

Preliminary HF results from the Metal Oxide Space Cloud (MOSC) experiment

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Abstract

Artificial Ionospheric Modification (AIM) can occur through deliberate or incidental injections of aerosols, chemicals or radio (RF) signals into the ionosphere. The Metal Oxide Space Clouds (MOSC) experiment was undertaken in April/May 2013 to investigate chemical AIM. Two sounding rockets were launched from Kwajalein Atoll and each released a cloud of vaporized samarium (Sm). The samarium created a localized plasma cloud that formed an additional ionospheric layer. The effects were measured by a wide range of ground based instrumentation; this included a 17 channel direction finding chirp receiver. This system detected the new layer which remained visible to the HF sounder for approximately 25 minutes. The layer's maximum usable frequency peaked at approximately 10 MHz immediately after release. The direction to the reflection point remained constant at 355° whilst the new layer was visible to the sounder.

1. Introduction

Artificial Ionospheric Modification (AIM) can occur through deliberate or incidental injections of aerosols, chemicals or radio frequency (RF) signals. The Metal Oxide Space Clouds (MOSC) experiment was conducted in April/May 2013 to investigate chemical AIM [1]. Two sounding rockets were launched by NASA from the US Reagan Test Facility on the Kwajalein Atoll in the Pacific Ocean (part of the Marshall Islands, 9.395°N, 167.469°E, Figure 1). Each rocket released a cloud of vaporized samarium (Sm) that created a localized plasma cloud. The experiment was designed to investigate:

- The production of controlled increases in ionospheric density to mitigate and/or control scintillation
- On-demand space plasma generation (i.e. to modify HF propagation)

The effects were measured by a wide range of ground based instrumentation dispersed in several locations across the Marshall Islands. The instrumentation included optical observations, trans-ionospheric beacon measurements, and incoherent scatter measurements using the ALTAIR radar. This paper describes initial results from a sub-set of the ground based high frequency (HF, 2-30 MHz) ionospheric sounders that were also deployed.

2. HF measurement system

The effects of the samarium release were monitored using both oblique and vertical HF sounders (Table 1). The data presented in this paper was collected using the N-IRIS [2] receiver. This receiver comprises 18 coherent (i.e. phase locked to a master oscillator) receiver cards to provide a direction finding capability. N-IRIS was used in conjunction with a 17 element array of active magnetic loops. The array was disposed in a T configuration (Figure 2), with various spacings between the elements, to provide adequate angular resolution across the HF band. The 18th receiver channel was reserved for testing purposes and has not been used in the angle of arrival estimations.

For both launches N-IRIS recorded the FMCW (frequency modulated, continuous wave [3,4]) chirp transmissions from Likiep (range and bearing from Kwajalein: 204 km, 48.5°) and Rongelap (range and bearing from Kwajalein: 297 km, 339°). Both transmitters operated in the same time slot (1 Min, 04 sec past the 5 minute boundary), but were separated in start time by 20 ms. This enabled simultaneous reception of both transmitters with a single N-IRIS receiver. The transmitters swept at 100 KHz/s from 2 to 30 MHz. Results from both launches were similar and only results from the first launch are presented herein.

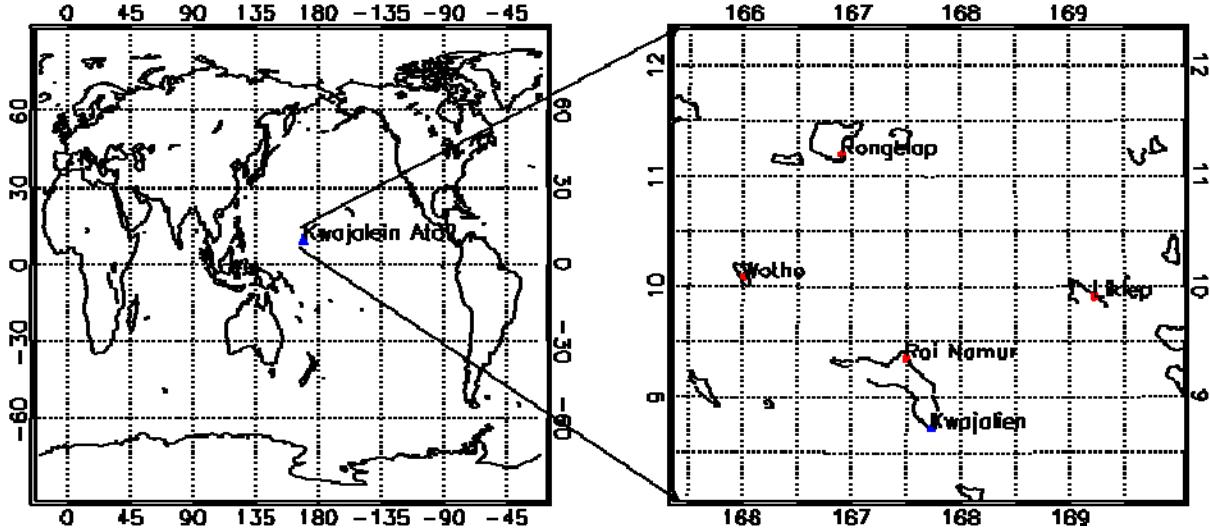


Figure 1: Map of the Marshall Islands

Table 1: Table of HF equipment deployed in the Marshall Islands. Site locations can be found in Figure 1. Rx=receiver; Tx=transmitter, FMCW=frequency modulated, continuous wave chirp waveform, FFPC=fixed frequency pulse compression waveform; SWPC=swept pulse compression waveform; MIT LL= Massachusetts Institute of Technology, Lincoln Laboratory.

Site (Figure 1)	Tx/Rx	Waveform	Hardware
Kwajalein	Rx	FMCW, FFPC	18 channel N-IRIS
Roi	Tx	FMCW	Leicester University chirp transmitter
	Rx	FMCW	IRIS (based on Racal receiver)
	Rx	FMCW, FFPC	MIT LL receiver
	Tx/Rx	SWPC	Digisonde
Likiep	Tx	FMCW	MIT LL
	Tx	FFPC	Roke X72/1/8922/510
	Rx	FMCW	IRIS2
Rongelap	Tx	FMCW	Roke X72/1/8922/510
	Tx	FFPC	Roke X72/1/8922/510
	Rx	FMCW	IRIS2
	Tx/Rx	SWPC	Digisonde
Wotho	Rx	FMCW	IRIS2
	Rx	FMCW, FFPC	MIT LL receiver

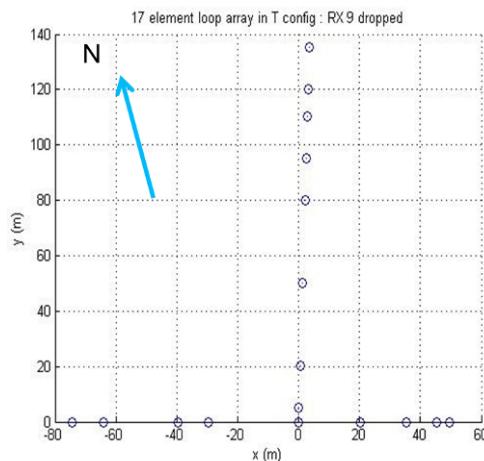


Figure 2 Schematic layout of N-IRIS 17 element antenna array

3. Results

The first launch occurred at 07:38:00 UT on 1 May, 2013. The samarium was released at 07:40:40 UT at a height of 170 km. The coordinates of the release (provided by NASA) were: 9.996°N, 167.648°E. An initial estimate, based on optical data, suggests that a lower than expected amount of samarium was ionized[1]. The causes of this are under investigation.

The chirp transmissions recorded by NIRIS were used to generate ionograms; i.e. plots of frequency versus group delay for the ionospheric returns. Prior to launch, a ground wave, E and F traces were visible on the Rongelap-Kwajalein ionograms (Figure 3a). After release, a new trace, extending to 9.9 MHz on the ionogram, was seen at a delay of 1.5 ms (Figure 3b). The new trace remained visible on the next five ionograms; however, the maximum usable frequency (MUF) of the layer dropped during that time to 2.4 MHz. Similar results were seen on the Likiep-Kwajalein path. In that case, the new trace initially extended to 9.8 MHz and decayed to 5.8 MHz over the next two ionograms.

Angle of arrival (AoA) estimates were calculated for both the Likiep-Kwajalein and Rongelap-Kwajalein paths. AoA ionograms (Figure 4) show that, from the receive site, the new layer is at a bearing of approximately 355° for both paths. This is consistent with the expected samarium cloud position based on the estimated release point.

4. Conclusions

A direction finding chirp sounder has been used to detect and characterize samarium clouds released by sounding rockets. Despite pre-launch predictions that the MUF of the layer would extend to above 30 MHz[1], the ionogram traces associated with the cloud reached a maximum frequency of just 10 MHz. This value is consistent with the lower than expected ionization rate that has been estimated from preliminary optical results [1].

Angle of arrival estimates for the ionogram traces have been obtained with a 17 channel phased array. They show that the reflection point of the new layer remained almost static after formation, which is also consistent with the preliminary optical results.

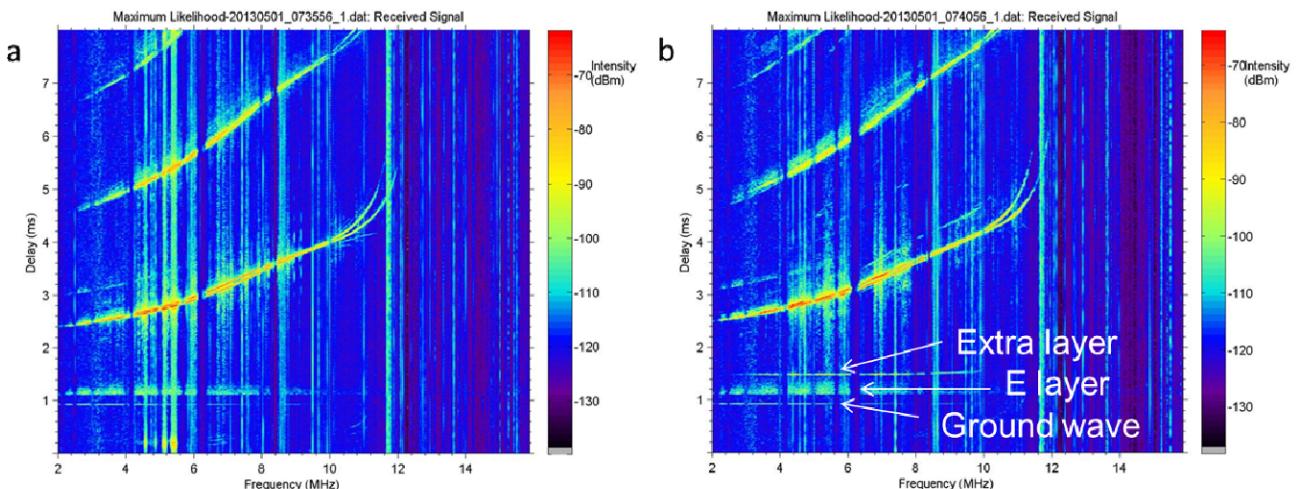


Figure 3 Ionograms of the Rongelap to Kwajalein path: a) ionogram recorded at 07:35 UT on 1st May 2013, just prior to launch. A ground wave, E and F traces are visible; b) ionogram recorded at 07:40 UT on 1st May 2013, just after the launch, a new layer at a delay of 1.5 ms is visible.

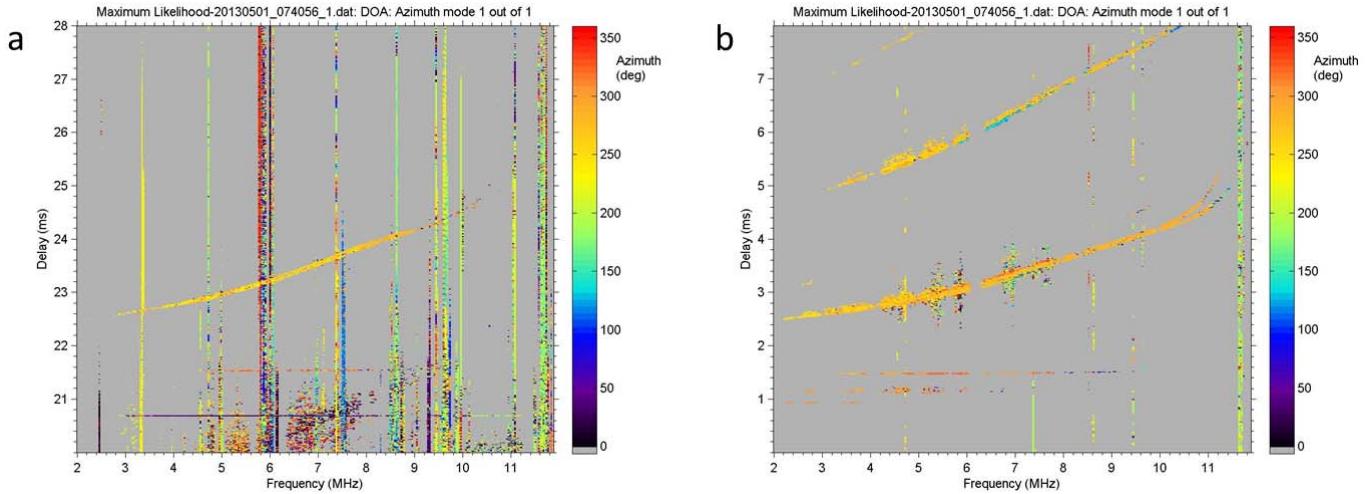


Figure 4 Angle of arrival ionograms for launch 1: a) the Likiep to Kwajalein path recorded at 07:40 UT. The new layer is visible at 21.5 ms with an AoA of approximately 355°. Note delays are offset by 20 ms; b) the Rongelap to Kwajalein path recorded at 07:40 UT. The new layer is visible at 1.5 ms with an AoA of approximately 355°.

5. Acknowledgments

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6. References

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