# 1997 YEAR-END REPORT
# SPY WEATHER EXPERIMENT

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## LONG-TERM GOALS

There currently exists no method to characterize environmental conditions throughout the volume surrounding the battle group. Valuable environmental parameters include measurements of precipitation extent, wind profiles, cloud layer extent, and air turbulence. With the application of advanced signal processing techniques, a tactical Navy radar such as the AN/SPY-1 radar can provide accurate, real time weather information to benefit a variety of units in the battle group. SPY-1 provides the sensitivity and flexibility to integrate a secondary capability of weather surveillance, with minimal impact on the primary role of tactical surveillance. The weather surveillance processing could be accomplished through an auxiliary environmental signal processor that operates in parallel with the tactical system. Such a processor could, with minimal impact on tactical operations, provide real time performance improvements to the SPY-1 radar operation and provide valuable information to be disseminated for the support of fleet operations.

## OBJECTIVES

The overall object of the specific effort was to provide "proof of concept" of a tactical phased array radar to collect reliable weather information in the form of the intensity, mean radial velocity, and spectral spread of meteorological phenomena using the normal operating modes of the radar. This was demonstrated using the AN/SPY-1B radar at the Navy's CSED Site. A particular scientific objective was to demonstrate the feasibility of using pulse compression waveforms to perform, satisfactorily, the weather surveillance function.

## APPROACH

The ability of SPY-1 to conduct a weather surveillance scan was quantified through a series of data collection sets, combined with system analyses. Three data collection sets comprised the full experiment. Each data collection set consisted of several data collection missions, combined with the post processing and analysis of data from the missions. A data collection mission was comprised of a single data collection event using a SPY-1 radar. The order of execution of the data collection sets was: (1) Baseline data collection set (to verify the data collection system and signal processing); (2) Proof of concept data collection set (to provide a comparison of

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spectral moments with NEXRAD); and (3) Clear air observation data set (to evaluate wind profiling and cloud layer detection).

The port face of the AN/SPY-1B radar system at the Navy's Combat System Development (CSED) facility, in Moorestown , NJ, was used to conduct the data collection missions. The first data collection (the baseline data set) validated the data collection and signal processing methodology. The second set, the proof of concept data collection, was run in coordination with one of the National Weather Service's (NWS) Next Generation Weather Radar (NEXRAD), which is located approximately 22 miles away at Fort Dix, NJ. A comparison between NEXRAD and SPY-1 quantified SPY-1's ability to make accurate weather measurements utilizing the system's tactical waveforms. The final data collection, the Clear Air data set, investigated the ability of the radar to detect cloud layers and measure clear air winds. An overview of the data collection sets, purpose of each, and time period of each set (including data collection, data post processing, and analysis) is shown below.

| DATA SET | PURPOSE | TIME PERIOD |
|---|---|---|
| Baseline | Validation of Data Collection and Processing System | 2/96 - 5/96 |
| Proof of Concept | Comparison with NEXRAD | 6/96-11/96 |
| Clear Air Observation | Investigate Cloud Layer Detection and Wind Profiling Capabilities | 12/96-6/97 |

## WORK COMPLETED

During FY97, the following tasks were completed:

(1) Analysis was completed on the Proof-of-Concept Data Set, and results presented at a Technical Interchange Meeting held in Moorestown on February 18, 1997. SPY-1 observations were compared to those from NEXRAD for three different data collection events. They include a set of thunderstorm data from June 19, 1996, a set of rain data from August 21, 1996, and data taken as the remnants of Hurricane Fran passed through New Jersey on September 6, 1996. The analysis consisted of the off-line generation and evaluation of the three weather moments (precipitation density, mean radial velocity, and spectrum width). Comparisons were made both with the NEXRAD radar located at Ft. Dix, and with measurements made using the NEXRAD waveform as transmitted from the SPY-1 radar.

(2) The Clear Air Data Set was initiated, data collection conducted, and analysis of the data completed and results presented at a Technical Interchange Meeting held at ONR on August 11, 1997. Data was collected over seven different days that spanned the period from March 18, 1997, through July 26, 1997. Data was collected at various times throughout the day, and from very clear conditions through cloudy conditions, to heavy cloud conditions with light precipitation. The three radars involved in the clear air data collection events were located so that their coverage overlapped (namely SPY-1, NEXRAD, and the Penn State University W-Band Cloud Detection Radar).

## RESULTS

Results of analysis performed during the Proof-of-Concept Data Set have clearly shown that the SPY-1 radar is capable of making accurate precipitation measurements. These measurements are made almost entirely with tactical waveforms and are very accurate when compared to NEXRAD measurements and measurements made from SPY-1 using the NEXRAD waveform. Detailed analysis has shown that the SPY-1 reflectivity maps match very well with those of NEXRAD. For the case of a 10 dB signal-to-noise ratio, the following error estimates were generated for measurements made with SPY-1 waveforms: (1) reflectivity estimate accuracy of 1.3 dBZ, (2) mean radial velocity estimate accuracy of 0.6 m/s, and (3) spectrum width estimation accuracy of 0.9 m/s.

Results of the Clear Air Analysis Data Set have demonstrated SPY-1's ability to detect and profile boundary layer turbulence and cloud layers. It has been further demonstrated that the SPY-1 radar can generate accurate wind profiles, providing measures of wind speed and direction as a function of altitude directly above the radar. A W-Band (94 GHz) radar provided by Pennsylvania State University has confirmed the SPY-1 ability to measure clouds, and to help conclusively demonstrate that SPY-1 profiles of structure in the boundary layer were made from turbulence scattering, and not scattering from wind-carried debris. In addition, SPY-1 profiles of wind speed and direction were shown to be accurate when compared to those generated by NEXRAD. A number of profiles were made between altitudes of 10,000 and 18,000 feed. Errors between the two radars were minimal, showing that the offset Velocity Azimuth Display (VAD) technique, as applied to the SPY-1 radar data, is accurate in the generation of wind profiles. Wind speed differences between the two radars were usually less than or equal to 2 m/s, and the wind direction differences were very small.

## IMPACT

Local real-time weather surveillance offers many benefits to the U.S. Navy. Knowledge of precipitation and winds in the vicinity of air operations can significantly increase the efficiency and safety of those operations. The ability to detect cloud layers would also be of benefit to the coordination of air operations, which are affected by varying visibility conditions. The ability to monitor real time weather conditions can also provide improvements in the performance of tactical sensors through effective waveform and pulse repetition frequency (PRF) selection, and by aiding in the removal of undesirable clutter tracks which correlate to weather return. If ducting conditions can be identified through a weather surveillance function, radar performance will be improved. Additionally, precipitation and winds information can be provided for further dissemination to operational units.

The basic environmental measurements made from a tactical radar such as SPY-1 can be used to generate products such as (1) Nowcasts and Forecasts to support operational planning, (2) highly-detailed clutter maps to improve radar waveform selection and radar sensitivity in heavy clutter conditions, (3) wind field measurements to assess TBM warhead dispersion, to predict ballistic weapon trajectories, and to support aircraft operations, (4) continuous, volumetric measurements of the environment to aid in radar propagation assessment, and (5) measurements of the marine boundary layer which may prove to be critical for improving real-time operational assessment of radar performance.

## TRANSITIONS

This experiment has clearly demonstrated the capability of the SPY-1 radar to make measurements of precipitation, profiles of cloud layers, profiles of boundary layer turbulence, and measurements of wind speed and direction. Transition of this capability to an at-sea operational capability will soon begin with the initiation of the Tactical Environmental Processor At-Sea Demonstration. This two-year program is jointly sponsored by the AEGIS Program Office (PMS-400), N096, and ONR, and is expected to begin early in FY98. The objectives of this program is to develop a near-real-time COTS-based processor to host the advanced environmental signal processing function, and demonstrate this onboard an AEGIS ship in FY99.

## RELATED PROJECTS

Although not directly addressed within the scope of the current project, there exist a number of closely related projects within the Navy and academia which can benefit from the radar-based environmental data generated to date, and the data soon to be generated as part of the At-Sea Demonstration. Storm sequence data was provided to Mr. Mark Weber at MIT Lincoln Labs for use in evaluating storm tracking algorithms, under funding from ONR. Weather Moment data was also provided to Dr. Qin Xu at NRL to assist in their on-going efforts to retrieve full wind field information from radial velocity measurements and to assimilate radar data with numeric models. Other related efforts include the Remote Refractivity Sensing Project led by Ted Rogers at NRaD, the NRL Onboard Model Development efforts, and the Penn State University initiatives to assimilate radar data with propagation models.

## REFERENCES

"SPY-1 Weather Experiment Final Report", 31 October 1997, Lockheed Martin document number NS-L-TWR-T-2004

"SPY-1 Weather Experiment Final Report Supplement", 31 October 1997, Lockheed Martin document number NS-L-TWR-T-2005