Refractivity Data Fusion and Assimilation

L. Ted Rogers
SPAWARSYSCEN (SSC) San Diego, Code D858
49170 Propagation Path
San Diego CA 92152-7385
phone: (619) 553-1413 fax: (619) 553-1417 email: trogers@spawar.navy.mil

Document Numbers: N0001402WR20353 and N0001402WX20262
http://sunspot.spawar.navy.mil/

LONG-TERM GOALS

The goal of the RDFA project is to improve the accuracy and timeliness of estimates of the state of the electromagnetic (EM) propagation environment through (a) the development of the means to estimate atmospheric refractivity from radar clutter observations (refractivity-from-clutter or "RFC"), and (b) to develop data fusion (DF) methods to fuse those data with background fields from numerical weather prediction (NWP) models.

OBJECTIVES

In Fiscal Year 2002, the project focused solely on the advancement of techniques for inferring refractivity parameters from radar sea clutter observations.

APPROACH

At the frequencies of common naval air search radars (0.9--10 GHz), anomalous propagation effects at low altitudes are probably more the rule than the exception. The most common ducting structure is the evaporation duct formed by the atmospheric surface layer. Estimating that structure from observations of radar sea clutter has been described in *Rogers, Hattan and Stapleton* [2000]. Work and results on a remaining issue will be discussed later. The next most common structures are surface based ducts that are associated with either the subsidence inversion capping the marine atmospheric boundary layer or with thermal internal boundary layers.

The inversion of surface based duct parameters from radar sea clutter has many resemblances to source localization and tomographic inversion problems in ocean acoustics. One approach is to characterize the propagation environment using global parameters and map the environmental parameter combinations into the space of the clutter observations using a parabolic equation (PE) propagation model in conjunction with a radar and a clutter model. Dr. Peter Gerstoft (Scripps Institution of Oceanography) has modified his Simulated Annealing / Genetic Algorithm (SAGA) code to address the RFC problem. At the same time, the fact that the data in the RFC problem is in the same direction as the marching direction of the PE model invites the use of recursive Bayesian (RB) estimation methods for estimating refractivity. Neither Kalman filtering nor extended Kalman filtering methods (both RB methods) are applicable in the RFC problem because of the highly non-linear way that refractivity parameters enter into the PE model. A "particle filtering" approach by *Anderson, et al.*

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2002**	2. REPORT TYPE	3. DATES COVERED **00-00-2002 to 00-00-2002**
4. TITLE AND SUBTITLE **Refractivity Data Fusion and Assimilation**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **SPAWARSYSCEN (SSC) San Diego, Code D858,,49170 Propagation Path,,San Diego,,CA, 92152**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The goal of the RDFA project is to improve the accuracy and timeliness of estimates of the state of the electromagnetic (EM) propagation environment through (a) the development of the means to estimate atmospheric refractivity from radar clutter observations (refractivity-from-clutter or ???RFC???), and (b) to develop data fusion (DF) methods to fuse those data with background fields from numerical weather prediction (NWP) models.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

[2001] is an RB method that characterizes *a priori* and *a posterior* distributions as a collection of samples and is sufficiently general to handle the RFC problem.

In order to provide an RFC-SBD capability that could work within the time constraints of a proposed advanced technology demonstration in FY03-05, SSC San Diego has also developed the Monte-Carlo Maximum A Posteriori (MC-MAP) techniques that borrows heavily from the two preceding efforts. MC-MAP uses 20,000 "canned" deterministic replica fields (i.e., modeled clutter realizations) based on a uniform sampling of the environmental parameter space. A random processes model – that accounts for both amplitude variations and horizontal shifting of clutter – maps the deterministic replicas into ~ 1.5M realizations. The goodness-of-fit for each realization is calculated. The density of realizations associated with a given deterministic replica whose goodness-of-fit is within (say) the 99.9 percentile level is determined. Since there is a one-to-one correspondence between the environmental parameter combinations and the deterministic replica fields, this serves as an approximation to the a posteriori probability density of the environmental parameter combinations.

WORK COMPLETED

LCDR Marc Eckardt (Naval Postgraduate School) examined the effects of model error on the RFC evaporation duct algorithm (RFC-ED). RFC-ED assumes a neutral-stability profile where the vertical structure of refractivity has an exponential profile that is described using a single parameter, the evaporation duct height (δ). However, the neutral stability and the associated exponential profile are only a special case of the behavior of refractivity associated with the surface layer. Surface layer models such as that of *Liu, Katsaros and Businger* [1979] (LKB) show substantial variations from the exponential profile when the stability (defined by the Monin-Obukhov length, --- which is strongly related to the air sea temperature difference (ASTD)), differs from the neutral case. On the other hand, the same LKB model exhibits sensitivity to errors in ASTD such that small changes in the ASTD lead to very large changes in the refractivity structure. So the question is whether the model error with RFC-ED outweighs the sensitivity to input errors in LKB or vice-versa. LCDR Eckardt's work has examined this question in a systematic fashion.

Dr.Gerstoft (SIO) adapted SAGA to handle multiple elevation data with the RFC problem and implemented the algorithm on S-Band radar data from Wallops '98. The implementation of SAGA at a single elevation is described in *Gerstoft et al.* [2002], and use of multiple elevations is described in a submission to IEEE J. Oceanic Engineering that is under review at this time. Prof. Krolik (Duke University) implemented a critical angle constraint derived from multiple elevation data for use in the marching algorithm. Ted Rogers and Lee Wagner (both SSC San Diego) developed a Monte-Carlo Maximum A Posteriori algorithm and implemented the same on data from the Wallops '98 and 2000 experiments.

Janet Stapleton (Naval Surface Warfare Center Dahlgren Division (NSWC-DD)) is evaluating the performance of MC-MAP output for the estimation of propagation and derived products intended for use in optimizing radar performance. The data are from the Wallops 2000 measurement campaign (see *Stapleton, et al*. [2001]). The data includes direct measurements of propagation via boat and shore mounted transmitting and receiving equipment and *in situ* measurements of refractivity via both a helicopter-born instrument package and rocket-sondes, and (c) radar observations of sea clutter via the space range radar (SPANDAR) and a SPY-1 system.

RESULTS

LCDR Eckard's analysis yielded that the cost -- in terms of detection range calculations – of model errors in RFC were comparable those arising from design-basis errors when using *in situ* measurements for the same purpose. It should be noted that this finding addresses only one of several factors that must be considered in order to determine the goodness of RFC relative to the goodness of in situ measurements.

Dr. Gerstoft showed that using the critical angle constraint determined from clutter power at different beam elevations improved inversion performance when the data used in the objective function of the inversion algorithm was from the horizon elevation beam. He then achieved the same degree of improvement in inversion results by augmenting the data vector used in the objective function with clutter data from a beam at or near the critical angle.

The analysis of the performance of the MC-MAP algorithm on cases from Wallops 2000 is in progress. Early results indicate that "unsigned" error statistics – median absolute error, root mean squared error, etc. indicate comparable performance. For example the median absolute error for predicting low altitude propagation, over ranges from 5 to 30 nm, is roughly 5dB for both in situ measurements and MC-MAP. However "signed" error statistics – bias, percentiles, and the median error, are worse for MC-MAP than for *in situ* measurements. For example, the 20% level errors for RFC is –10 dB, while that for in situ measurements is 6 dB. Efforts are underway to improve the algorithm's performance in this regard.

IMPACT/APPLICATIONS

Air targets: Knowledge of propagation conditions is required to estimate the signal-to-noise (S/N) and signal-to-clutter ratio (S/C) for targets of a given radar cross section (RCS). This information can then be used to tune the radar (i.e., adjustment of sensitivity, waveform, etc.) to the detection environment. Long-term, we expect that RFC-based prediction of target S/N and S/C values will be used for automated radar resource allocation.

Sub-surface targets: The RFC and data fusion efforts both support the capability to determine propagation loss and the sea clutter radar cross section ($\sigma°$) from radar clutter returns. Knowledge of $\sigma°$ coupled with spectral data from the radar, and fused with wind and wave fields, can be expected to yield better characterization of sea surface. If, in particular, this can be extended to estimate the existence and density of bubble plumes, then this will impact active sonar target classification criteria.

TRANSITIONS

A letter of intent (LOI) has been submitted to ONR-322 for bringing RFC under the N096/ONR/PMW-155 sponsored Rapid Transition Program (RTP).

RELATED PROJECTS

Tactical Environmental Processor and B/D upgrade (Lockheed-Martin): The Tactical Environmental Processor (TEP) is a system for extracting quantities that are normally associated with weather radars (e.g., reflectivity, spectral moments, etc.) from SPY-1. Those data are needed in order to use RFC. The B/D Upgrade is a project for upgrading some components of SPY-1A ships to SPY-1B/D specifications. It is quite likely that TEP will be included in the B/D Upgrade.

NRL Nowcast: The objective of Nowcast is to bring weather products (i.e., gust-front detection, etc.) that are usually available at commercial airports, to aircraft carriers. This system requires TEP or another radar.

REFERENCES

Anderson, R., S. Vasudevan, J.L. Krolik and L.T. Rogers, Maximum a posteriori refractivity estimation from radar clutter using a markov model for microwave propagation, *Proc. International Geoscience and Remote Sensing Symposium*, Sydney, Australia, July, 2001.

Rogers, L.T., C.P. Hattan and J.K. Stapleton, Estimating evaporation duct heights from radar sea echo, *Radio Science*, 35(4), Jul.-Aug., 2000

Stapleton, J., D. Shanklin, V.R. Wiss, T. Nguyen, E. Burgess, W. Thornton and T. Brown, Radar propagation modelling assessment using measured refractivity and directly sensed propagation ground truth – Wallops Island, VA 2000, NSWCDD/TR-01/132, Sep., 2001

PUBLICATIONS

Burk, S.L., T. Haack, L.T. Rogers and L.J. Wagner, Island Wake Dynamics and Wake Influence on the Evaporation Duct and Radar Propagation, accepted by *J. of Applied Meteorology*, July, 2002

Eckardt, Marc, Impact of Sea Surface Temperature Errors on Evaporative Duct Height, Masters Thesis, Naval Postgraduate School, access via http://library.nps.navy.mil/uhtbin/hiperion-image/02Mar_Eckardt.pdf, 2002

Gerstoft, P., L.T. Rogers, J.L. Krolik and W.S. Hodgkiss, Inversion for refractivity parameters from radar sea clutter, accepted by *Radio Science*, June, 2002

Gerstoft, P., J. Krolik, L.T. Rogers, L.J. Wagner, and W.S. Hodgkiss, Applying inverse methods to radar backscatter data, SPAWAR/ONR Inversion Techniques Workshop, Gulfport, MS, May 2001.

Vasudevan, S., R. Anderson, and J. Krolik, "MAP Sequence Estimation of Microwave Refractivity from Radar Clutter via a Particle Filtering Implementation of the Viterbi Algorithm" Proc. of IEEE Intl. Conf. On Acoustics, Speech, and Signal Processing, Orlando, Florida, May 13-17, 2002.