Spatial K-means Clustering of HF Noise Trends in Southern California Waters

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Abstract—**This paper presents high-frequency band noise characteristics, measured over a fourteen-day period while underway off the coast of Southern California. The investigation uses k-means clustering to identify spatial noise variations. Local domains provide insight on regions where high noise HF communications are expected.**

I. INTRODUCTION

Rapid growth in worldwide ship traffic increased HF and VHF band radio frequency emissions, including broadband noise [1]. Consequently, these large aggregations of noise become a limiting factor in the reception of weak signals whether added coherently or not. Specifically, medium-to-high frequency noise components are likely more of a concern. Aware of this issue, this work furthers naval understanding of spatial noise variations at sea.

II. INTRODUCTION: AT-SEA HF NOISE COLLECTIONS

The overall measurement approach profiles the existing ambient RF environment while characterizing the noise floor. A spectrum analyzer was used as the primary measurement device. A single antenna covering the frequency range of 2-30 MHz onboard combined with a spectrum analyzer and laptop comprised the receive measurement system. Raw RF data collections from the spectrum analyzer were recorded every two minutes and post-processed. Results of the post processing within these bands constitute the baseline ambient noise floor measurement.

The noise power is dependent on the type of antenna used in the collection. In the present case, an HF whip antenna was used. Prior to deployment, the loss in the antenna system was determined and extracted from the estimated antenna noise figure, F_A [2-6]. Measurements for the noise power were performed over a 3kHz bandwidth. The spectrum analyzer (controlled via LabVIEW program) connected to the antenna recorded the entire HF spectrum every minute, 24 hours per day while at sea.

Fig. 1 shows the collection area for the HF noise spectrum survey performed in the coastal waters off Southern California. The survey was conducted over the course of 14 days. Collections were performed initially at the dock in San Diego Harbor, while underway, and again during redock. The survey area was approximately 100mi x 100mi. The different color markers in Fig. 1 refer to different timestamps.

III. DATA PROCESSING AND HF NOISE LEVEL RESULTS

A Gaussian Mixture Model [2] post-processing algorithm extracted the HF noise level and estimated the effective antenna noise figure F_A. The GMM smoothing algorithm works as follows. The noise test system samples RF noise power at a given frequency for a period of several days. From this sampled data, the algorithm forms a histogram of the RF noise power. The histogram for an RF source in decibels is Gaussian. If there were multiple sources at that frequency, the histogram describes a series of Gaussians. The algorithm then defines quasi-minimum RF power as the centroid corresponding to the weakest Gaussian (local RF transmission will normally have higher RF power levels than this quasi-minimum RF power).

Fig. 2 presents the spectrogram of the HF collection from 2 to 30 MHz over the 14-day collection period. The spectrogram presents an overall picture of the noise profile throughout the underway period. Day and night changes are noted on the plot as well as shore-based signal fading as the collections increase in distance from shore. Atmospheric broadband noise differences between day and night are normally noted below 18 MHz; man-made and RF signals exhibit day and night changes throughout most of the HF band (e.g. Citizen's Band). Two local, high-frequency (HF) coastal ocean dynamics applications radars (CODAR) are found in the region and are apparent in the spectrogram. Despite this, the antenna was disconnected and the outcome of the post-processing has a result that is equivalent to the noise floor of the measurement systems (*displayed average noise level*, DANL)[1] as evident in the region of Jan 25-28 in Fig 2.

IV. SPATIAL NOISE LEVEL RESULTS

Fig 3 shows spatial results of the at-sea shipboard collection using the K-means clustering algorithm. A Gaussian mixture model using only a full variance matrix and no sharing of covariance is applied to the algorithm to derive four spatial clusters of Fig 3. For brevity in analysis, Fig. 4 presents results of the effective antenna noise F_A processed from the daily HF spectrum collections. Fig. 4 also shows a comparison of results for the ITU-R noise model for various established noise levels (e.g., city, rural, quiet rural). Also of particular interest is comparison to Quasi-minimum Noise (QMN), a standard used by the Navy as the design criteria for HF communication systems [2-5].

Elevated noise levels appear at the lower end of the HF band with spatially dependent regions in the upper spectrum. In particular, higher levels exist in regions where all noise sources within the monitored frequency band add coherently, excluding intentionally radiated RF signals (radio broadcast, television broadcast, communications signals, etc.). These spatial trends are expected to converge to their mean values, in accordance

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[1] This occurs since ambient noise floor levels were not easily detectable due to power fluctuations, cable loss, and antenna loss. RF characterizations are still being updated to account and correct for these issues.

with standard probability theory. Further study can confirm this. The measurement and analysis techniques presented here provide a means to evaluate ambient noise both on shore and at sea in an effort to better understand electromagnetic environmental effects.

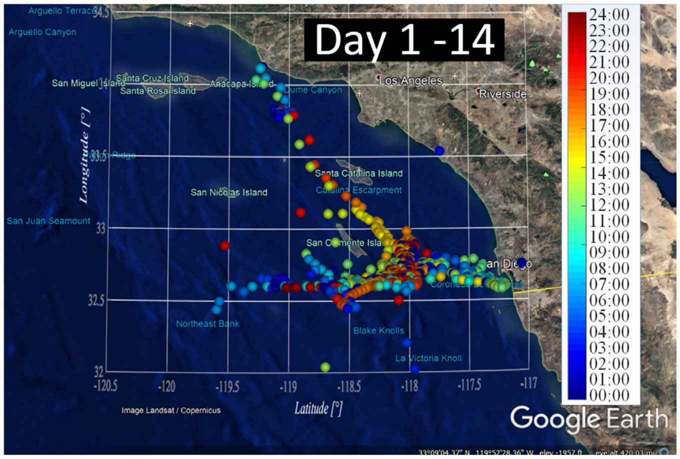

Fig. 1. Off-shore collection areas for HF noise survey.

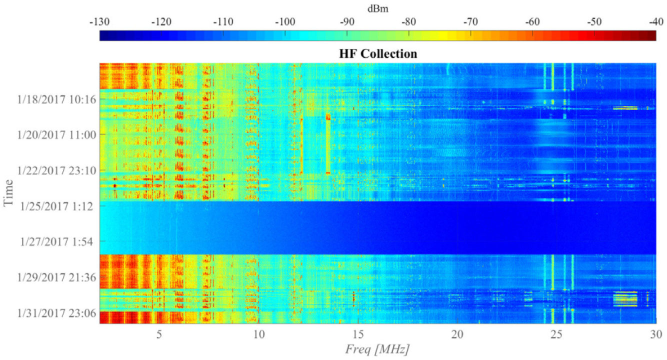

Fig. 2. Spectrogram recording.

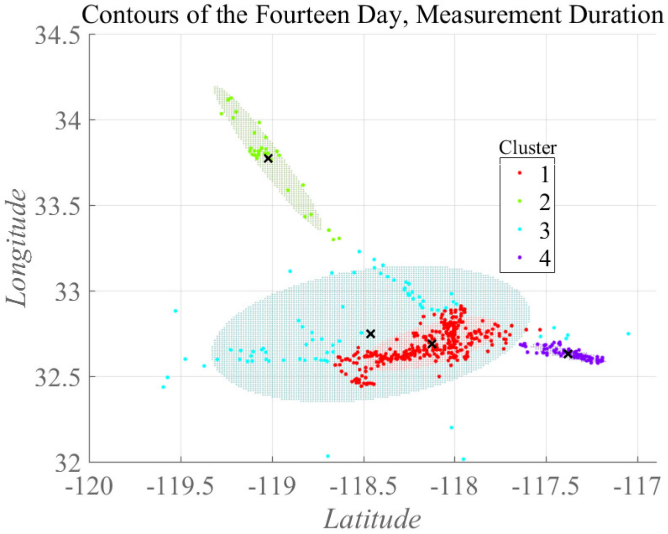

Fig. 3. Spatial-at-sea, k-means clustering. Centroids of each cluster are marked using a black x.

CONCLUSION

This paper presented a spatial survey of HF atmospheric noise at-sea in the Southern California area. Results indicate elevated noise levels throughout the HF band with minor spatial variation. Further investigation of measurements is of interest to enhance naval understanding of time-varying effects induced from deployment to at-sea operations as well as HF receiver design. Figure 5 helps in the identification of high noise narrowed to within ten points of the cluster centroid. More sophisticated algorithms may help de-correlate identifiable noise sources with spatial dependencies induced from specific operations and mission sets of time-varying and atmospheric changes.

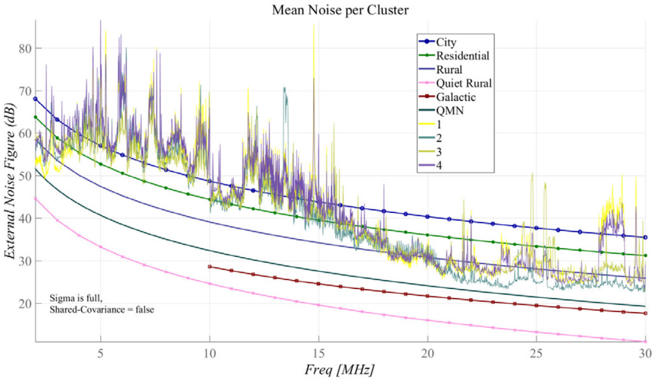

Fig. 4. Mean noise per K-means cluster.

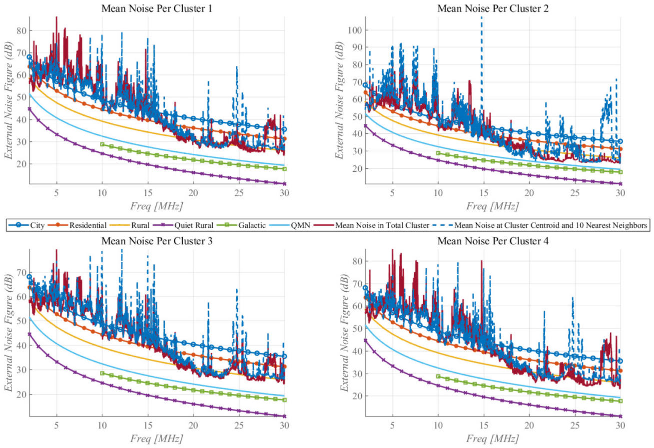

Fig. 5. Comparion of mean noise in the centroid of each K-means cluster; Sigma is full, shared covariance is false.

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