RF Propagation Characterization in the Arctic

Measurements from JHU/APL participation in 2018 SODA campaign

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Abstract—This paper details Johns Hopkins University Applied Physics Laboratory's (JHU/APL) participation in the Office of Naval Research's (ONR) 2018 Stratified Ocean Dynamics of the Arctic (SODA) campaign emphasizing characterization of the RF propagation environment. Several sources of data were collected including meteorological data and RF signals of opportunity. Apart from observing long range HF signals via expected ionospheric reflection, instances of anomalous tropospheric RF propagation were also observed on several occasions during a month-long underway, along with meteorological data collected to help model the phenomena.

Keywords—JHU/APL; SODA; RF propagation; Ducting; HF

I. INTRODUCTION

The 2018 SODA cruise took place between September 14 and October 18 aboard the US Coast Guard icebreaker Healy. The SODA campaign is a larger scientific initiative to better understand how the upper Beaufort Sea responds to changes in inflow and surface forcing through characterizing buoyancy, momentum, and heat. As Arctic temperatures have been significantly rising, the extent of Arctic sea ice has been declining. This has begun opening sea routes in the Arctic between North America and Asia. Thus, the US Navy has invested in better understanding the Arctic environment. Not much is known about the RF propagation environment in the Arctic and how communications and radar systems behave there with little measured data and uncertainty in the accuracy of weather models in the region. To better characterize the meteorological conditions and directly measure signals of opportunity at HF and microwave frequencies, JHU/APL employed a variety of equipment, described further in Section III, onboard the USCGC Healy during the 2018 SODA cruise. A few particularly interesting measured results are highlighted in Section IV.

II. RF PROPAGATION BACKGROUND

RF systems operating in low-elevation geometries can often be impacted by the RF propagation environment. These effects can generally be broken down into two regimes by frequency: frequencies in the 1's to 10's of MHz impacted by ionospheric and surface wave effects and frequencies in the 100's of MHz and higher affected by tropospheric conditions.

The ionospheric effects are caused by reflection off high-altitude ionized layers (E and F layers) in the atmosphere and have a strong diurnal cycle based on incoming solar radiation creating an attenuating lower altitude ionized layer (D layer) as well as a strong dependence on latitude. These reflections are referred to as "skywaves" and often result in receiving signals many hundreds or even thousands of km beyond the normal geometric horizon. A different propagation mechanism, surface waves bolster similar frequency signals transmitted near the surface in a more continuous fashion, but typically not as far.

The tropospheric effects result from vertical gradients in the index of refraction that can bend energy up or down. The index of refraction at RF frequencies is non-dispersive and can be computed from knowledge of meteorological conditions, namely temperature, pressure, and humidity. These conditions can be broken down into several categories, as shown in Fig. 1. The most anomalous propagation categories tend to be surface ducting, where energy can be trapped at low elevation angles and sent well beyond the horizon. Additionally, surface ducts present at the source of the transmitter or receiver, can transition into elevated ducts and eventually more standard conditions downrange, but still provide a channel for energy to travel over-the-horizon and reach high altitudes, which cannot be depicted in the traditional range-homogeneous categorical sense.

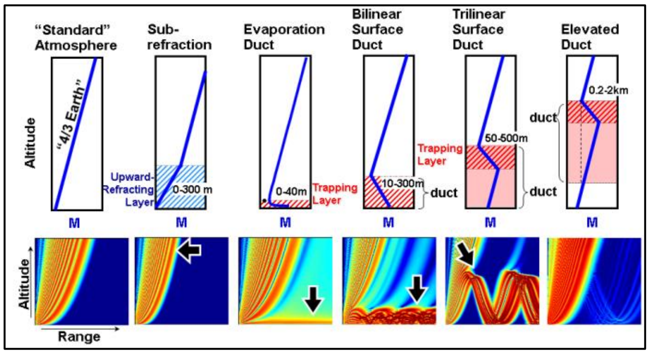

Fig. 1. Categories of tropospheric refraction conditions shown in M-units.

III. EQUIPMENT

The equipment used to characterize these various propagation mechanisms consists of the JHU/APL Automated Environmental Assessment System (AEAS), two software defined radios (SDR) each controlled by a Raspberry Pi single board computer, a commercial Automatic Identification System (AIS) receiver and an ASTRA CASES high data rate GNSS (GPS) receiver. One of the SDRs was used tuned to around 5 MHz to receive HF signals from various Coastal Ocean Dynamics Applications Radar (CODAR) sites on the northern coast of Alaska as described in [1]. The other was tuned to 1090 MHz to receive Automatic Dependent Surveillance-Broadcast (ADS-B) data from commercial aircraft. The AEAS recorded air temperature, relative humidity, barometric pressure, IR surface temperature, and wind speed and direction from two separate weather stations one on the port and one on the starboard side of the level above the bridge of the Healy. Additionally, 16 small radiosondes were launched periodically from the Healy during the 35 day underway to measure the conditions in the lowest ~1km of atmosphere where the predominant tropospheric refractive effects occur.

IV. RESULTS

During the underway, 840 hours of AEAS, AIS, and raw GNSS data were collected. The ADS-B receiver identified 825 unique aircraft over 560 hours (see Fig. 2) and HF CODAR data on most of the days. Throughout most of the underway, evaporation duct heights as modeled from meteorological measured data were low (<5m). This will act to reduce the RF horizon relative to other warmer locations. Anomalous RF propagation was observed between Oct 3 – 7 of ranges over 500 km, and in one instance aircraft transmissions were received from over 950 km (see Fig. 3). This coincided with atmospherically stable conditions where the air was warmer than the surface. This is a notoriously difficult phenomenon for weather models to accurately forecast.

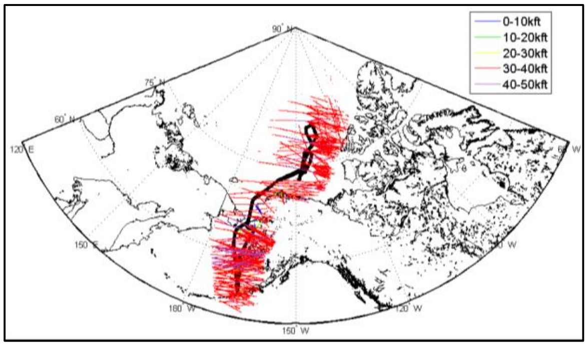

Fig. 2. All ADS-B aircraft location data received, color-coded by altitude (13 Sep – 19 Oct 2018). The thick black line represents the path of USCGC Healy.

Harsh weather conditions caused previously unseen failure modes in otherwise seaworthy equipment. With occasional temperatures as cold as -10.4°C and sustained winds of 20 m/s, AEAS sonic anemometers became coated with rime ice and gave incorrect readings. Radiosondes launched by the ship generally measured standard atmospheric conditions, with an occasional weak elevated or near-surface duct (see Fig. 1 for reference), but nothing as strong as has been seen offshore of more warm and arid regions, e.g. Southern California.

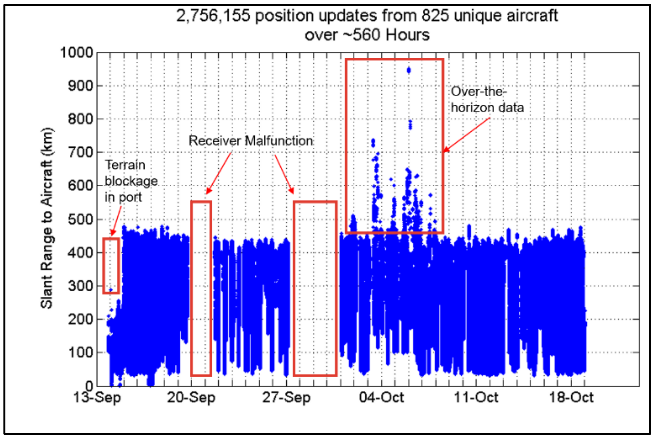

Fig. 3. Received aircraft ADS-B signal ranges vs. time

The received HF signals showed strong diurnal variation as well as daily variations in the strengths and locations of reflected energy, which were primarily multiple bounces from the E region. The direct path of the energy was typically received via over-water surface wave propagation. Analysis of ionospheric scintillation effects from received GNSS signal data as well as correlations with observed auroral activity are ongoing.

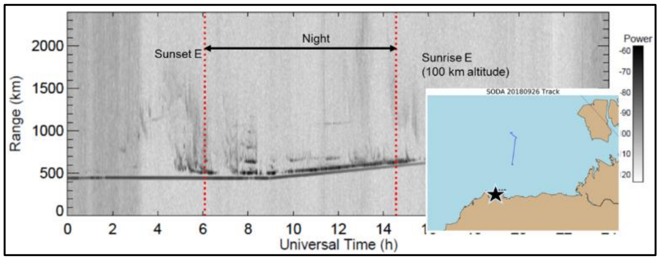

Fig. 4. Received HF signal range vs. time on 26 Sep 2019 from the CODAR station in Cape Simpson, AK, showing multiple reflections from the E region of the ionosphere, primarily during the nighttime. Inset shows the track of the USCGC Healy during this time with the CODAR station as a black star.

V. NEXT STEPS

Repeating the same experiment with more RF receivers listening to additional frequencies, e.g. VHF and HF Aircraft Communications Addressing and Reporting System (ACARS) data links, will enable more spatiotemporal measurement of propagation conditions over various geometries. This combined with meteorological measurements and magnetometer data can yield a rich dataset for validation of high-fidelity weather and ionospheric models. Increased intercontinental air traffic will continue to provide a rich source of signals of opportunity for studying the Arctic environment.

REFERENCES

[1] E. S. Miller, et al., “Sounding the ionosphere with signals of opportunity in the high-frequency (HF) band,” Presented at the USNC-URSI National Radio Science Meeting, Boulder, CO, 10 Jan 2019.