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NOAA Response to the Science Advisory Board (SAB) Ecosystem Sciences and Management Working Group (ESMWG) Report, "Decision Making Under Deep Uncertainty: What Is It and How Might NOAA Use It?"

Background

The subject report was delivered to NOAA by the Science Advisory Board in March 2021. It describes the methods and process of decision making under deep uncertainty (DMDU) and makes recommendations as to how NOAA can incorporate some of these procedures into its decision making, when appropriate. Two areas of NOAA involvement: coastal planning and fisheries were highlighted for exploring DMDU approaches. DMDU approaches can be seen as extensions to current NOAA approaches about decision making under uncertainty, such as the use of Management Strategy Evaluations (MSE) in fisheries and Observing System Simulation Experiments (OSSE).

NOAA thanks the Science Advisory Board for its thoughtful exposition on DMDU in relation to ongoing efforts and potential applications throughout the Agency. Herein is the Agency's response to the specific recommendations and potential next steps drawn from the report.

Response To Recommendations

1. **Include elements of DMDU where risk-based planning is already used.** These applications might involve comprehensive, full-scale DMDU approaches or simply the incorporation of individual DMDU elements or insights. The goal would be to better represent the implications of uncertainty on decisions. For example:

a. Decisions based on probabilistic risk assessment could be "stress-tested" for their potential to be (un)successful under alternative future scenarios. This approach differs from sensitivity analysis in that it captures events that cannot be characterized with probability distributions and uses scenarios to explore unlikely but still plausible outcomes.

> **NOAA Response:** NOAA agrees that there is great value in the use of developing a parsimonious suite of alternative future scenarios to stress test the outcomes derived from probability-based models. We will look for opportunities to apply this approach. For example, there is a scenario development effort underway related to US east coast fisheries and climate change where there are ongoing discussions of bounding the suite of scenarios to be developed (https://www.mafmc.org/climate-change-scenario-planning). We have shared the DMDU report with the leaders of this effort.

b. In the case of MSE - Systematically and transparently explore aspects of system dynamics and alternative policies that would not typically be conducted. MSE test cases could be explored, allowing analysts and managers to visualize the effort involved and viable strategies for adapting selected MSEs to explore DMDU approaches. Test cases would allow for an

assessment of the potential "added value" provided by using more complete DMDU approaches.

> **NOAA Response:** Building upon and expanding ongoing Management Strategy Evaluations may be a relatively low cost way of incorporating and testing DMDU approaches. This could be accomplished in both the analytical approach (i.e., in envisioned changes to the operating model and as part of the stakeholder process (see above response related to scenario development). For the latter, we can use the already assembled stakeholders to help identify alternative variables and policies beyond the narrower boundaries typically explored. In some cases, inclusion of a wider range of potential stakeholder interests will facilitate exploring beyond the usual set of outcomes.

c. DMDU could also be incorporated into existing EBFM and IEA analytical approaches that are not MSE. However, the appropriateness and ease of using DMDU in these settings will depend on the specifics of the analyses and any decision constraints, such as short decision time frames, existing policies, and legal authorities.

> **NOAA Response:** As noted, while MSE's are often part of an EBFM or IEA analysis, these analyses may benefit from DMDU approaches even when not using MSE's. The SAB report will be shared with these groups so that they can consider where incorporation of DMDU approaches might be appropriate.

2. Explore potential applications of DMDU to inform coastal planning programs and activities
a. Outside of NOAA, DMDU has informed many coastal planning projects, suggesting the potential utility of these techniques within this setting. For example, DMDU could offer value for developing robust coastal infrastructure solutions, particularly when proposed investments are costly and cannot be easily adapted once installed.

> **NOAA Response:** Given the place-based nature of coastal planning projects, the implementation of DMDU will need to be supported at a local level and will require high resolution data, observations, and mapping, coupled with computing power and extensive stakeholder engagement. We should consider NOAA's capacity to provide continued support of these efforts and to work with stakeholders at local, state, and federal levels to better understand the data and information needed for DMDU approaches. NOAA's continuing efforts to strengthen local and regional engagement, including participation from stakeholders from underrepresented communities, is well aligned with the iterative nature of DMDU.

3. **Apply DMDU to design monitoring programs.** DMDU can be used to:

a. Prioritize additional data collection by identifying decision-relevant uncertainty, which are the data gaps that are likely to change decisions.

NOAA Response: NOAA continually balances data needs to support existing long-term mission areas alongside emerging needs. In addition to needing to identify gaps in data and observations being collected, there is also a need to evaluate our modeling capacity and to work towards improving our use and understanding of dynamic modeling and machine learning (AI). Furthermore, NOAA is strategically approaching how to expand our monitoring and data collection efforts to maximize reductions in model prediction uncertainty.

b. Prioritize monitoring of phenomena that are much more likely to change in unpredictable ways and seek to identify early warning signs of change.

NOAA Response: DMDU has application to NOAA's work in the Arctic as a major location of new extremes (see Climatic Change volume 168, Article number: 27 (2021)). See the response to a. above. NOAA's ability to apply DMDU in rapidly changing environments depends upon our capacity for dynamical modeling and increased computing power balanced by increasing our incoming data streams.

c. Consider how NOAA might make use of DMDU insights into the optimal sequencing of risk mitigation actions. Dynamic adaptive planning (DAP) is used to evaluate optimal interim decisions, including whether investments can be delayed, while awaiting new information that better constrains future conditions.

NOAA Response: The optimal sequencing of mitigation actions not only will depend upon our capacity to monitor and model the environment, but also on the specific needs of the communities within which mitigation actions are being taken. NOAA might explore this connection in greater depth with key stakeholders.

4. **Develop guidelines and data to enable systematic scenario development** to represent major sources of uncertainty across NOAA activities.

a. Methods for developing a parsimonious set of scenarios by representing all major drivers of change (and their potential range) and avoiding including scenarios with distinct drivers but similar potential outcomes.

NOAA Response: Same as the response to recommendation 1a, above. In addition, the idea of developing a methodology consisting of best practices will facilitate efficient use of scenarios in decision making. The NOAA MSE Working Group has developed a paper, "When should we conduct management strategy evaluation?" that addresses similar concerns raised here for DMDU.

b. Make use of the variability represented in climate change scenarios by making data more accessible.

NOAA Response: Under NOAA's Big Data Program (BDP), NOAA's Climate Data Records have already been shared with Cloud partners (e.g., Amazon Web Services) to improve

accessibility. An initiative is underway to move NOAA's entire archived data holding to the Cloud within the next few years. This will provide both increased accessibility and usability of the ~40 PB data record for both atmospheric and ocean observations. Finally, increased usability of the NOAA data records will enhance the utility of observing system Experiments (OSE's) and provide foundation for observing system simulation experiments (OSSEs) to evaluate future observing systems and the impact of those observations in assessing climate variability.

5. **Consider whether there are other promising areas of DMDU application within NOAA that have not been explored thoroughly within this report.**

a. This report has examined a few key areas in which DMDU techniques are likely to have high value and applicability. However, these techniques are likely to have value in applications beyond these examples. As two examples, policies on habitat restoration and aquaculture can be subject to deep uncertainty due to influences such as climate and ocean acidification.

NOAA Response: Habitat restoration and aquaculture are indeed good candidates for application of DMDU techniques. We have shared the DMDU recommendations with the Office of Habitat Conservation and the Aquaculture Office within NOAA. Even more likely to benefit from DMDU techniques is the Office of Protected Resources

Response to Suggested Next Steps

1. Initiate broader discussion of DMDU approaches within NOAA so that subject matter experts can consider its possible application to their programs to understand potential benefits and risks to using these techniques. Examples of potential activities might include:

• *OneNOAA Science Seminar series on DMDU.*

NOAA Response: We agree that the OneNOAA Science Seminars are a great vehicle to disseminate the concept of DMDU and potential applications in NOAA. Rather than establishing a distinct DMDU series, it may be more effective to incorporate DMDU presentations into existing series such as the Ecosystem series.

• *Present to coastal resilience and environmental intelligence teams of the Interagency Arctic Research Policy Committee.*

NOAA Response: DMDU relates directly to Priority Area 4: Risk Management and Hazard Mitigation of the IARP Arctic Research Plan 2022-2026. DMDU should be a part of several of the foundational activities identified including: Education, Training and Capacity Building and Monitoring, Observing, Modeling and Predicting.

• *Brief new NOAA Climate and Fisheries Initiative team for possible use.*

NOAA Response: The NOAA Climate, Ecosystems and Fisheries Initiative is an excellent avenue for application of DMDU concepts. Once the regional "implementation teams" have been formed, DMDU concepts will be introduced as part of the national coordination effort.

• *Brief relevant National Academy of Sciences boards regarding new research/potential use: Ocean Studies Board, Gulf Research Program, etc.*

NOAA Response: We will utilize the Ocean Studies Board and other appropriate collaborators to help identify new research and potential applications of DMDU and related concepts.

• *As relevant, initiate internal studies within the Line Offices to explore whether and how DMDU techniques might be applied.*

NOAA Response: The SAB report has essentially initiated a process of awareness raising regarding DMDU applications across NOAA Line Offices. We will continue to encourage examination of appropriate applicability of DMDU in all NOAA Programs.

2. Study the potential use of DMDU more thoroughly.

• *Identify what further research is needed to develop guidance on when and how to apply DMDU specifically for NOAA-relevant problems.*

NOAA Response: As NOAA gains experience in applying DMDU concepts, we can draw on that success to start to identify further research needs. The Council of NOAA Fellows might serve as a NOAA-wide venue to guide this effort.

• *Identify potential NOAA and NSF projects and funding opportunities that could further advance the DMDU knowledge base.*

NOAA Response: By implementing many of the SAB suggestions to increase awareness and uptake of DMDU and DMDU concepts in NOAA activities, agency personnel can utilize future funding opportunities to explore DMDU further. In addition to NSF, these issues should be explored with other organizations including our Cooperative Institutes.

• *Consider follow-up studies by the SAB to evaluate potential applications of DMDU within particular NOAA program areas in greater depth.*

NOAA Response: As NOAA more greatly incorporates DMDU concepts into its activities, we will seek opportunities to bring potential applications before the SAB for more detailed advice as needed.