SUMMARY and SYNTHESIS

of the Status of the Fundamental Scientific Basis for Sonar Performance Prediction and Identification of Research Directions to Improve that Basis

Based on Processes and Measurements, Modeling and Data Assimilation Working Group Reports and Plenary Discussion from the 9-10 April Scientific Workshop

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Capturing Uncertainty Review

End-to-End System Concept

- Sonar performance prediction requires end-to-end scientific systems: ocean physics, bottom geophysics, geo-acoustics, underwater acoustics, sonar systems and signal processing
- Uncertainties inherent in measurements, models, transfer of uncertainties among linked components
- Resultant uncertainty in sonar performance prediction itself
- Specific applications require the consideration of a variety of specific end-to-end systems

Interdisciplinary Issues

- Interdisciplinary, nonlinear, interactive, multi-scale dynamical processes require research
  - e.g. untangle the seabed and water column effects on acoustic propagation
- Effective coupling of components will involve cross-field understanding in a common vernacular
- An overall interdisciplinary approach for the end-to-end system is important and
- Multivariate, interdisciplinary statistical methods and data bases need to be developed
  - statistical (in)dependence among environmental and acoustical measures
  - interdisciplinary error covariances for interdisciplinary data assimilation.

Deterministic/Stochastic-Statistical Boundaries

- *deterministic process*: … one in which the past completely determines the future of the system.
- *deterministic model*: A deterministic model … is one which contains no random elements and for which, therefore, the future course of the system is determined by its position, velocities, etc., at some fixed point of time.
- *stochastic*: The adjective "stochastic" implies the presence of a random variable, e.g., stochastic variation is variation in which at least one of the elements is a variate and a stochastic process is one wherein the system incorporates an element of randomness as opposed to a deterministic system …. .
- *statistic*: A summary value calculated from a sample of observations, usually but not necessarily as an estimator of some population parameter; a function of sample values.
- *statistics*: Numerical data relating to an aggregate of individuals; the science of collecting, analyzing and interpreting such data.

From "A Dictionary of Statistical Terms," the International Statistical Institute (Kendall and Buckland, 1982, Longman Group Ltd., London and New York)

Deterministic/Stochastic-Statistical Boundaries

- In practice, a process is deterministic if dynamics is known and mean values of the state variables are larger than their uncertainties
- Boundaries are constrained by issues of measurability and modelability
- May be chosen for reasons of interest, efficiency and economy
- Amount of data available as well as the scales and processes considered can be the determining factor
- Seabed geoacoustic variabilities deterministic on the large scale; statistical on the small and fine scales; mesoscale may be deterministic or statistical (vertical layering characteristics)
- Complex deterministic dynamics may be simplified, with simplifying approximations guiding treatment of resultant uncertainties by stochastic-statistical methods

Representation of Uncertainties

- Research on the representation of uncertainties and transfers is important
- Efficient representations vary with scales, processes and applications
- Attribution of uncertainties to unmeasured or unmeasurable variabilities, data errors, model errors, and methodological errors
- Sensitivity studies to determine the hierarchy of uncertainties
- Representation of uncertainties via PDFs is yielding useful results
  - research on nonlinear and non-Gaussian effects
  - construction of multivariate interdisciplinary PDFs
- Confidence level of the uncertainty should be estimated for scientific purposes
- Monte-Carlo (ensemble) is a general method for transferring uncertainties across interfaces
  - results used to develop useful representations in terms of scalars, vectors, covariances, etc.

Models and Data Sets:

Models extend measurements

- Direct or "raw" measurability describes how well measurements can locally describe an ocean feature or field

- "Effective" measurability describes how well features and fields can be measured when ocean physics is included
  - e.g. wave equation extends a local point measurement in space and time

- Geo-acoustic properties by direct measurement or by:
  - measurements of sediment primitive parameters coupled to physics-based models
  - geologic modeling of processes that deposit sediment strata
  - acoustic measurements coupled to a geo-acoustic inversion model.

Models and Data Sets:

Data Assimilation

- Data assimilation in physical oceanography is now being extended to interdisciplinary ocean science

- Data and models are melded to estimate state variables (fields) and parameters
  - estimation theory or control theory techniques
  - melded estimate better than either the model or the data.
  - weighting scheme based on data errors and model errors
  - data assimilation based on errors is naturally applicable to uncertainty studies

Models and Data Sets:

Data Assimilation

- Assimilation of physical data extends the usefulness of that data for acoustic propagation
- Data assimilation coupling oceanography and acoustics is being initiated
  - assimilation of transmission loss, noise and reverberation
  - research will involve PDFs which are range, depth and azimuth dependent
- Multivariate approach, using interdisciplinary acoustical-physical-geological covariance matrices, is a key element of the method.

Models and Data Sets

- Physical and acoustic propagation models are generally sound, research needed in reverberation modeling
  - research for small-scale turbulence, coastal internal waves
  - research on three-dimensional acoustic propagation.
- Feature modeling of oceanographic and acoustical processes with uncertainties in the feature parameters
- Adaptive sampling for observations of greatest impact and optimal exploitation of available resources

Models and Data Sets:

Joint and compatible dedicated models and data sets

- Add new quantities to model outputs/inputs
  - model error estimates, sensitivities, robustness of parameters, statistical moment equations, and ensemble estimates
- Interdisciplinary databases with new useful representations of data and data uncertainties.
- Need for a **Dedicated Uncertainty Experiment**
  - concepts and methods tested in a unified experiment
  - jointly measured variabilities in oceanography, ocean-acoustics and geo-acoustics
  - in addition to the science objectives, include other components to test end-to-end uncertainty formalism