OPerational ECology

Ecosystem forecast products to enhance marine GMES applications

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OPEC Overview

"OPEC provides an enhanced capability to predict indicators of good environmental status in European regional Seas"

The OPEC project (Operational Ecology) will help develop and evaluate ecosystem forecast tools to help assess and manage the risks posed by human activities on the marine environment, thus improving the ability to predict the "health" of European marine ecosystems. The programme will focus on four European regional seas (North-East Atlantic, Baltic, Mediterranean and Black Seas) and plans to implement a prototype ecological Marine Forecast System, which will include hydrodynamics, lower and higher trophic levels (plankton to fish) and biological data assimilation.

Products and services generated by OPEC will provide tools and information for environmental managers, policymakers and other related industries, laying the foundations for the next generation of operational ecological products and identification of knowledge / data gaps.

OPEC will use the EU's Global Monitoring for Environment and Security Marine Service as a framework and feed directly into the research and development of innovative global monitoring products or applications. This in turn will advise policies such as the European Marine Strategy Framework Directive and Common Fisheries Policy, as well as the continued monitoring of climate change and assessments of mitigation and adaptation strategies.

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Executive Summary

The main objective of this task is to provide recommendations for the future development of operational ecosystem seasonal forecast. These have been arrived at following a synthesis of the progress and the problems that arose and the lessons learnt from the seasonal forecast experiments, summarizing the predictive skill of the five model systems; two in the Mediterranean, one in the NE Atlantic, one in the Black Sea and one in the Baltic Sea.

Relevance to Policy

OPEC has demonstrated that its systems have the potential to make robust seasonal ecosystem forecasts. Task 4.4 synthesizes the final outcomes of WP4, where the main the objective is to assess the predictability of target indicators in lower and higher trophic level at seasonal time scales. This is important because it provides information on how well the seasonal forecast indicators could be used by the policy makers for environmental management.

The next step is to trial in a pre-operational mode. Seasonal forecasts will provide continuous predictions of potential future states of marine ecosystems. OPEC seasonal forecast could potentially support key policy areas, such as the European Marine Strategy Framework Directive and Common Fisheries Policy. By providing information on the future state the environment for key indicators related to MSFD Descriptors, regional and national stakeholders will be better able to plan, manage and report on their waters.

Introduction

The marine ecosystem is a complex nonlinear dynamical system, with significant spatial variability, strongly linked to the circulation of the atmosphere and oceans, and temporal variability ranging from hours to decades. Marine ecosystem forecasters interact with society mainly because of the latter's demands for accurate and detailed ocean environmental forecasts. A consequence of the complexity of the oceanic ecosystem is that quantitative predictions can only be made using comprehensive numerical models, which encode the relevant laws of dynamics, thermodynamics and biochemistry for a complex dynamical system. Typically, such models include some millions of scalar equations, describing the interaction of physics and biochemistry on scales ranging from tens of kilometres to tens of hundreds of kilometres. These equations can only be solved on large computers.

This article is intended to move beyond merely summarizing the D4.2 and D4.3 activities; indeed, we specifically avoid this kind of summary as this has extensively described in the aforementioned deliverables. Our main purpose is to supply definitive statements regarding current skill in seasonal prediction with emphasis on marine ecosystem indicators and how the forecasts could be used for societal benefit.

Following the WP4 workplan specified in the DoW, an experimental plan was developed (D4.1) to assess model skill and inform the setting of priorities for the further development and application of the existing dynamical models for seasonal prediction recognizing that this kind of process necessarily requires

(i) robust interactions amongst the biophysical science and applications communities and

(ii) an appreciation of the balance between scientific feasibility and application requirements.

Finally, the report outlines a set of specific recommendations for improving seasonal prediction skill and enhancing use of seasonal prediction information for applications.

Progress towards seasonal forecast

WP4 addressed four basic questions:

- What factors are limiting our ability to improve seasonal predictions?
- What factors are limiting the application of our seasonal predictions?
- What is the measure that a marine ecosystem could be predictable?
- What seasonal forecast indicators could be used for environmental management?

The maximum predictability of the marine ecosystem has yet to be achieved in the context of operational seasonal forecast. This assertion is based upon the recognition that:

(i) model error continues to limit forecast quality and that

(ii) the interactions among the non-linear terms of the ecosystem set the limits of predictability.

The model error continues to be problematic as evidenced by the need for successful calibration efforts and the effective use of empirical techniques to improve dynamical model forecasts. Essentially there is untapped predictability because we currently do not take into consideration all important interactions between the physical and biological components of the ecosystem. The maximum achievable predictability is unknown and assessing this limit requires much additional research.

Chaos theory developed from an attempt to demonstrate the limited predictability of atmospheric variations (Lorenz 1963). In the past, the topic of predictability has been a somewhat theoretical and idealized and too some extent not applied to the practicalities of operational prediction. While the predictability problem can be formulated e.g. through a Liouville equation (Epstein 1969), in practice, estimates of predictability are created from multiple (ensemble) forecasts of comprehensive atmospheric and ocean prediction models (Toth and Kalnay 1993, Kalnay, Kanamitsu et al. 1996, Toth and Kalnay 1997, Kalnay 2003). The uncertainty associated with model error and initialization is quantified by contracting ensemble members where the individual members of the ensemble differ by small perturbations (Leith 1973). For instance, the predictability of weather is largely determined by uncertainty in a forecast's starting conditions (Buizza, Hollingsworth et al. 1999, Buizza, Miller et al. 1999), whilst the predictability of ecosystem variations is also influenced by uncertainty in representing computationally the equations that govern the biogeochemical model (for example, to what extent the phytoplankton species should be represented, and subsequently what will be the model error). Furthermore, chaos theory shows that these kinds of environmental forecasts have to be expressed probabilistically (Leith 1973); the laws of physics dictate that relatively long-term accurate weather and ocean forecasts cannot be expected. These probability forecasts quantify uncertainty in weather and ecosystem prediction. The duty of the forecaster is to strive to estimate reliable probabilities; not to disseminate predictions to people with a precision that cannot be justified scientifically. Examples have shown that, in practice, the economic value of a reliable probability forecast (produced from an ensemble prediction system) exceeds the value associated with a single deterministic forecast with uncertain accuracy (Katz and Murphy 1997, Palmer 2002).

Previous research suggests unequivocally that predictions should be provided only as probabilities, utilizing either ensembles with dynamical models or appropriate alternatives along with empirical models. Metrics involved with probability estimations, and also their interpretations, are generally more complex compared to all those for the deterministic ones. The necessity for a procedure that provides a framework including all aspects of ecosystem seasonal forecast is incontestable. This requirement is urgent, considering the steadily expanding demand and use of the model estimations. The use of hind-casts will be the standard method for improving the sample measurements. However, hind-casts may also have many challenging concerns that should be tackled, like insufficient initialization data, the non-stationary nature of observing systems and the non-stationary nature of the marine ecosystem.

Producing reliable probability forecasts from ensembles of atmospheric/biophysical model integrations put enormous demands on computer resources. Computer power is essential so that one can resolve the details of such a system (Palmer 2000). It has been argued that, as a result of the nonlinear nature of a given system, a systematic mistreatment of small-scale phenomena may lead to the systematic mistreatment of large-scale phenomena. However, one can find reasons for studying small-scale phenomena in their own right. From an ecosystem prediction perspective, it is essential to have the ability to simulate such details, if models are able to forecast significant events like spring-blooms or fish stocks. However, this poses a significant dilemma given the current computing resources. In order to simulate extreme events, models with considerable complexity and resolution are required. On the other hand, estimating reliably changes to the probability distributions of extreme and relatively rare events, a large number of ensembles have to be used. One fact is certain; the more the necessity to provide reliable forecasts of uncertainty in the predictions of weather and ecosystem, the more the demand for computer power exceeds availability. Indeed the call for quantitative predictions of uncertainty is typically a relevant consideration related to the design of future generations of supercomputers; ensemble prediction is typically a perfect application for parallel computing!

Model errors, particularly in areas exhibiting strong inter-annual variability e.g. of the ocean circulation and vertical mixing, such as the winter-spring period, continue to hamper seasonal prediction skill. The benefit of reducing the model error has not been overstated. There is a range of strategies for improving models including a better representation of the interactions among the elements of the ecosystem (tuning and customization to reduce any model bias), better representation of biogeochemical cycles, and substantially increased spatial resolution. All of these strategies ought to be vigorously pursued. Except the model errors, the production of seasonal forecast quality remains hindered using a wide range of factors, including:

Unlike daily forecasts, seasonal predictions can be obtained only a few times per year, creating difficulties in accumulating the information required to provide stable estimates of great quality (together with the expense of producing the predictions when ensembles are utilized)

Lessons learnt from OPEC and Recommendations

Predictability of ecosystem variables varies between years, across the Mediterranean, Atlantic, Baltic and Black Sea with strong evidence that these variations are also related to atmospheric and hydrodynamic variability

Most metrics of seasonal forecast quality, are mainly technically presented in a nature not easily communicated to audiences outside the seasonal forecasting community

Several broad qualitative and quantitative outcomes have been produced from the experiments reported in D4.2 and D4.3 leading to the following recommendations:

(i) Seasonal predictions are more skilful in some regions the others, skill generally being higher in areas when the oceanographic response to meteorology is relatively small. Furthermore, climatology, or persisting recent seasonal anomalies in many cases can provide useful information.

(ii) The quality of seasonal predictions varies on an inter-annual basis, partly connected to inter-annual variability of the specific marine ecosystem dynamics; average quality also differs between specific seasons.

(iii) Of the major seasonal variables of interest, predictions of hydrodynamic variables (temperature, salinity, etc.) generally are of a better quality than biogeochemical variables, such us chlorophyll, nutrients, primary production etc.

(iv) As rule of thumb, but with some exceptions, initial conditions provided from data assimilation, improve the model projections. However information on spatial patterns is lost quite quickly. Forecast initialization is an area that requires active research. Ocean data assimilation has improved forecast quality. Coupled data assimilation should be a field of active research requiring enhanced support and maybe international coordination. There is certainly significant evidence that coupled atmosphere-ocean-biochemical data assimilation should improve forecast quality.

(v) OPEC has demonstrated that in some regions and during some seasons, seasonal predictions have quality, but their translation into useful information for end-users is far from optimal. It is essential that a concerted effort is made to engage customers and seek their quantitative definition of value, so that the forecasts will be able to be used in decision-making issues. Since the direct connection between seasonal forecast quality and value has not been established, appropriate processes need to be engaged to measure value in specific decision making instances independently from the assessment of quality. It should be noted that experience in climate variability (e.g. the chances of varied scenarios, despite forecasts) could aid applications/planning/management. The applying of forecasts requires trust in the overall quality of the forecasts and knowledge of forecast uncertainty.

(vi) Multi-model methodologies (Ehrendorfer 1997) (Houtekamer, Lefaivre et al. 1996, Buizza, Hollingsworth et al. 1999) are a useful and practical approach for quantifying forecast uncertainty as a consequence of the model formulation. Still, there are open questions associated with the multi-model approach. For example the approach is ad-hoc meaning that the choice of models isn't optimized. Nor has the community converged to any best strategy for combining the models. Multi-model calibration activities tend to yield positive results, but considerable work has to be done. These problems as well as others require additional research. It is also important to realize that the multi-model approach should not be utilized to obviate the need to improve models.

(vii) Validation needs to be routinely undertaken on seasonal dynamical application models. These models ought to be complex enough to capture non-linear interactions, and at the same time being sufficiently simple to avoid over tuning through non-constrained parameters.

(viii) The relationship of forecast quality, in applications of fish models is often highly non-linear with respect to meteorological and biophysical models. Consequently, quality inside the prediction of seasonal chlorophyll might not be translated into quality within the prediction of mean fish stock, for example. Such application models like fish models should have additional metrics of forecast quality. Furthermore, these metrics should be suitable for a selected user group.

Conclusions

There exists a clear need to provide seasonal forecast information at local scales. For many applications, forecast information is required at local space and time scales. Further research effort combined with pre operational implementation is essential to provide and increase such information, e.g. through statistical and/or dynamical downscaling. Although there are numerous examples of seasonal forecast application (e.g., atmosphere, ocean, water management), they are generally still in a development phase. More effort is required for the development, the production and understanding of probabilistic forecasts. Understanding of what exactly is predictable and what is not predictable should be enhanced. The value of predicting 'extremes' can also be incredibly important, for example to the insurance industry.

The societal benefit of such work has yet to be realized. This is in primarily due to the formative state of seasonal ecosystem forecast. OPEC has demonstrated that its model systems have aspects of seasonal forecast skill, and therefore going forward there is a need to interact with potential stakeholders. Stakeholder issues go beyond the technical improvement of forecast quality and making forecasts readily available. The ecosystem scientists should actively understand users' requirements, in an effort to provide improved information, prediction products and services leading to enhanced applications. Users also have to maintain an active dialogue with the physical scientists and forecast providers so that their climate information needs are taken into account. Successfully communicating uncertainty and the limitations of seasonal forecasts is critical to the process of making seasonal forecasts useful. Model applications can be used with seasonal forecasts to provide a metrics that combines quality and value. For example, the quality of a seasonal forecast of fish stocks is both a proper measure of skill and a measure of potential value. Seasonal predictability research should be encouraged. Collaborations and interactions with the climate change community need to be encouraged and have the potential for significant benefits.

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