Electro-Optic Propagation

Stephen Doss-Hammel
SPAWARSYSCEN San Diego code 2858
49170 Propagation Path
San Diego, CA 92152-7385
phone: (619) 553-4578 fax: (619) 553-1417 email: hammel@spawar.navy.mil

Charles McGrath
phone: (619) 553-1416 fax: (619) 553-1417 email: mcgrath@spawar.navy.mil

Jeffrey Reid
phone: (619) 553-1419 fax: (619) 553-1417 email: jreid@spawar.navy.mil

Dimitri Tsintikidis
phone: (619) 553-1418 fax: (619) 553-1417 email: tsintiki@spawar.navy.mil

Award Number: N0001402WX20582
http://sunspot.spawar.navy.mil

LONG-TERM GOALS

The development and testing of a comprehensive infrared and optical propagation assessment model suite for the marine atmospheric boundary layer, and the improvement of weather-dependent range predictions for the Target Acquisition Weapons Software (TAWS) in the marine environment.

OBJECTIVES

The electro-optical propagation objectives are:
1) The acquisition and analysis of mid-wave and long-wave infrared transmission and scintillation data in a well-characterized marine atmospheric surface layer, over typical maritime ranges of 7 to 15 kilometers; 2) Model development for infrared and visible extinction, refraction, and scintillation using local; 3) Development and evaluation of ocean and coastal aerosol models; 4) Study of the optical properties of non-spherical dust aerosols and the evaluation of global behavior; 5) The improvement of naval marine target modeling in TAWS by adding the effects of the wake to the boat and ship target and background models

APPROACH

INFRARED PROPAGATION There are two elements to the electro-optical propagation model development. The first element is the design and execution of field experiments to generate useful field data, and the second element is the creation and testing of predictive models. A close collaboration between SSC San Diego and TNO (Netherlands) is developing a new propagation assessment tool called EOSTAR (Electro-Optical Signal Transmission and Ranging). EOSTAR will ultimately provide a coverage diagram providing the probability of detection for arbitrary environmental conditions.

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 **Electro-Optic Propagation**		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 San Diego code 2858,,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 development and testing of a comprehensive infrared and optical propagation assessment model suite for the marine atmospheric boundary layer, and the improvement of weather-dependent range predictions for the Target Acquisition Weapons Software (TAWS) in the marine environment.

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)**	**8**	

TARGET WAKE MODELLING The wake of a boat target often produces greater target-background radiance contrast and greater target area than the boat structure itself. The addition of wake effects will make it possible for TAWS to predict the detection of high speed planing-hull boats and improve range predictions of displacement-hull vessels.

WORK COMPLETED

INFRARED PROPAGATION A major effort was devoted to the preparation, data-collection, and analysis of infrared transmission data as an element of the Rough Evaporation Duct (RED) experiment in August and September 2001. We developed and calibrated a broad-beam source explicitly for a floating, yawing platform. An initial data analysis has been performed on the data.

We also integrated the bulk model MORIAH into research EOSTAR. MORIAH is developed by the Naval Postgraduate School. The central function of EOSTAR is a prediction capability based upon relatively primitive meteorological data that is localized both temporally and spatially to the propagation range seen by the sensor. A micrometeorology module (utilizing MORIAH, TARMOS, or other bulk models) will initialize the model by generating vertical profiles of the relevant meteorological variables. Vertical profiles of extinction due to molecules and aerosols are generated from the models MODTRAN and ANAM 3 (Advanced Navy Aerosol Model). A geometric ray-tracing model then calculates the specific ray-path for the environment from sensor to target. This information will be used by the model to predict 1) the mean signal intensity at various ranges, 2) the variance in the signal; and 3) a coverage diagram which indicates which portions of the geometrical environment are 'visible' to the sensor.

TARGET WAKE MODELLING Field data was analyzed and the prototype displacement hull wake model was tested in TAWS. Breakwater bow waves were added to the model. Algorithms to reduce runtime were explored and tested in MuSES. An effort to improve accuracy and reduce runtime in TAWS was initiated. High performance computing hydrodynamics models in conjunction with field data results were prepared to build empirical algorithms to replace some of the slower computational portions of the model. Interim reports have been published and the model has been extended to include the high speed planing-hull powerboat and the Boghammer patrol boat which will be tested and further developed in FY03.

*MARINE AEROSOL MEASUREMENTS AND MODELLING_* The bulk of the marine aerosol program for FY02 has been spent in archiving, quality assuring, and analyzing data collected during the Rough Evaporation Duct (RED) experiment conducted in Sept. 2001. First order eddy correlation measurements of momentum and sensible and latent heat flux have been generated and pass quality assurance. As part of the FY02 proposal, we proposed developing a more coherent surface layer model that is suitable for both electro-optical and electro-magnetic radiation. We have initiated a cooperative project with the Naval Research Laboratory (Washington DC) to run the Navy's mesoscale model COAMPS (Coupled Ocean Atmosphere Mesoscale Prediction System) for the RED campaign.
In FY02 the final validation work of the Advanced Navy Aerosol Model (ANAM) was completed. The main activity in FY02 consisted of the statistical analysis of rotor-rod data from the RED campaign to continue the ANAM development by the establishment / improvement of (empirical) relations between the aerosol concentration and the meteorological scenario. We continue to develop marine aerosol and radiative transfer models to support Navy assets. Cooperative work is continuing with investigators

from NASA Goddard Space Flight Center to develop radiative transfer algorithms which can be implemented into the Navy's aerosol and target models.

DUST AEROSOL MEASUREMENTS AND MODELLING Work relating to the dust aerosol measurements and modeling task have focused on a second round of analysis of data and model results from the Puerto Rico Dust Experiment (PRIDE). We continued to study the optical properties of non-spherical dust aerosols and evaluate how they vary globally. We performed a first order evaluation of the impact of dust aerosols on visible and IR propagation and identified problem areas in the theory and community data sets. As with the Marine Aerosol Project, we are collaborating with investigators from NASA on the development optical radiative transfer models for predicting slant path visibility when airborne dust is a significant factor.

RESULTS

INFRARED PROPAGATION The analysis and modeling of infrared propagation data from the Rough Evaporation Duct (RED) campaign was a primary element of our work for the year. The RED experiment provided a unique opportunity to study a propagation environment with warm water, sustained winds, and correspondingly rough sea surfaces in a nearly open ocean environment. Application of the ray-trace models to the RED propagation environment yielded a surprising result: there is a rough surface effect on IR propagation that is dependent upon the transmitter / receiver geometry. For the transmission test geometry that we used, the rough sea surface acted primarily as a barrier to the appearance of an inferior mirage image of the source. This removes the possibility for a signal augmentation by refractive propagation factors.

The fundamental puzzle generated by the infrared measurement campaign during RED is to reconcile a model that over-estimates the measured signal by factors that vary from 2.5 to 5. The RED experiment provided an opportunity to integrate a new model for aerosol extinction (ANAM 3.0). Over the entirety of the test the received infrared signal was smaller than our model predictions by a factor that ranged from 2.5 to 5. The small signal induced a further problem in signal-noise ratio, which in particular made calculations of C_n^2 problematic. The resolution of this question may necessitate a follow-up experiment in another environment with similar meteorological conditions. The discrepancy may also provide impetus for further work on the scaling parameters for the aerosol extinction models NAM and ANAM.

TARGET WAKE MODELLING The findings of the near-wake task show that the new computational wake model improves the accuracy of the ship models, but a combination of computational and empirical modeling are required to meet the TAWS operational efficiency requirements. The wake model task began with an algorithm development to model the wake effects of the displacement hull ship, the Research Vessel Point Sur. The NRL KELSEA model provides the skeleton model from which the centerline turbulent wake, the bow and stern breaking wave, and the Kelvin system are modeled for a wind-driven random sea. We proved that the wake radiance calculations and the SeaRad ocean background radiance model require finer and more accurate input of the vertical structure of upper atmospheric profile. Also, the current wake model underestimates target radiance because it includes too many background water facets. Discrimination algorithms are being developed to better define how much of the wake to include in the apparent target area.

MARINE AEROSOL MEAUREMENTS AND MODELLING Research in this program focused on the analysis of data collected during the Rough Evaporation Duct (RED) experiment. During higher wind periods, positive fluxes of coarse mode salt particles from sea-spray were observed at statistically significant levels. For the study period we found upward flux values of salt particles for 10 m/s wind speeds that are a factor of two higher than those in the commonly used *Smith et al.*, [1993] algorithm but a factor of two lower than those proposed by *Monahan et al.,* [1986], *Andrea et al.,* [1998], and *Reid et al.,* [2001]. Based on this new data we feel that salt fluxes are measured known to a factor of 3, rather than previously estimated uncertainties which were on the order of 5 or more. A more detailed analysis is underway.

The Rotorod data set acquired during the RED experiment was analyzed. In short, a lognormal curve was fitted to each observation, and statistical regression was performed to relate the lognormal parameters to the meteorological scenario at the time of observation. The analysis showed that the RED data set (acquired in open ocean environment) fitted nicely with the majority of existing Rotorod observations (obtained in coastal areas). It has been established that the vertical large-aerosol distribution in open ocean does not significantly differ from a coastal area with onshore flow. This conclusion could not have been reached without the RED experiment. The analysis of the RED data allowed us to refine the Rotorod base set on which the ANAM parameterization is based.
Also during FY02 we began a project to utilize ship based visibility reports to help construct aerosol climatologies suitable to evaluate the NRL Aerosol Analysis and Prediction System (NAAPS).

DUST AEROSOL MEASUREMENTS AND MODELLING Investigations under the dust program can be divided into two broad categories: Dust storm meteorology and microphysics. Using the Puerto Rico Dust Experiment (PRIDE) as a context, we have studied dust transport patterns and in particular processes which define dust vertical profiles.

The vertical distribution of dust in the Caribbean was found to be highly variable during the PRIDE field campaign, with both "typical Saharan Air Layer (SAL)" and lower level transport of dust being observed. The presence of dust in the marine boundary layer was not correlated with any "typical" atmospheric sounding profile, in particular it did not correlate with the strength of the trade inversion in the Caribbean. In fact, as the trade inversion is heavily influenced by local conditions, the SAL and trade inversions can be de-coupled.

Microphysics investigations have focused on parameterization methods of dust particle size distributions such that they can be input into radiative transfer code. We compare dust size distributions from geometric, aerodynamic, and optical methods taken during PRIDE. Large differences were found, particularly between optical particle counters and the aerodynamic methods. A review of other size distributions in the literature shows that this is a consistent bias in the community data sets. This suggests particle size (and hence radiation) uncertainties in currently established dust models used by the scientific community are probably twice as large.

We found geometric sizing of particles by electron microscopy techniques likely biases particles towards larger sizes. None of the methods compared can adequately reproduce the measured mass extinction or mass scattering efficiency of the dust using spherical geometry methods. Utilizing such methods leads to ~30% underestimate of particle scattering. Given all of the uncertainties in the sizing methods, we promote the use of fundamental and quantifiable descriptors of particles. In particlar, the use of mass as a function of aerodynamic diameter seems to be the most well-definable variables.

IMPACT/APPLICATIONS

INFRARED PROPAGATION 1) The development of realistic models for infrared propagation along low altitude horizontal paths. 2) Evaluation of near-surface paths for laser vibrometry remote sensing laser radars, and high-energy lasers. 3) Performance prediction for infrared and other electro-optical sensors in realistic environments. This will permit the development of sensor equipment better suited to the tasks at reasonable costs. Better performance prediction will also permit real-time assessment of sensor capabilities, which can be used in sensor resource management or incorporated into doctrine. 4) When combined with a target signature and background model, the EOSTAR model suite will be a full electro-optical tactical decision aid.

TARGET WAKE MODELLING The current wake model development and investigation has resulted in important changes to improve the overall performance of TAWS. These include the addition of more boat targets to TAWS, allowing multi-layer inputs for MODTRAN, and utilizing external models and remote sensing products to bypass or initialize internal models.

TRANSITIONS

The current wake model has transitioned to TAWS 4.0 PR1, which is a prerelease for testing prior to the final fleet version.

RELATED PROJECTS

The near-wake task is also tied to a larger 6.2/6.4 EO Rapid Transition Proposal (RTP) in conjunction with NRL Monterey. The work here will also be considered for the Air Force night vision goggle complement to TAWS called Night Vision Goggle Operations Weather Software (NOWS), and the scene rendering complement to TAWS called Infrared Target Scene Simulation software (IRTSS). The range predictions from TAWS are also presented as overlays to the Pilot's Flight Planning Software (PFPS). Future inputs for better visibility, optical depth, and transmission will come from the NRL Aerosol Analysis and Prediction System (NAAPS).

REFERENCES

1. Church, Steve, *Implementation of an Accurate Marine Radiance Model into Tactical Acquisition Weather Software (TAWS)*, Arete Associates, Inc., Sherman Oaks, California, 91403, 2000.

2. Hubbard, D. W., O. M. Griffin and R. D. Peltzer, "Foam Generation and Air Entrainment Near a Free Surface," Naval Research Laboratory Memorandum Report 6038, 1987.

3. Keramidas G.A., H.T. Wang, J.A. Burke and W. Bauman, "*KELSEA, An Interactive Computer Code for Kelvin and Random Ambient Sea Waves*, " Naval Research Laboratory Memorandum Report 5848, 1986.

4. Koivunen, A.C., K.R. Johnson "*Implementation Of An Efficient And Accurate Marine Radiance Model Into The Electro-Optical Tactical Decision Aid (EOTDA),"* ThermoAnalytics, Inc., Calumet, Michigan 49913, 1997.

5. Gouveia, M.J., "TAWS Version 4 Software Requirements Specification (SRS)," Northrop Grumman, Reading, MA, 19 August 2002.

6. Denneno, A.P., "Subsystem Design Analysis Report: Integrate the Target-Wake Capability into the Target Acquisition Weapons Software (TAWS)," Northrop Grumman, Reading, MA, 17 July 2002.

7. Innis, G.E., T. O'Shea, R.S. Graham, D. Wyatt, "SAIC TAI Ship Wakes February 2002 Progress Report," Science Applications International Corporation, San Diego, CA, February 2002.

PUBLICATIONS

1. Colarco, P. R., O. B. Toon, J. S. Reid, J. M. Livingston, P. B. Russel, J. Redemann, B. Schmidt, H. B. Maring, D. Savoie, J. Welton, J. R. Campbell, B. N. Holben, R. Levy, *J. Geophys. Res.*, submitted, 2002.

2. Doss-Hammel, S. M., Zeisse, C. R., Barrios, et al.., ``*Low-Altitude Infrared Propagation in a Coastal Zone: Refraction and Scattering*'', Applied Optics, **41**, 3706--3724, (2002).

3. Doss-Hammel, S., ``*A Passive Ranging Technique for Objects within the Marine Surface Layer*'', Biennial Review 2001, Space and Naval Warfare Systems Center, TD 3117, (2001).

4. Doss-Hammel, S.,``*Mirages, Magnification, and the Refractive Propagation Factor*'', Proc. SPIE **4820**, (2002).

5. Doss-Hammel, S., and C. Zeisse, ``*Refraction and Scintillation in the Atmospheric Surface Layer*'', Proc. SPIE **4821**, (2002).

6. Doss-Hammel, S.,D. Tsintikidis, and C. Zeisse, "*Measurement of IR transmission and scintillation in a summertime desert environment*", technical report for NATO TG-11 Long Path turbulence trials for Coherent Vibration Sensors, (2002).

7. Doss-Hammel, S., A. Barrios, C. Zeisse*, "The Refractive Amplification Factor for Infrared Propagation in the Marine Atmospheric Surface Layer"*, BACIMO 2001, Ft. Collins, Colorado, July 2001.

8. Hughes, H.G., "*Evaluation of the Target Acquisition Weapons Software (TAWS) for Predicting Performance Ranges,*" Science and Technology Corp. September 2002.

9. Koivunen, A.C., L. Coke, "*Addition of Ship Wake IR Signature to MuSES/TAWS*," Contractor's Report, ThermoAnalytics, Inc., Calumet, MI, 49913, 07 July 2002.

10. Livingston J. M., J. Redemann, J. S. Reid, P. B. Russell, B. Schmid, D. Allen, Omar Torres, R. C. Levy, L. A. Remer, B. N. Holben, A. Smirnov, O. Dubovik, E. J. Welton, J. Campbell, R. Kahn, S. A. Christopher, J. Wang, Airborne sunphotometer measurements of aerosol optical depth and columnar water vapor during the Puerto Rico Dust Experiment, and comparison with land, aircraft, and satellite measurements, *J. Geophys. Res.*, in press, 2002.

11. Maring H., D.L. Savioe, M.A. Izaguirre, L. Custals, J.S. Reid, Vertical Distributions of Dust and Sea Salt over Puerto Rico During PRIDE Measured from a Light Aircraft, *J. Geophys. Res.*, in press, 2002.

12. Maring H., M.A. Izaguirre, D.L. Savioe , L. Custals, J.S. Reid, Mineral dust aerosol size distribution change during atmospheric transport, *J. Geophys. Res.*, in press, 2002.

13. McGrath, C. P., "*Remote Sensing Support for the Target Acquisition Weapons Software (TAWS)*," Proceedings SPIE 9th International Symposium on Remote Sensing, September 2002.

14. Navarro, L. J. , A.M.J. van Eijk, G.J. Kunz, A. Phelippeau-Gosselin and P.G. Mestayer (2002). Influence de la couche atmosphérique marine sur la propagation électrmagnétique. 4ièmes Journées d'études "Propagation électromagnétique du décametrique à l'angström", 13-15 March, Rennes, France.

15. Reid, E.A., Aerosol Data Archiving, Quality Assurance, and Analysis: Final Report. Science and Technology Corp., 2001.

16. Reid, E. A., J. S. Reid, A. P. Broumas, S. S. Cliff, M. Meir, M. Dunlap, K. Perry, T. A. Cahill, Characterization of African Dust Transported to Puerto Rico by Individual Particle and Size Segregated Bulk Analysis, *J. Geophys. Res.*, submitted, 2002.

17. Reid, J.S., B. Brooks, T. Hirstov, and E.A. Reid, Preliminary results on particle fluxes from the Rough Evaporation Duct Experiment, RED Data Workshop, Feb. 2002, La Jolla, CA.

18. Reid, J. S., H. H. Jonsson, H. B. Maring, A. A. Smirnov, D. L. Savoie, S. S. Cliff, E. A. Reid, M. M. Meier, O. Dubovik, and S-C Tsay, Comparison of Size and Morphological Measurements of Coarse Mode Dust Particles from Africa, *J. Geophys. Res.*, in press, 2002.

19. Reid, J. S., J. E. Kinney, D. L. Westphal, B. N. Holben, E. J. Welton, S-C. Tsay, S. A. Christopher , D. P. Eleuterio, H. H. Jonsson, J. M. Livingston, H. B. Maring, M. Meier, P. Pilewskie, E. A. Reid, P. B. Russell, D. Savoie, A. Smironov, and D. Tanré, Measurements of Saharan dust by airborne and ground-based remote sensing methods during the Puerto Rico Dust Experiment (PRIDE) , *J. Geophys. Res.*, in press, 2002.

20. Reid, J. S., and H. B. Maring, An introduction to the Puerto Rico Dust Experiment*, J. Geophys. Res.*, submitted, 2002.

21. Reid, J.S., D. L. Westphal, J. Livingston, D. S. Savoie, H. B. Maring, P. Pilewskie, D. Eleuterio, The vertical distribution of dust transported into the Caribbean during the Puerto Rico Dust Experiment*, Geophys. Res. Lett*., in press-available online, 2002.

22. Wang, J., S. A. Christopher, J. S. Reid, H. Maring, B. N. Holben, J. M. Livingston, P. Russell, and S. K. Yang, GOES-8 Retrieval of Dust Aerosol Optical Thickness over the Atlantic Ocean during PRIDE**,** *J. Geophys. Res.*, in press, 2002.

23. van Eijk, A. M. J. and P.G. Mestayer (2001). SeaCluse progress report II. TNO Physics and Electronics Laboratory, report FEL-01-A091.

24. van Eijk, A.M.J. , L.H. Cohen, L.J. Navarro and G. De Leeuw (2002). "Near-surface aerosol transmission in the marine environment". Proc. SPIE **4884**.