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Global Search for High-Value Extended-Range Forecast Products

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RELEVANT AND ACTIONABLE DECISION SUPPORT FROM EXTENDED METOC
EXECUTIVE SUMMARY

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Project Summary
The U.S. Navy's Earth Systems Prediction Capability (ESPC) provides value exceeding the value of climatology at subseasonal to seasonal (S2S) lead times for key impact variables and operational limits for certain regions seasons. This project used value-of-information (VOI) analysis and data farming, together with ESPC reforecasts produced as part of the subseasonal experiment together with a reanalysis data set for verification and climatology, to conduct an automated global search for regions, seasons, operational limits, and other decision parameters that produced a high VOI. This flips the script on looking for users—high-value scenarios are identified first, then the search for users who correspond to the scenario's parameters can begin.

Through outreach to Meteorology and Oceanography (METOC) personnel and users, we mapped mission and decision contexts to the variables and appropriate structure for VOI analysis. While missions that involve transit, such as ship routing, require more complicated models, many important mission sets can be represented using straightforward extensions of a single-variable, binary METOC outcome, binary decision (1 x 1 x 1) cost:loss decision scenario, in particular by adding multiple decision stages, and multiple forecast and operational impact variables.

For example, decisions on preparation for adverse METOC at shore installations, e.g. tropical cyclone conditions of readiness, can be represented with a modified 1 x 1 x *n* cost:loss scenario where the outcome depends on *n* valid times. For Arctic operations, surface and air temperature and winds are all important, and combinations of these variables are very important. For some missions, however, an *n* variables x 1 x1 scenario can be used. Similarly, for underway replenishment, winds and waves are most important, but using 2 x 1 x 1 model can be used when neither combat nor logistics vessels has a long transit. Preparation for climate extremes, e.g. of temperature or precipitation, can be represented with a 1 x 1 x 1 scenario by aggregating valid times and locations.

Keywords: *decision science, decision-making, data farming, meteorology and oceanography (METOC), Earth Systems Prediction Capability (ESPC), subseasonal to seasonal (S2S)*

Background
The United States Naval meteorology and oceanography (METOC) community seeks a better understanding of when, how, and to what extent Naval METOC guidance, forecasts, and advice can improve decision-making. This understanding is critical to determine how best to collaborate with the broader Navy and Marine Corps, and to guide investments in future research and training.

Commonly, when meteorology and oceanography researchers develop capabilities and resulting forecast products, they reach out to the user community with open-ended questions about what products would users find most valuable. This can work well, especially for identifying products "near" existing products that are relatively easy for users to understand and integrate into their current decision processes. Users, however, often cannot anticipate how they will use an innovative product until they have it in their figurative hands.

Our novel approach combines value-of-information (VOI) analysis with data farming (Sanchez & Sanchez, 2017) to conduct a very broad and automated search for combinations of end-user parameters for which potentially available forecasts can produce high-value in decision making. These results can be used to identify candidate products that combine variables or exploit subseasonal to seasonal (S2S) predictability provided by the Navy's Earth Systems Prediction Capability (ESPC) (Barton et al., 2019) and end-users who could exploit these forecasts.

We used ESPC reforecasts from the Subseasonal Experiment (SubX) experiment with lead times up to 1062 hours (45 days) to represent the capabilities of the European Centre for Medium-Range Weather Forecasts (ECMWF), together with verifications and climatology from the ECMWF reanalysis, for 2m-temperature, sea surface temperature, 10-m winds, sea ice concentration, total cloud cover and spray icing prediction index. We coded a flexible cost:loss decision scenario and used data farming to explore regions, seasons, operational limits and other decision parameters that produced a high value-of-information (VOI).

Through outreach to METOC users, we mapped mission and decision contexts to the variables and appropriate structure for VOI analysis.

Findings and Conclusions

We identified clear benefits of ESPC extended-range forecasts as a function of METOC variable and user parameters. Although we anticipated that the value of S2S forecasts is affected by the manner in which shorter-range forecasts are used to adjust decisions (Regnier, 2008), we found that for many parameter combinations, the impact of the short-range decisions was lower than anticipated.

A better understanding of when, how and to what extent, Naval METOC guidance, forecasts, and advice impacts decision-making in the Navy, is critical to N2/N6 to guide investments in future research, training, and collaboration with the broader Navy and Marine Corps. This research supports the 26 March 2020 Oceanographer of the Navy (OPNAV N2N6E) Fiscal Year 2021 Research, Development, Test and Evaluation Priorities (Paragraphs 3e and 3f).

As detailed in the project summary, ESPC forecasts have the potential to improve decisions in many critical missions. Missions that involve transit, such as ship routing, require more complicated computations, many important mission sets can be represented using simpler models. Straightforward extensions of a single-variable, binary METOC outcome, binary decision (also called atomic or 1 x 1 x 1) cost:loss decision scenario, in particular by adding multiple decision stages and multiple forecast and operational impact variables, cover many mission contexts, as detailed in the Project Summary.

Because short-range forecasts are more accurate than extended-range forecasts, when decisions can be delayed, they can exploit higher-accuracy forecasts. Decisions that cannot be delayed will exploit extended-range forecasts. These decisions typically share the following characteristics:

- involve slow-moving assets such as ships and many logistics decisions;
- take a long time to implement, are costly, and therefore only undertaken for a rare METOC event;
- are relatively more complex, as many more decision variables are undetermined at longer lead times, and therefore the details of extended-range decisions are less well-defined; and
- further decisions that can be taken at shorter-range lead times substantially influence the outcome of extended-range decisions.

Naval missions that can benefit from extended-range forecasts include:
- ship routing, in particular for logistics and in the Arctic;
- positioning assets regionally; and
- preparation for extreme events at fixed geographic locations.

In addition, Naval missions that can benefit from extended-range forecasts almost always involve short-term flexibility and, in particular, may include the ability to move operations geographically and temporally with shorter-lead times, for example postponing air operations or underway replenishment for hours or days, or moving operations a few tens or hundreds of nautical miles.

The ability to exploit geographic flexibility at both extended and short lead times is much more typical of Naval missions than civilian and commercial decision contexts. With the exception of preparing for extreme adverse events, civilian and commercial decisions that exploit extended-range forecasts often involve temporal flexibility—decisions about when to schedule an operation, or timing of water resource management decisions such as drawing down reservoirs. This indicates that Naval missions benefit from Navy-focused investigation of S2S forecast value.

Recommendations for Further Research

The current project showed that the Earth Systems Prediction Capability (ESPC) can provide high value—for some regions, seasons, and operational limits. The extended-range forecast capability is new, and therefore new products can be developed and presented to users. We recommend developing a tool or tools to help operational forecasters interactively identify high-value products so they can use that information to choose products to use and develop tailored products for specific end-users and even specific missions. Although the current project was limited by the variables and other limits in the subseasonal experiment data base, it does provide a method and algorithms, and at least a preliminary code base, for such a tool. There is a substantial value to be exploited by using newly available capabilities and existing forecasting capabilities that have not yet been incorporated into mission-planning and shorter-range decision processes. Finding and exploiting these opportunities requires a productive interaction between end-users and the METOC community (Regnier & Feldmeier, 2021), and operational forecasters are in an ideal position to be able to identify these opportunities.

While many missions can be represented by the decision scenarios explored in the current project, missions that involve transit, such as ship routing, require more complicated computations. We recommend using the VOI and data farming approach, together with existing mission planning models, such as the Replenishment at Sea Planner developed at NPS and optimal-track ship-routing algorithms, both in use and under development at the Naval Research Laboratory, to assess the value of adding both short and extended range (ESPC-derived) forecasts to these models.

Both the approach and code base developed in this project can now be used to explore the value of ESPC forecasts for variables not available for this project, such as waves. They can also be used to answer questions of interest to the METOC community regarding forecast product development such as: choice of ensemble summary (mean and standard deviation vs. percentiles); frequency and size of ensembles for ESPC and other forecasting models; and alternative ways of combining variables, including identifying new indices (analogous to El Niño-La Niña indices) with high predictive value.

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Acronyms

ESPC	Earth Systems Prediction Capability
ECMWF	European Centre for Medium-Range Weather Forecasts
ESPC	Earth Systems Prediction Capability
METOC	Meteorology and Oceanography
NPS	Naval Postgraduate School
NRP	Naval Research Program
S2S	sub-seasonal to seasonal
SubX	Subseasonal Experiment
VOI	value-of-information