RAPID ENVIRONMENTAL SENSING USING TACTICAL NAVAL RADAR

by

Tom McNellis
Lockheed Martin
Mooresown, NJ 08057
thomas.j.mcnellis@lmco.com

Tim Maese
Lockheed Martin
Mooresown, NJ 08057
tim.maese@lmco.com

John McCarthy
Aviation Weather Associates Inc.
Palm Desert, CA 92211

Summary

In today's battlespace, where response time is measured in minutes and not hours, the adequacy of environmental measurements available for tactical METOC analysis is called into question. Often, a fleet forecaster only has minutes from the time environmental data are received to assess, review and formulate an analysis for the deployed task force. The impact of time-late information available to the tactical decision maker can mean the difference between mission success and failure, as has been demonstrated time and again in operational missions.

The modern warfighting world of precision targeting against a mobile adversary requires timely and accurate in-situ environmental assessment. The Naval Transformational Roadmap, Power and Access... From the Sea, calls for "Real-time meteorological and oceanographic battlespace characterization for gaining asymmetric advantage by collecting, processing and exploiting environmental data on-scene in synchronization with the battle forces" [1]. The use of "through the sensor" techniques is making possible the employment of the Navy's highly capable and multi-functional SPY-1 radar system in support of this objective with real-time, high quality in-situ measurements of the atmosphere as it affects sensors and weapons. This new capability can directly support critical battlegroup missions such as area air defense, strike, and expeditionary operations by supplying up-to-the-minute measurements of critical parameters including RF propagation and ducting, 3D winds, cloud base, and precipitation.

Since 1995, the U.S. Navy and Lockheed Martin have been developing new, more efficient methods of characterizing the environment by utilizing through-the-sensor techniques. These studies culminated in a highly successful at-sea demonstration of the Tactical Environmental Processor (TEP) aboard USS O'Kane (DDG77), an Aegis guided missile destroyer. TEP consists of commercial off-the-shelf processors and specialized algorithms that convert radar returns from SPY-1 into environmental measurements known as spectral moments. Unlike other environmental sensing techniques, TEP performs these measurements simultaneously with normal radar operation and therefore does not require additional radar resource time, leaving the radar free to
continue all other tactical operations. These capabilities have been demonstrated at-sea on USS O'Kane and USS Normandy during various exercises including JTFEX, Fleet Battle Experiments, and Limited Objective Experiments conducted by COMSECONDFLT [2,3].

**Warfighting Need**

A deployed naval battlegroup faces difficult and often severe environments in two critical mission areas, Strike Warfare and Ship Self-Defense. Clutter, anomalous propagation, winds and RF propagation impact sensor and weapon performance; clouds and severe weather impact joint fleet operations. As reported in the *Proceedings of the Symposium on Tactical Meteorology and Oceanography*, hosted by the National Research Council in September 1995, "Ninety percent of the Navy's strike missions have been adversely affected by weather in the past three years" [4]. The at-sea warfighter requires current, relevant information on the ever-changing environment surrounding the battlegroup. This is particularly important in the littoral zones, where restricted space and volatile environmental conditions often combine to make the effects of meteorological change constant and dramatic.

Compounding the effects of the dynamic littoral environment is the very nature of modern naval warfare. Consider the 1997 *Defense Technology Area Plan* assertion that [5]:

"*The nature of conflict has evolved to highly localized, intense but short-lived battles involving the use of high-tech weaponry. This, in turn, has shifted the focus of lower atmosphere environment support to the warfighter. This shift emphasizes the need for battlespace awareness products in greater detail, spatially and temporally, than were ever required in the strategically driven cold war. [...] As a result, the warfighter needs knowledge of the lower atmosphere environment, its dynamics, and its impact on sensor and weapon systems. [...] Achieving this requirement demands a capability to continuously observe or monitor the battlespace in 3D using remote and in situ sensors operating on space, ground, and air (manned and unmanned) platforms.*"

The importance of controlling op tempo for maximum advantage dictates the need for increased situational awareness and the ability to readily share information that can support distributed warfighters. The Navy's FORCEnet provides the architectural backbone of distributed sensors, weapons, and integrated networks required to enable dispersed decision-makers. Among other data items, the resulting integrated picture called the "4D Cube" includes the real-time METOC battlespace characterization that will fuse direct measurements (such as rawinsondes) and remote sensors (such as radar). The use of existing tactical radar provides a significant cost advantage over the use of expendables such as rawinsondes or rocketsondes, and has the important advantage of providing direct optimization of radar based on measured in-situ environmental conditions.
Strike warfare, especially time-critical strike, involves a complex coordination among joint warfighters to penetrate an adversary's defenses, deliver ordinance on target, conduct battle damage assessment, and safely return to base. The primary zones of coverage for environmental sensing are (1) launch area, (2) en route, and (3) target area. Conditions that can affect the success of the strike include cloud cover, winds, storm cells, RF propagation, and optical visibility. Launch-area environmental conditions can be obtained with tactical radar with up-to-the-minute 3D measurements.

En route and target area conditions are more reliant on forecasts due to lack of local observations in data denied areas. However, given that forecasts are only as accurate as the data used to initialize them, there is a potentially large benefit in using battlegroup radar measurements to supplement other global weather information in forecast models. This promises to produce more accurate and time-relevant synoptic and mesoscale forecast products, depending on the range to the target. The coupling of rapid environmental assessment with NOWCAST decision aids will lead to the next-generation of highly resolved forecast models that can support the needs of today's high-precision warfighter to efficiently and precisely carry out strike missions. A secondary benefit of high-quality in-situ radar data is the ability to verify the Navy's mesoscale numerical forecasts using current observations of wind and precipitation patterns. Since the nature of mesoscale forecasting on fine special and temporal scales results in an inherently higher degree of uncertainty, this ability to validate the forecast can provide the warfighters with a higher degree of confidence and better decision making.

Air defense, and in particular ship self-defense, utilizes sensors and weapons in a very time-compressed battlespace to detect hostile aircraft or missiles and to provide an appropriate response before delivery of ordinance. Modern cruise missiles flying at low altitudes and high velocities place tremendous demands on a fast reaction time weapon system to detect threats as early as possible, and then quickly close the fire control loop. To maximize performance of weapon systems against sea-skimming missiles, knowledge of RF propagation and clutter conditions is crucial. This capability is especially crucial in littoral zones, where the threat from land-launched cruise missiles is greatest and where the nearby existence of land formations and structures can contribute dramatically to the clutter environment. TEP can provide the necessary information on RF propagation and clutter conditions that maximizes defense capabilities against these low-flying weapons. Critical zones for environmental characterization consist of (1) 100 km around the ship, (2) 100 km from shore, and (3) 100 km inland.

Modern, low radar cross section missiles with their low-altitude, high-speed flight profiles provide a limited window of opportunity for weapon systems to detect, acquire, target and engage these threats. The move towards radar with higher power and higher sensitivity comes with the side effect of a larger impact of clutter and atmospheric phenomena on the system performance. These phenomena can cause increased signal attenuation and increased point and dis-
tributed clutter, resulting in increased track loading on the radar. The result is a decrease in the volume search rate, and reduced detection ranges against critical threats. The Navy tactical guideline, COMSURFWARDEVRG GRU TACMEMO, provides the following direction [6]:

To adequately define expected detection ranges for a given [air] threat, an accurate assessment of the environment and its impact on sensor systems and employment is required. Depending on the environmental conditions being experienced, system performance could be enhanced or degraded. The primary environmental factors which impact detection ranges are temperature, atmospheric pressure, relative humidity, and local weather. The operating environment (e.g., nearland/overland, littoral, or open ocean) also affects ranges. Ducting, low altitude, and sea-surface effects can result.

<table>
<thead>
<tr>
<th>Phenomena</th>
<th>Effects</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric</td>
<td>Attenuation</td>
<td>Loss of Signal Significant in all bands</td>
</tr>
<tr>
<td>Backscatter</td>
<td>False returns, Clutter</td>
<td>Significant to any active system</td>
</tr>
<tr>
<td>Refraction</td>
<td>Ducting, Line of Sight</td>
<td>Significant in all bands</td>
</tr>
<tr>
<td></td>
<td>bending</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Typical Environmental Phenomena and Effects for Radar

Typical environmental phenomena that affect radar are shown in Table 1. Unfortunately, today’s hand-held measurements and soundings do not provide sufficient temporal resolution to accurately measure the rapidly changing, heterogeneous environment. To counter these effects, radar systems can utilize rapid environmental assessment to optimize performance based on current conditions either through automatic feedback or through operator control. Detailed clutter maps including measurements of folded clutter can be used to better counter the clutter. Measurements of refractivity from clutter can provide azimuth-dependent characterization of the RF propagation conditions that can enable the warfighter to know precisely where these conditions render him more vulnerable to attack. Furthermore, environmental assessment can provide critical situation awareness to the Tactical Action Officer and the Commanding Officer to better understand and proactively manage the current threat scenario.

A variety of other warfighting missions can also benefit from the use of tactical radar to perform high-quality rapid environmental assessment. For example:

- **Air operations.** The environment has a direct impact on the ability to safely conduct flight operations, both manned and unmanned, and weather data timeliness and accuracy for both current and forecast conditions is critical. Each phase of flight operations (pre-launch, launch, local area operations, and recovery) requires specific environmental data for the operator and/or controller. Local battlegroup radar such as the Aegis SPY-1 can readily provide NEXRAD-quality weather data to support pre-flight briefings as well as launch and recovery weather data. Weather for the
The area under control during local area operations can be directly provided out to the limits of the battlegroup radar, and indirectly through better initialization of high-resolution forecasts.

- **Expeditionary and Special Ops.** The knowledge of surface conditions out to the beach and ashore is critical to expeditionary forces. Wind conditions and wave heights, as well as severe weather and storm cells can provide valuable tactical information for safety and effectiveness of operations. Furthermore, an up-to-date measurement of refractivity and ducting is crucial to assessing communications capabilities and detection vulnerability. Support from battlegroup radar can provide accurate, high-resolution and time-critical data without the use of expendables.

- **Naval Surface Fire Support.** Naval fire support is an integral element in littoral operations, whether in support of amphibious operations, expeditionary warfare, or operational maneuver from the sea. With the use of extended range gun systems and precision guided munitions, the sensitivity to environmental conditions is increased. This includes the effects of weather conditions on ballistic trajectories, weapon accuracy, and the effectiveness of targeting sensors due to ducting and optical visibility.

- **Anti-Terrorism/Force Protection.** In chemical/biological warfare, the transport and diffusion of materials and gasses depend critically upon the wind speed, direction, and turbulence that can be directly observed with shipboard tactical radar. This information can be fed directly into dispersion models and dead reckoning systems to provide predictions of fallout and possibly reverse tracking to the point source.

- **Surface Warfare.** The ever-increasing importance of defense from small, slow-moving surface craft provides significant challenges to weapon systems that were designed for Cold War-era warfare against blue-water navies. A slow-moving, low cross-section surface vessel blends into the surface clutter environment with similar velocities and reflection coefficients as the sea surface, making it difficult for the radar to distinguish. The use of detailed clutter maps and an accurate assessment of ducting and RF propagation can be critical to successful detection and acquisition.

**SPY-1 Tactical Environmental Processor (TEP)**

Lockheed Martin, in partnership with the US Navy, has developed prototype versions of an advanced radar processor that extracts detailed environmental measurements from existing surveillance radars such as the AN/SPY-1 phased array radar aboard the US Navy’s Aegis cruisers and destroyers. The Tactical Environmental Processor (TEP) program, started in 1996, completed a highly successful at-sea demonstration aboard USS *O’Kane* (DDG 77) in the fall of 1999 as the ship transited from Bath, Maine to Pearl Harbor, Hawaii. TEP benefits both the warfighters and the meteorologists, and has been proven an effective tool for both communities.
In addition to providing high-quality radar meteorological data, TEP generates real-time clutter characterization for use in optimizing weapons and sensors, and for identifying factors limiting their performance. Using SPAWAR’s Refractivity From Clutter (RFC) algorithms, TEP can also provide timely and direct measurements of the 3D propagation environment surrounding the battlegroup. Additional high-sensitivity waveforms are available for cloud characterization and wind mapping.

**TEP At-Sea Demonstration**

During the *O’Kane* transit from Maine to Hawaii with TEP and subsequent Combat System Ship Qualification Trials (CSSQT), TEP gathered environmental data from a range of atmospheric conditions in the Atlantic, the Gulf of Mexico, and the Pacific to validate the system. Key TEP findings and accomplishments include:

- Validation of TEP with “ground truth” from shore-based NEXRADs;
- Accurate, real-time assessments of propagation and ducting conditions by azimuth using “Refractivity From Clutter” techniques (Figure 1);
- Rapid volume scans of severe storm conditions (Figure 2);
- High-resolution mapping of surface clutter to improve detection of anti-ship cruise missiles;
- Accurate mapping of clouds and winds in non-precipitating conditions.

Following the *O’Kane* demonstration, TEP was installed aboard USS Normandy (CG 60) in May 2000 to support a Limited Objective Experiment during JTFEX 00-2. TEP data were transmitted via SIPRNET to the Naval Atlantic Meteorological and Oceanographic Center (NLMOC) web site where it was made available to the joint task force. This exercise provided valuable information on how TEP could support a deployed battlegroup.

![Refractivity-from-clutter (RFC)](image)

**Figure 1: Strong Surface Ducting August 29, 1999 off Wallops Island, VA (plots courtesy of SPAWAR)**

**Warfighter Payoff**

Weather and the environment play major roles on warfighter operations in all theaters. The 1997 *Defense Technology Area Plan* asserts that [5]:

*As was demonstrated in Operation Desert Storm, weather was the major cause of aborted strike missions, causing 40% of ordnance to be unused over targets and greatly compromising battle damage assessment. Increased knowledge and quality/timeframe of forecasts are needed to ensure that operations occur successfully, with reduced casualties and decreased costs, in system development and asset utilization. A unique DoD need is provision of operational support in data-sparse and data-denied areas. [...] A better under-*
standing of the lower atmosphere and its dynamics is critical to radar.

Figure 2: Northern Rain Bands of Hurricane Dennis Observed by TEP on August 30, 1999

In *Utility of Tactical Environmental Processor (TEP) as a Doppler At-Sea Weather Radar*, by Sean Robinson, Naval Postgraduate School, June 2002, the author studies the needs and shortcomings of environmental characterization for air operations, and reports that [7, 9]:

> From FY90-98, weather related mishaps to the aviation community were found to have caused $69$ million in damage and produced 11 fatalities per year. From a safety of flight standpoint, an at-sea weather radar is long overdue; without it, the Navy lags further behind CONUS and other landbase weather safety capabilities. TEP could be used to identify aviation hazards like approaching storms or severe wind shifts. This would allow for smoother operational transitions between launch/recovery cycles, and provide the CVN or LHD CO/OOD with an excellent planning tool. Additionally, TEP would prove useful as an aid in flight planning, not to mention the potential TEP offers for strike planning.

The need for rapidly updated, local environmental observations is evident also for shipboard weapon systems. The *Operational Requirements Document for MORIAH*, a shipboard system that incorporates both a digital windbird and the SMOOS(R) METOC observing system states that [8]:

> The pace and complexity of operations aboard ship and ashore at naval air stations and METOC Centers require accurate, continuous and timely METOC data. The shortcomings of existing systems are reliability, accuracy, manpower requirements, personnel safety, and ship integration. [...] Existing shipboard measurements do not adequately support current weapon systems, flight operations, and navigation. The measurement accuracy is insufficient for obtaining the required sea surface temperature, IR extinction, insolation, and high-resolution vertical profiles of temperature, pressure and humidity.

With the recent cancellation of installation of the SMOOS(R) subsystem for Aegis surface ships, a significant shortfall was created. The need for surface observations of sea surface temperature and other METOC parameters are primarily required for support of refractivity and ducting models. However, affordability is a key issue for
collecting these measurements through other means.

Direct measurement by balloons, dropsondes, and rocketsondes cost more than $250 per launch for equipment, plus the labor required to stock the expendables and man the launch and monitoring equipment. If we estimate another $250 for these items, and factor in a minimal requirement of two launches per day (which is actually grossly inadequate to support ship self-defense), then the cost per ship comes to $1000 per day out of ship operations funds. The savings from these operations can quickly offset the cost of an add-on Tactical Environmental Processor.

Operationally, TEP offers benefits to the Navy in many warfighting mission areas, including strike warfare, ship self-defense, air warfare, expeditionary warfare, and chem./bio warfare to name a few. TEP uses a "through-the-sensor" technique to derive up-to-the-minute high-quality measurements of critical parameters such as RF propagation and ducting, 3D winds, cloud base, and precipitation using the existing, SPY-1 radar system aboard US Navy Aegis cruisers and destroyers. Benefits to the Aegis platform itself focus on ship self-protection, for which TEP supports two primary areas:

- **Optimization of sensors and weapons** - detailed characterization of the clutter and ducting conditions surrounding the battlegroup can be exploited to optimize sensors and weapons, and thereby increase the warfighter's tactical advantage through increased depth of fire.

- **Improved situational awareness** - timely and accurate information on severe weather and propagation conditions can help ensure mission success through increased situational awareness and accurate mesoscale forecasting (or Nowcasting).

**Conclusion**

The TEP Demonstration aboard USS O'Kane conclusively validated the accuracy and efficiency of TEP environmental characterization in an operational at-sea environment that included a wide range of weather conditions in littoral environments. It also validated TEP's ability to operate without any negative impact to the normal operation of the SPY-1 radar. TEP can significantly improve the accuracy and timeliness of environmental measurements demanded by the modern warfighting world of precision targeting against an increasingly mobile and technologically savvy adversary.

**References**


[3] "Dual-use Shipborne Phased Array Radar Technology and Tactical Environmental


