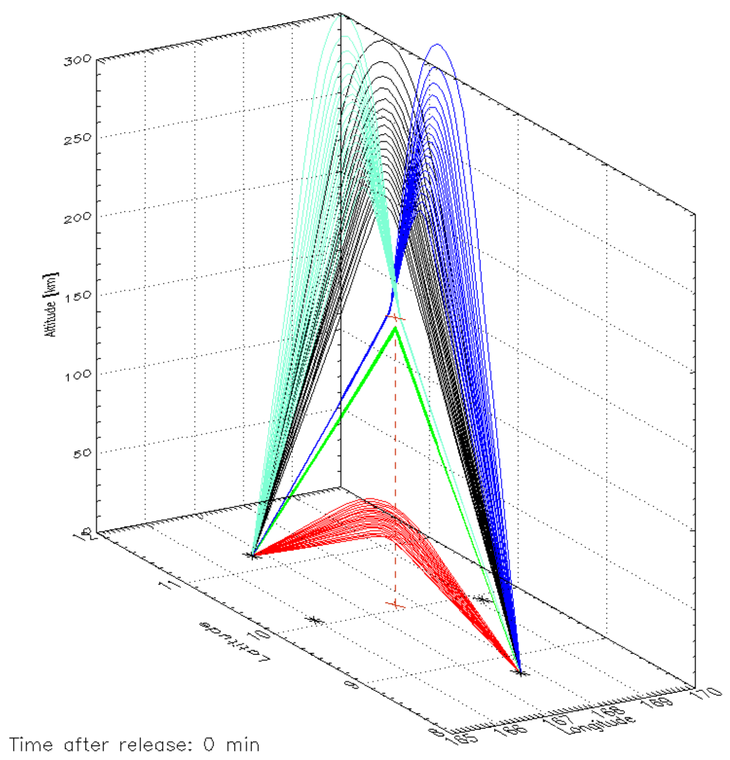


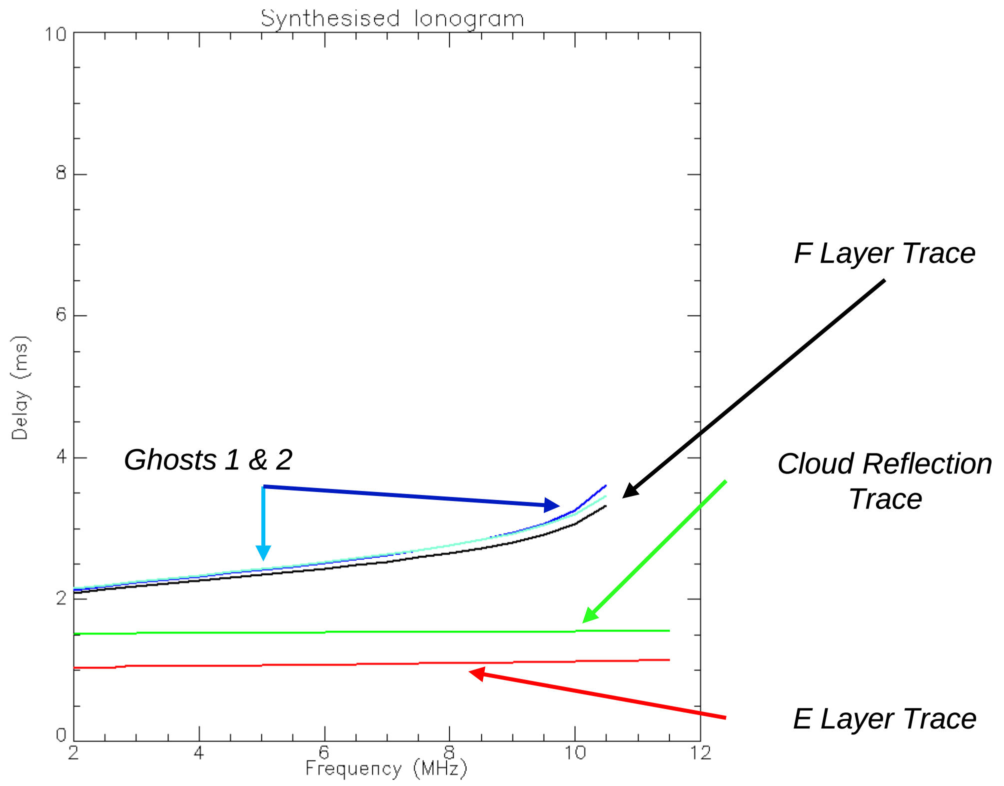
- 2D projection of cloud visualised (shaded region on the base).
- If the hit point deviates from target its ray is no longer included (dashed traces).
- Ionogram can be reconstructed using time of flight of rays.

Possible Geometries



Complete Reconstruction

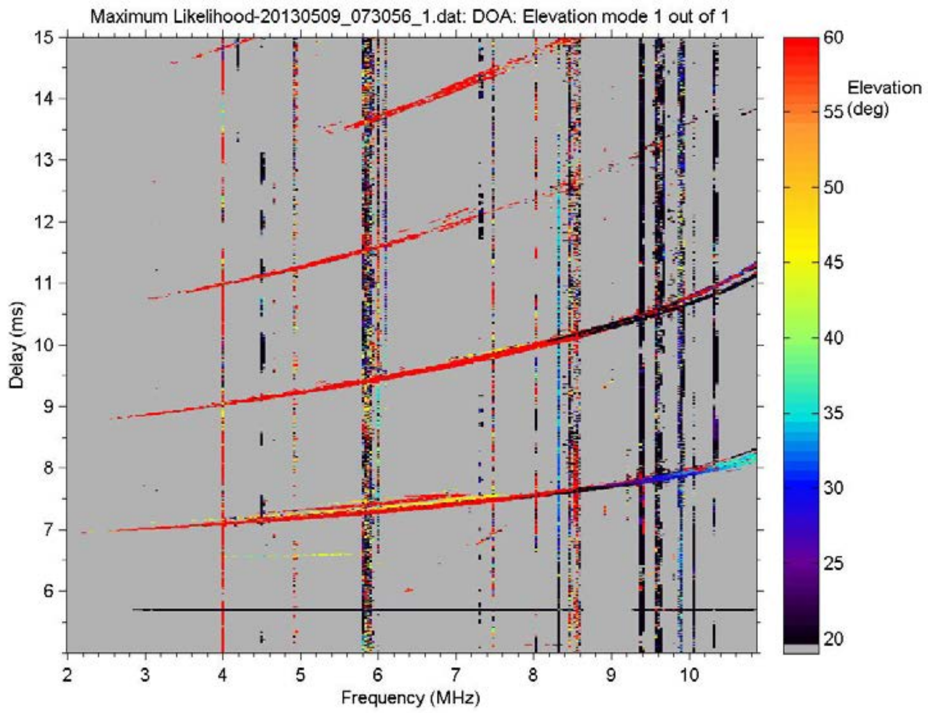




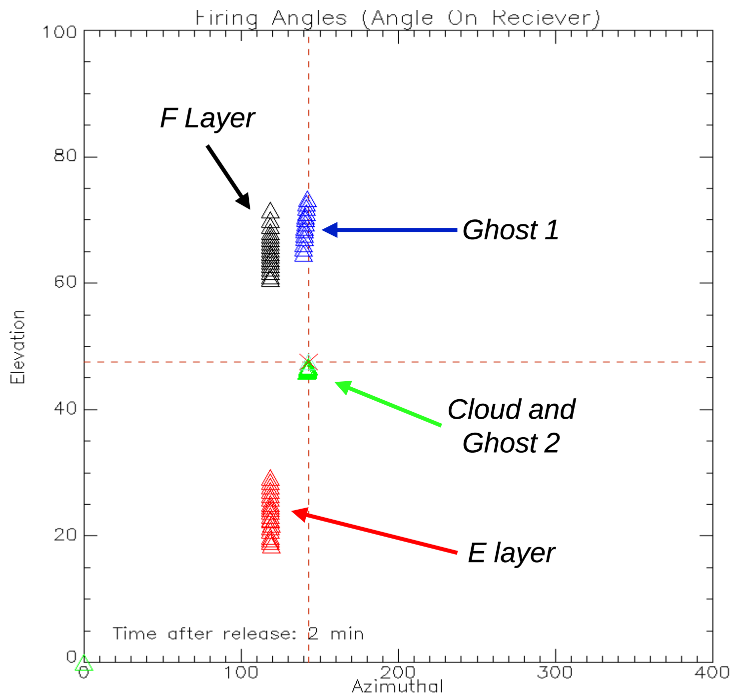
Time: 07:25:58 UT (time of release).

Complete Reconstruction – Angle of Arrival

Experimental - Elevation



Simulated

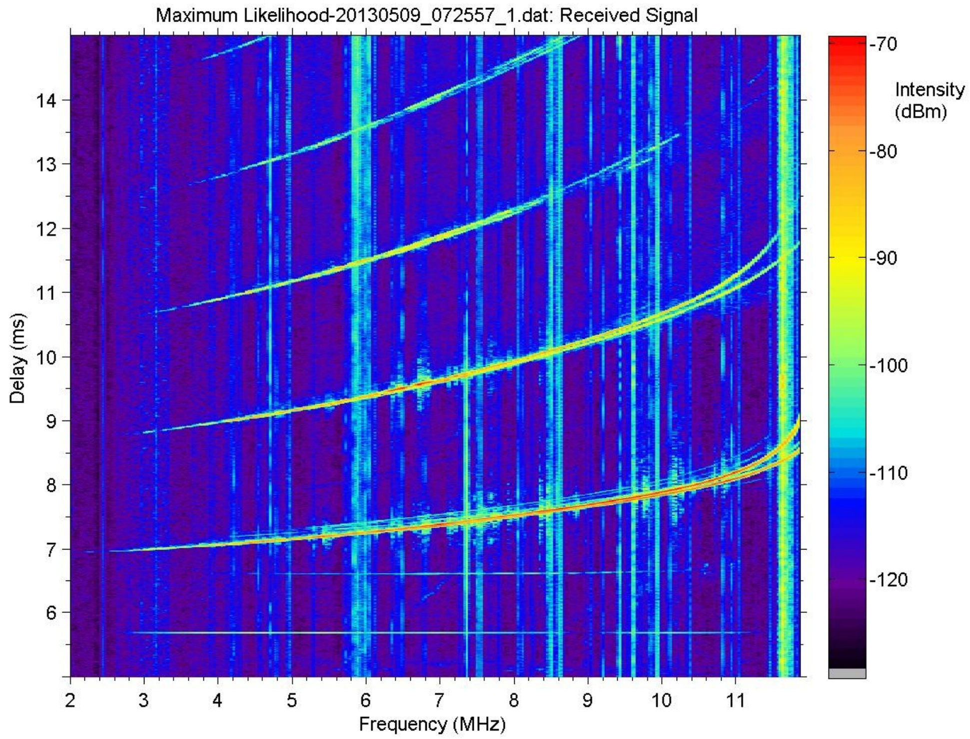


- Now able to extract angle of arrival of distinct rays.
- A comparison to AoA data from MOSC can confirm predicted ray geometries.

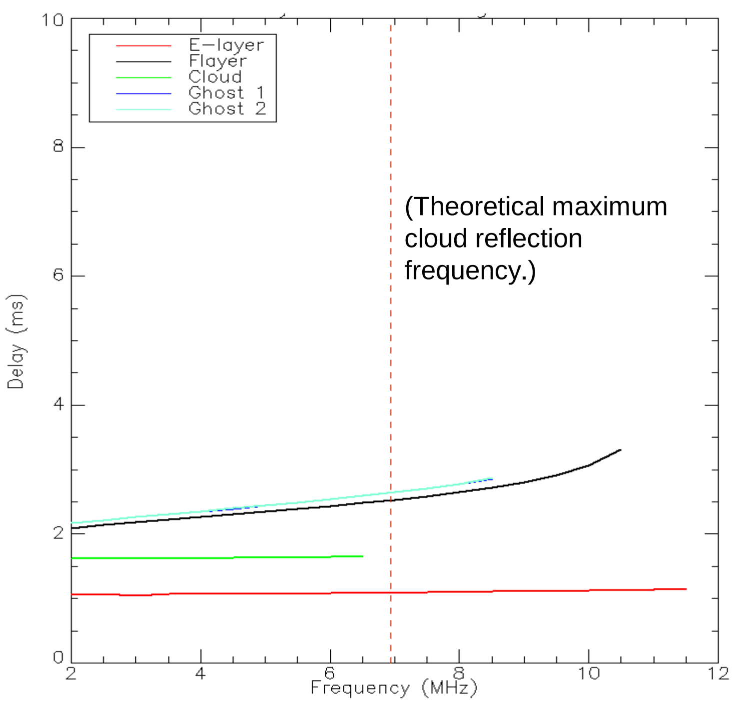
Complete Reconstruction

Ionograms of the Rongelap to Kwajalein path, *07:27:58 UT* (2 minutes after release).

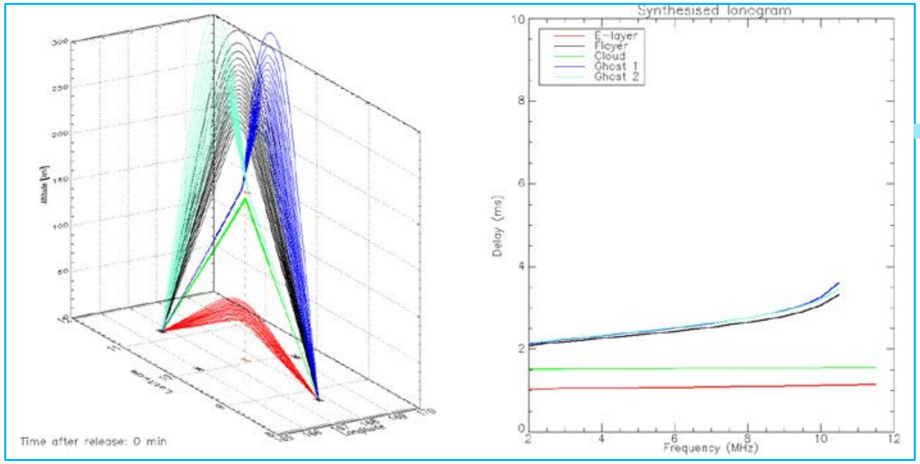
Observational Ionogram



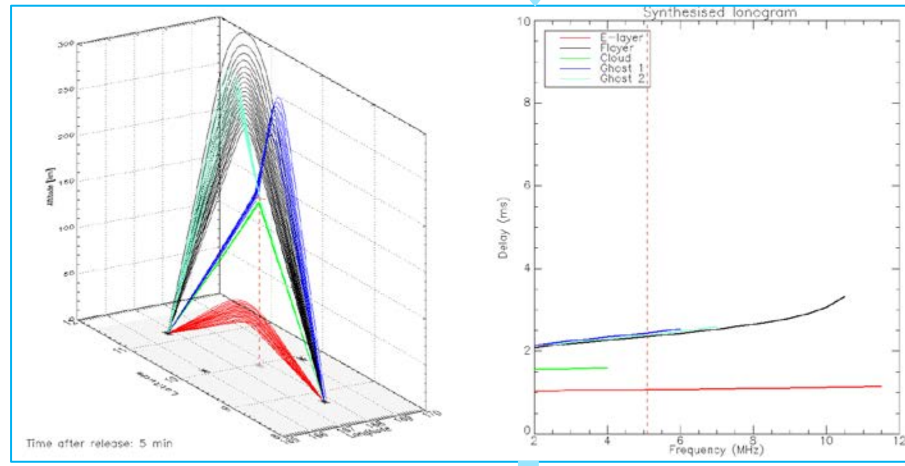
Simulated Ionogram



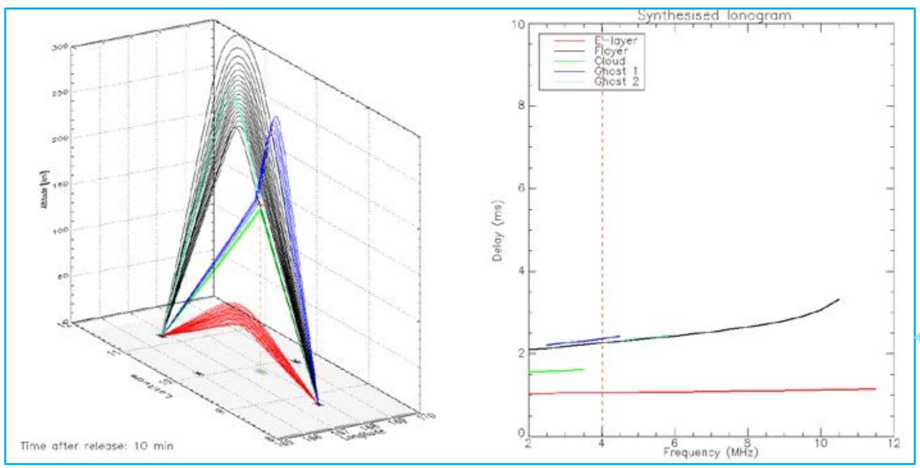
Time Evolution



After 5 minutes



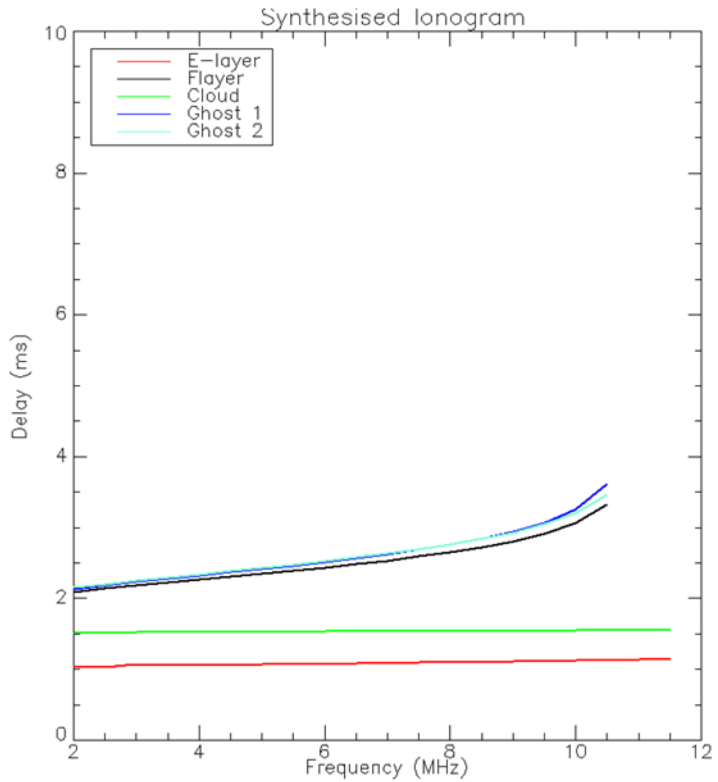
After 10 minutes



Conclusions

Conclusions

- AFRL cloud model successfully incorporated into ray trace
- The synthetized ionograms reproduce the correct delay times for the respective layers seen in the experimental plots.
- The synthetic ionograms also contain the new layers due to an interaction with the plasma cloud.
- The ‘Ghost’ layer sitting above the F layer is due to a ray scattering off the cloud to the F layer and then reflected down to the receiver. This longer route causes a small time delay as seen on both the recorded and synthesized ionograms.



Questions?