Technical Metrics for Acoustic Evaluation

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***Abstract*- A Technical Metrics Workshop was held at NRL Stennis Space Center, MS, by the NRL Acoustics Division April 29 - May 1, 2008. The primary goal of the workshop was to identify the state-of-the-art technical and scientific metrics for the acoustic and oceanographic research and development communities. A second goal was to relate scientific metrics to engineering and performance metrics, and outline the inclusion of uncertainties in various parameters using metric variability.**

Participation in the workshop was significant. State-of-the-art technical applications, as well as brief insights into future metrics, requirements for metrics, standards or reference level metrics were presented. This paper briefly summarizes and presents the conclusions of the workshop. This work is a useful reference for building consistent technical metrics within the ocean and acoustic research and development community, as well as providing common guidance for measuring exit and milestone criteria, and for quantifying the contributions of interdisciplinary projects.

I. INTRODUCTION

Scientific / technical metrics are widely used by various communities at multiple levels from basic scientific analysis to decision making. The Navy and other communities have specific requirements that could benefit directly from such metrics. The overarching goal of this workshop, held at NRL Stennis April 28-May 1, 2008, was to have an interdisciplinary discussion on how these ongoing efforts could meet higher level needs (e.g. decision makers). Under this approach, more specific goals of the workshop were then to describe and identify technical and scientific metrics, build on current methods and discuss how these tools could be adapted / applied to operational and management metrics in the future.

II. PARTICIPANTS

The NRL Technical Metrics workshop committee 2008 was lead by Josette Fabre, Naval Research Laboratory, Stennis Space Center (NRL SSC) Code 7180 (acoustics). Other members of the committee included (in alphabetical order) Emanuel Coelho, NRL SSC Code 7320 (oceanography) / University of Southern Mississippi (USM), James Dykes, NRL SSC Code 7320 (oceanography), Pat Gallacher, NRL SSC Code 7330 (oceanography), Roger Gauss, NRL Code 7140 (acoustics), Dr. Joe Metzger, NRL SSC Code 7320 (oceanography) and Dr. Tom Murphree, Naval Postgraduate School (NPS) (meteorology/ oceanography/ climate/metrics). Contributors to the workshop and report included Dr. Merrill Stevens, Commander, Naval Meteorology and Oceanography Command (CNMOC), Dennis Krynen, Naval Oceanographic Office (NAVO), Keith Atkinson (NAVO), Steve Woll (Weatherflow, Inc.), Dr. Bill Stevens (Applied Operations Research), Dr. Tom Murphree (NPS), Bruce Ford (Clear Science, Inc.), Barbara Brown, National Center for Atmospheric Research (NCAR), Dr. Gregg Jacobs (NRL SSC), Joe Metzger (NRL SSC), Dr. Tim Duda Woods Hole Institute (WHOI), Dr. Peter Mignerey (NRL), Dr. Roger Oba (NRL), Dr. Orest Diachok, Johns Hopkins University / Applied Physics Laboratory (JHU/APL), Dr. Roger Gauss (NRL), John Perkins (NRL), Dr. James Fulford (NRL), J. Paquin Fabre (NRL), Steven Dennis (NRL), Dr. Robert Miyamoto Applied Physics Laboratory/ University of Washington (APL/UW), Dr. Warren Wood (NRL), Dr. Pat Cross, Ocean Acoustical Services and Instrumentation Systems (OASIS), Emanuel Coelho (USM / NRL), Dr. Steve Finette (NRL), Kevin Heaney (OASIS), Dr. Paul Elmore (NRL), Dr. Roger Gauss (NRL), Dr. Ray Mahdon (United Kingdom MetOffice), Dr. Frank Bub (NAVO), James Dykes (NRL), Dr. Chad Steed (NRL), and Bruce Northridge (CNMOC).

III. THE WORKSHOP

The workshop was organized as follows. During the introduction or motivation, the shortfalls of operational requirements that could benefit from application of some type of metrics analyses were presented. Next, the state-of-the-art metrics were presented, emphasizing how efforts could be steered towards the relevant problems. The state-of-the-art talks were categorized into the subject areas of Meteorology and Oceanography (METOC), acoustics, bottom and uncertainty. Finally, technical metrics were related to higher level decision making, addressing the questions on how to assimilate metrics of different types, along with other approaches to address the shortfalls identified at the beginning of the workshop. These efforts identify our current technical / scientific metrics state, identify shortfalls and research directions and help design an end-to-end roadmap for the future.

The workshop emphasized how direct observations and model estimates can be combined to provide better operational guidance and assist in solving specific end-user requirements. This will allow enhanced quantitative confidence for the end-user,

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14. ABSTRACT

A Technical Metrics Workshop was held at NRL Stennis Space Center, MS, by the NRL Acoustics Division April 29 - May 1, 2008. The primary goal of the workshop was to identify the state-of-the-art technical and scientific metrics for the acoustic and oceanographic research and development communities. A second goal was to relate scientific metrics to engineering and performance metrics, and outline the inclusion of uncertainties in various parameters using metric variability. Participation in the workshop was significant. State-of-the-art technical applications, as well as brief insights into future metrics, requirements for metrics, standards or reference level metrics were presented. This paper briefly summarizes and presents the conclusions of the workshop. This work is a useful reference for building consistent technical metrics within the ocean and acoustic research and development community, as well as providing common guidance for measuring exit and milestone criteria, and for quantifying the contributions of interdisciplinary projects.

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and therefore, provide not just an improved “final answer” but also identify scenario-dependent performance drivers and provide estimates of uncertainty that can more reliably and robustly inform operational decisions.

IV. State-of-the-Art Metrics

The focus of this workshop was on acoustic performance prediction, therefore the models and data used to drive the acoustic models as well as acoustic models and analysis techniques, were presented and discussed. The ocean and acoustic models were introduced by subject matter experts from NAVO. They stressed the need for timely products and a way to communicate product confidence to end users. The ocean model output is highly dimensional in space and time; because of the computation times required to compute acoustic performance predictions, derived parameters and change metrics are required to determine how to choose appropriate input scenarios for the acoustic performance predictions. Verification and Validation (V&V) metrics are also required to compare predictions to data and indicate acceptable variations.

Due to the many aspects of the acoustic dependence on the environment (surface, water, bottom), there are multiple sources of inaccuracy or uncertainty. Such errors need to be propagated through to the acoustic answer and communicated to the end users.

Significant work has been done in end-user metrics [1]. There are many levels of metrics that can be provided to the end-users, for example, quantification of the impact of various quantities (e.g. environmental) and how well they are represented, on the end products (e.g. performance estimates). Metrics should always be developed with the end goal in mind.

Metrics were presented from a wide variety of disciplines for multiple purposes including, but not limited to, various direct comparisons of measurements to models, spatial feature analysis of weather models and its potential application to ocean models, sampling metrics for determination of sensor placement and resolution requirements, metrics for determining the impact of a measurement on a predicted performance and its accuracy, coherence metrics in signal processing, metrics showing the impact of mis-represented data in models, specialized curve comparison, quantifying uncertainty and acoustic performance metrics.

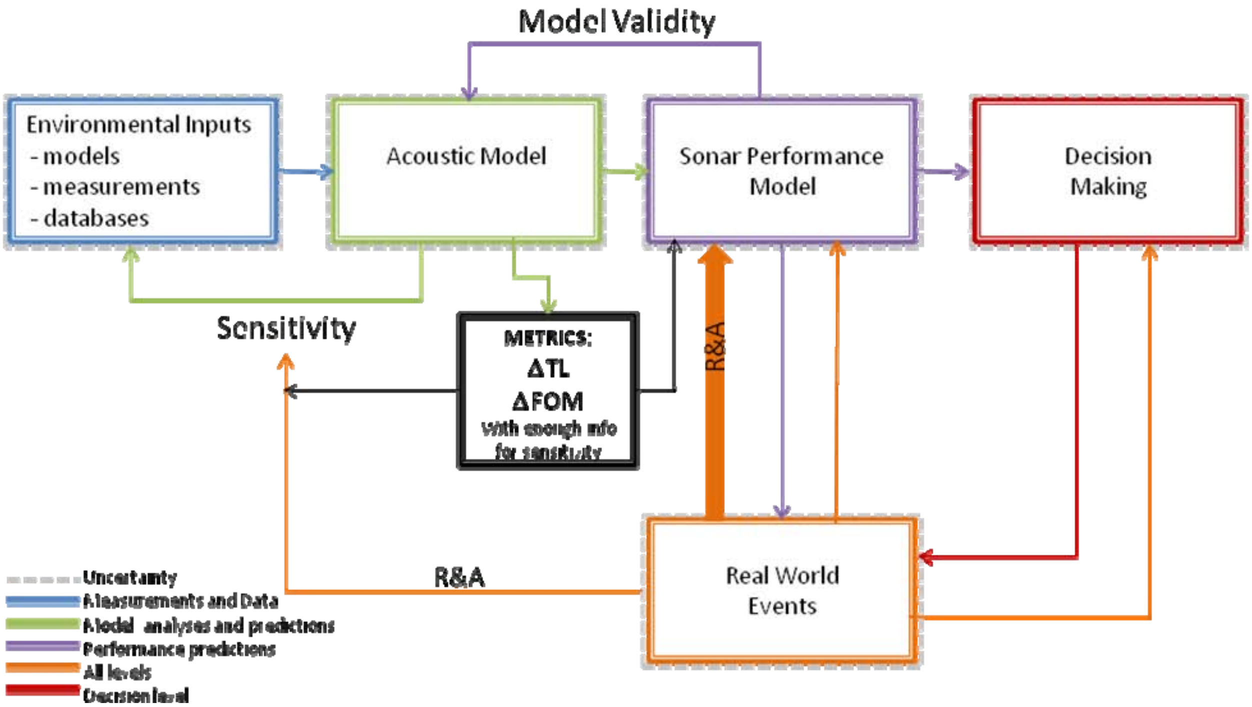
V. Results

It was shown that mature metrics exist in each of the categories of metrics that are appropriate to this community: scientific / technical, performance and operational. The community has impressive metrics capabilities within the science and engineering domains. Similarly well-defined operations metrics have been developed within the Navy operations research community. What is missing is a general-purpose approach for tracing scientific improvements (e.g. a better temperature and salinity forecast) to engineering impacts (e.g. resulting improved ability to estimate sonar performance) to warfighting impacts (e.g. resource allocation and time to operate). This methodology must provide the means to also trace uncertainties and errors from METOC data collection, assimilation, and modeling to end-user operational effectiveness: --- **correcting this shortfall is a primary long-term objective of the NRL Technical Metrics Committee (NTMC).**

It was determined that the metric transmission loss (TL) difference and/or figure of merit (FOM) difference with enough information for uncertainty or sensitivity will provide a common scientific / technical assessment that can be computed at the output of each process and can then be easily translated to performance quantities. The FOM is used to translate the TL to a more system specific quantity of detectable signal, or signal excess.

The Navy acoustics S&T community is comfortable with TL, but much less so with FOM because of the inclusion of equipment capabilities, operator proficiency, and other factors which are hard to quantify in a scientifically rigorous fashion. Nevertheless, TL is of limited value operationally without an estimate of a FOM value or distribution of possible FOM values. This represents a disconnect between the operational and the Navy acoustics communities.

Figure 1 shows the overall acoustic performance prediction process generated at the workshop. It begins with the descriptions of the environment in terms of the measured and databased quantities. Note that each process has an associated uncertainty that must be considered in some fashion. These input quantities are fed to the acoustic model and sensitivities to environmental inputs and metrics are generated. Sonar performance predictions are made using the acoustic model outputs or derived metrics. The performance predictions are passed to decision makers or operators. Assessments of the validity of the performance model can be fed back (based on actual performance or other knowledge) to the acoustic model for modification of inputs or modifications to the model itself. Decisions based on these assessments are passed to the operators. After an exercise is complete, reconstruction and analysis (R&A) lessons learned can be fed back to all aspects of the process.



VI.

Figure 1. Schematic of how metrics relate to various stages of operations.

VII. An Example

An example of applying a technical or scientific metric is given here to demonstrate the process of tracking metrics from the level of measurements or data, all the way to their end use. A sensor has been developed that will provide high spatial resolution temperature and salinity data for a relatively small area and we would like to assess the impact of such data on a real-world application such as our ability to predict the performance of an acoustic sonar detecting the bottom or objects on the bottom. An ocean model is run with and without assimilating the high resolution oceanographic data, and the sound velocity is predicted for an area of interest. This provides assessments of the environment that represent both the new capability and the original capability. These assessments are input to an acoustic propagation model and transmission loss, with uncertainty, is predicted for both cases and compared. Figure 2 shows an example comparison between two TL curves, one using a low resolution ocean description to simulate an existing capability (blue) and the other a high resolution ocean description to simulate an improved measurement capability. Appropriate figures of merit (with associated uncertainty) are applied and the detectable signal is assessed. In Figure 2, this FOM is indicated by the red line. Above the line, objects can be detected, and below the line they can't. In this example, the original prediction was over-optimistic, indicated that objects would be detectable to a range of approximately 1600m, whereas the prediction using the higher resolution ocean, indicates detections only to about 1100m. In general, single values with error bars or probability distribution functions are then input to the performance prediction model to compute values such as probability of detection or sensor coverage, and these values are used to make decisions. The resulting differences in the performance predictions and the decisions made can be assessed and the impact of the higher resolution oceanographic data can be quantified. Here, a decision regarding the sensor range coverage would have been in error by approximately 500m. This is a simplistic case, but can be expanded with uncertainty information and other metrics, for example, area coverage for the entire area, or probability of detection over the area and the differences can be communicated to decision makers in terms that they are familiar with. A conclusion using this example might be that an improved performance prediction provided TL that was more accurate by up to 10 dB and resulted in an improved range estimate of approximately 500m. These metrics can be take further to assess the problem in terms of sensor placement or allocation.

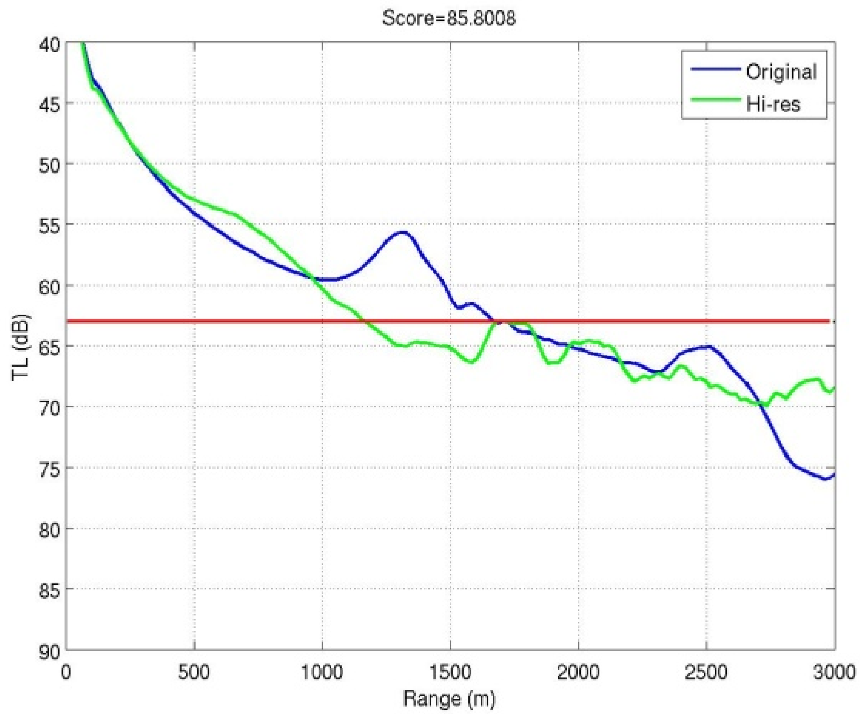


Figure 2. TL predicted using original profile (blue) compared to TL predicted using higher resolution oceanographic data (green). The red line is a generic FOM that indicates what part of the predicted range would be "visible" by the sensor.

VIII. THE WAY AHEAD

The METOC R&D community is now thinking along the lines of how their metrics need to be presented to the operational and decisional communities. A preliminary way ahead follows.

The decision making community would like to quantify the value-added of METOC assimilation, modeling, database, or TDA developments. The operational community would like this information in addition to how to obtain and employ new capabilities. Another important aspect of this is that for a new capability to be fielded, the resulting capability improvements need to be substantial enough to warrant the cost of transitioning to the new system.

The scientific community must be able to express their impacts in changes in transmission loss (TL) or figure of merit (FOM). For many, that requires running an acoustic model. Different models apply to different applications and each scientist should understand which models apply to their particular research application.

Because of this TDAs have been developed that try to deal with the FOM issue directly. Moving from TL to the other terms in the sonar equation could hence be part of a new focus on metrics.

Next, a general-purpose approach for tracing scientific improvements that have been expressed in terms of TL or FOM, to engineering impacts to warfighting is being developed and will be made available to the community. This methodology must be capable of tracing uncertainties and errors from METOC data collection, assimilation, and modeling to end user operational effectiveness. It must be as simple as possible so as to be relevant to multiple applications, with the knowledge that further analysis may be required. This effort must be coordinated with the existing capabilities on both ends (e.g. N81/N84/CNMOC and NAVO/NRL/R&D community) so as to provide consistent and agreed upon results. Some capabilities do currently exist, but are likely not in a format that can be easily used by the S&T community.

Metrics such as sonic layer depth and cutoff frequency considered with the sensor configuration is an example of using environmental factors to compute a measure that is operationally meaningful. There are other approaches as well. The committee should be able to define a range of approaches, building on work done in the studies briefed at the workshop and elsewhere and put this together as a "code of best practice" for estimating METOC impacts on warfighting effectiveness. DoD and NATO have developed something similar called the "C4I Analysis Code of Best Practice" [2].

The next step in this metrics process will then be to research, identify and propose an approach or approaches for development of the aforementioned methodology. This approach will be different for various systems, but the initial focus will be on current systems discussed during the workshop. An example approach would be to develop a generic scenario for which environmental acoustic products and their variations can be applied to quantify the operational impacts of the product in terms that can be communicated to decision makers. Stevens et al. (2008) provide examples that can be followed for this type of approach.

It is expected that the scientists that participated in this workshop will continue to develop and improve their metrics for more easy translation to higher level metrics. It is well understood that there is no “silver bullet” metric, however, steps can be and are being made to bring the two communities closer together.

Future directions in this area should: 1. present new technical metrics and progress on existing technical and related metrics since the 2008 workshop; 2. develop and refine the general procedure for deriving operational metrics from technical metrics; document the issues involved; and potentially to begin applying the procedure to a test case; and 3. get feedback from the various entities involved on the technical metrics way ahead.

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References

[1] http://met.nps.edu/metrics/metrics_reports.html

[2] http://www.dodccrp.org/.