Final Report

Development and evaluation of a seasonal-to-interannual statistical forecasting system for oceanographic conditions

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Accomplishments

What were the major goals and objectives of this project?
The overall goal of our project is to develop a seasonal-to-interannual statistical prediction system for ocean temperatures on the Northeast U.S. Shelf (NES), which will be tailored to the needs of the National Marine Fisheries Service (NMFS) Northeast Fisheries Science Center (NEFSC) for fisheries stock assessments. The measures of uncertainty and predictability skill of the prediction product will be rigorously evaluated against three independent long-term regional hindcast simulations based on probabilistic skill metrics. Our first goal is to use previously described statistical relationships linking shelf ocean temperature to atmospheric circulation, Gulf Stream path, and coastal sea-level to develop a prediction system at the 3-36 month time scale. Our second goal is to evaluate this system in the context of selected stock assessments performed by the NEFSC. Our third goal is to clarify the dynamical basis for the statistical relationships using ocean hindcast models and coupled ocean-atmosphere models.

What was accomplished under these goals?
Statistical prediction
We have developed a hierarchy of statistical seasonal predictions for NES bottom temperatures. A simple, damped local persistence prediction model produces significant skill for lead times up to ~5 months in the Mid-Atlantic Bight (MAB) and up to ~10 months in the Gulf of Maine (GoM), although the prediction skill varies notably by season. Considering temperature from a nearby or upstream (i.e., more poleward) region as an additional predictor generally improves prediction skill (Fig. 1), presumably as a result of advective processes. Large-scale atmospheric and oceanic indices, such as Gulf Stream path indices (GSIs) and the North Atlantic Oscillation Index, are also tested as predictors for NES bottom temperatures. Only the GSI constructed from temperature observed at 200 m depth significantly improves the prediction skill relative to local persistence. However, the prediction skill from this GSI is not larger than that gained using models incorporating nearby or upstream shelf/slope temperatures. Based on these results, a simplified statistical model has been developed, which can be tailored to fisheries management for the NES. The result is published (Chen et al. 2021).

The Woods Hole Assessment Model (WHAM)

Stock and Miller continued to develop the WHAM software package, which fits stock assessments with the capability to incorporate oceanographic time-series data (Miller and Stock 2020). In this reporting period they improved the WHAM documentation and testing, developed additional features, and supported use by other research groups. They also conducted simulation tests, described the model equations and options, and presented WHAM in the NOAA National Stock Assessment Science Seminar Series (Stock and Miller 2021). Stock, Miller, and Nye completed a case study using WHAM to investigate time-varying survival and natural mortality of Southern New England-Mid Atlantic yellowtail flounder (Stock et al. 2021). WHAM applications incorporating environmental effects are underway for three stocks in the region: Southern New England-Mid Atlantic winter flounder, GoM Atlantic cod, and Southern New England-Mid Atlantic yellowtail flounder. We aim to incorporate the short-term forecasts of bottom temperature developed by Chen et al. (2021) in some of these applications.

Mixed Layer Depth (MLD) Climatology for NES
We have produced a MLD climatology for 1993-2018 based on an observational dataset from the NEFSC hydrography program. This MLD climatology is the first regional climatology for the NES. The MLD exhibits clear seasonal cycles across five eco-regions on the NES, with the largest amplitude in the western GoM (69.2±25.3 m), and smallest in the southern MAB (31.9±7.6 m). Spatially variations are seasonally dependent, with greatest homogeneity in summer (Fig. 2). Interannual variability dominates long-term linear trends in most regions and seasons. We also compared observational MLDs to the MLDs from a high-resolution ocean reanalysis GLORYS12V1. These results can be a starting point for future studies on the drivers of temporal and spatial MLD variability on the NES continental shelf. The result is submitted (Cai et al. 2021).

U.S. Northeast Climate-Fisheries Monthly Seminar Series
Saba has coordinated this new seminar series started in January 2021. This seminar series focuses on sharing climate-fisheries research in the U.S. Northeast region with the goal of building broader awareness of efforts across research groups and facilitating collaboration. Our project outcomes have been presented by Chen (March 2021) and Stock (June 2021).

<u>What opportunities for training and professional development has the project provided?</u>
Three postdocs have been involved in the project. NRC postdoc fellow/WHOI postdoctoral investigator Zhuomin Chen (advised by Fratantoni, Kwon, and Ke Chen) has developed the statistical forecast model of bottom temperature. NRC postdoc fellow Brian Stock (advised by Tim Miller) has been incorporating environmental variables into stock assessment models. Ocean Frontier Institute postdoc fellow Robert Schlegel (advised by Ke Chen) worked on drivers of marine heatwaves in the Northwest Atlantic. In addition, a WHOI Summer Student Fellow Cassia Cai (advised by Kwon, Fratantoni, and Zhuomin Chen) has developed the new NES MLD climatology.

<u>How were the results disseminated to communities of interest?</u>

Our results in this reporting period have been disseminated via 5 papers published or submitted in peer-reviewed journals, 5 oral presentations at conferences, annual State of the Ecosystem reports, and model code and tutorial on GitHub, as listed in the Products Section.

Participants & other collaborating organizations

What individuals have worked on this project?
Young-Oh Kwon (PI; MA, USA; <1 mo): Overall coordination of the project, acting as the primary supervisor to the postdoc Zhuomin Chen, organized the bi-weekly subgroup meetings and bi-monthly all-PI meetings, co-authored 2 papers; Collaborated with individual in foreign country: NO; Travelled to foreign country: NO

Ke Chen (Co-PI; MA, USA; <1 mo): Co-authored 2 published papers, contributed to the bi-weekly subgroup meetings and all-PI meetings, and co-advised the postdoctoral researcher Zhuomin Chen, acted as the primary supervisor to postdoc Robert Schlegel; Collaborated with individual in foreign country: YES; Travelled to foreign country: NO

Glen Gawarkiewicz (Co-PI; MA, USA; <1 mo): Co-authored 1 published paper, contributed to the bi-weekly subgroup meetings and all-PI meetings, and provided guidance to the postdoctoral researcher Zhuomin Chen; Collaborated with individual in foreign country: NO; Travelled to foreign country: NO

Terry Joyce (Co-PI; MA, USA; <1 mo): Co-authored 1 published papers, contributed to the bi-weekly subgroup meetings and all-PI meetings, and provided guidance to the postdoctoral researcher Zhuomin Chen; Collaborated with individual in foreign country: NO; Travelled to foreign country: NO

Zhuomin Chen (Postdoc; MA, USA; 12 mo): Developed the statistical prediction model for the NES temperature and lead-authored the resulting paper, co-authored 1 paper, communicated the progress with the PIs through the bi-weekly subgroup meetings; presented in all-PI meeting and two conferences, co-advised the summer student Cassia Cai. Collaborated with individual in foreign country: NO; Travelled to foreign country: NO

Paula Fratantoni (Co-PI; MA, USA; <1 mo): Co-authored 2 published papers, contributed to the bi-weekly subgroup meetings and all PI meetings, and co-advised the postdoctoral researcher Zhuomin Chen and summer student Cassia Cai, especially as the NRC postdoc host; Collaborated with individual in foreign country: NO; Travelled to foreign country: NO

Vince Saba (Co-PI; NJ, USA; <1 mo): Analyzed on various model simulations especially in terms of the marine heat wave, contributed the state of ecosystem report, contributed to all-PI meeting, coordinated the U.S. Northeast Climate-Fisheries Monthly Seminar Series; Collaborated with individual in foreign country: NO; Travelled to foreign country: NO

Tim Miller (Co-PI; MA, USA; <1 mo): Worked on the Woods Hole Assessment Model, contributed to the all-PI meetings, and supervised the NRC postdoc Brian Stock; Collaborated with individual in foreign country: NO; Travelled to foreign country: NO

Brian Stock (Postdoc; RI, USA; 12 mo): Worked on the Woods Hole Assessment Model, lead-authored 2 papers and co-authored 1 paper, presented at the all-PI meetings and a conference; Collaborated with individual in foreign country: NO; Travelled to foreign country: YES
Janet Nye (Co-PI; NY, USA; <1 mo): Worked on the marine heat wave and vulnerability of coastal communities; Collaborated with individual in foreign country: No; Travelled to foreign country: No

What other organizations have been involved as partners?
University of Tasmania

Have other collaborators or contacts been involved?
Robert Schlegel (Dalhousie University)

What was the impact on the development of the principal discipline(s) of the project?
Our project will advance our understanding of the Northeast US Shelf environment by: (1) diagnosing temperature variability over the last 30+ years, including the recent 2017 extreme event, (2) exploring the predictability of the SST and bottom temperature, and (3) linking variability in the physical environment to changes in fish distribution and abundance. We have also developed the first regional MLD climatology for the NES.

What was the impact on other disciplines?
Outcomes from our project will contribute to advancing: (1) the statistical and numerical seasonal-to-interannual prediction, (2) climate variability and change, and (3) physical-biological interaction.

What was the impact on the development of human resources?
Three postdoctoral scientists and an undergraduate summer student fellow have been trained within our project.

What was the impact on physical, institutional, and information resources that form infrastructure?
We have developed, documented and distributed the Woods Hole Assessment Model (WHAM) on GitHub following guidelines for free and open-source software of the NOAA Fisheries Toolbox and the Linux Foundation Core Infrastructure Initiative.