1. General Information

Project Title:
Downscaled seasonal forecasts for living marine resource management off the U.S. west coast

PI/co-PI names and institutions:
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Report Year:
FY18 (Year 1)

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NA17OAR4310105

2. Main goals of the project, as outlined in the funded proposal

The overarching goal of the proposed project was to produce and validate downscaled seasonal reforecasts for ~3 decades of California Current System (CCS) physical conditions as well as species distributions for target- and by-catch species of interest to US west coast fisheries. Key elements of the proposed work plan are

1. Extract and bias-correct global NMME fields, use them to force downscaled reforecasts (i.e., retrospective forecast experiments predicting what happened in the past) of CCS physics, and validate CCS reforecasts with observations.
2. Run and validate species distribution reforecasts for target- and by-catch species in the CCS.
3. Determine the added value of an ensemble approach to forecasting living marine resources.

3. Results and Accomplishments

Ocean Modeling
Global Climate Models from the North American Multi-Model Ensemble (NMME) are providing the forcing for our regional ocean projections in the CCS. To date, we have gathered output from the CanCM4 model (which has the highest skill of all phase I NMME members for CCS SST reforecasts) including all 2D atmospheric variables and 3D ocean variables needed to force our regional ocean model for 1982-2009. We have begun work on statistical downscaling of the atmospheric forcing to improve representation of surface fluxes, especially due to the wind, before performing the dynamical downscaling. The simplest version of this statistical downscaling is a lead-dependent bias correction using the ERA Interim reanalysis as truth; this step is complete. We have also begun working with collaborators at NOAA/ESRL to develop statistically downscaled forcing based on multiple linear regression EOFs, which allow one to recover higher resolution variability in surface fields (particularly the wind) from the relatively low resolution global model.

We have also done some analysis to explore how much skill is added by running additional ensemble members for a given model. For CanCM4, which has 10 ensemble members in its reforecasts, we computed skill for SST forecasts from single ensemble members, the full 10-member ensemble, and 'mini-ensembles' created by averaging 2-9 ensemble members. We computed forecast skill for all possible combinations of mini-ensembles and then averaged the skill by number of ensemble members. Looking at deterministic skill (anomaly correlation coefficient, ACC) by initialization month and lead time, we see that the skill patterns are consistent across different ensemble sizes, but that skill increases with number of ensemble members (Figure 1). However, the change in skill from 1 to 5 members is much greater than the change from 5 to 10 members, indicating diminishing returns with added ensemble members.

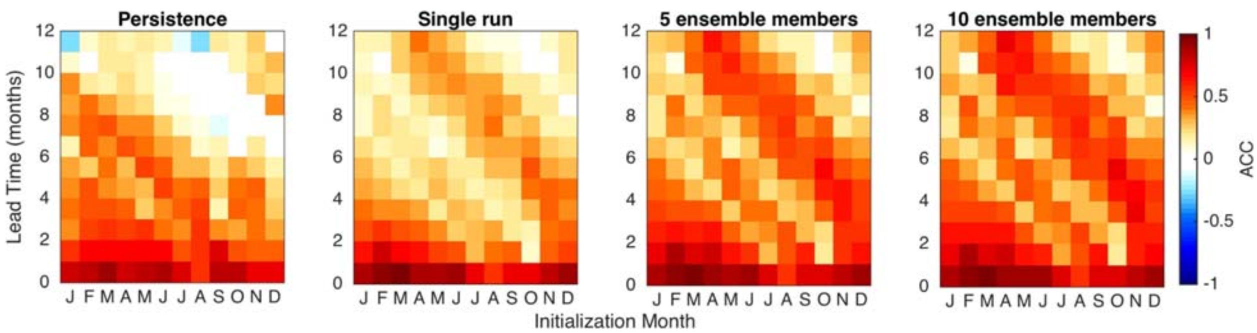

Figure 1: SST forecast skill (measured by anomaly correlation coefficient for 1982-2009) as a function of initialization month and lead time for different ensembles sizes of the CanCM4 model.

The dependence of forecast skill on ensemble size is illustrated further in Figure 2. When averaged across all lead times and initialization months, forecast skill for a single ensemble member is equal to that of a persistence forecast. Forecast skill increases appreciably up to ~4 ensemble members, after which additional gains are modest. At short lead times (0-5 months), a persistence forecast tends to be more skillful than a 1- or 2-member ensemble, while ensembles of 3 or more members beat persistence. At longer lead times (6-11 months) a single ensemble member already has an ACC ~40% higher than persistence, and substantial additional gains are possible with additional members. While the feasible number of downscaled ensemble members will depend on computational resources, this analysis suggests that one should aim for at least 3-4.

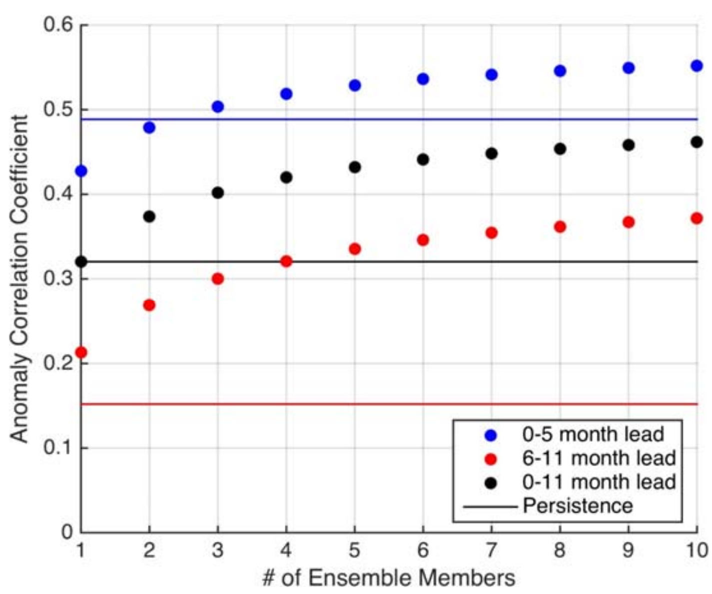

Figure 2: SST forecast skill (ACC) as a function of size of forecast ensemble for CanCM4. ACC is averaged across all initialization months for short (0-5 month), long (6-11 month) and all (0-11 month) lead times.

We have not yet begun to compare results from J-SCOPE's Pacific Northwest domain to the CCS-wide domain. The move of co-PI Samantha Siedlecki from UW JISAO to U Connecticut has slowed down work on the UW/UConn portion of the project. We are still in the process of establishing the funds at UConn. The plan is to subaward the first year and transfer the award to UConn after that. However, strong leverage to this objective is coming from other J-SCOPE funded activities and Siedlecki's startup funds.

Species distribution modeling

A manuscript was published describing the EcoCast tool, which integrates SDMs for swordfish and bycatch species in the swordfish fishery to define regions of relatively good and poor fishing grounds (*Hazen et al.*, 2018). This tool was developed primarily on a prior NASA-funded project, using remotely sensed data, and we have advanced it in several respects as part of this project. First, the tool has been operationalized so that environmental data are ingested and automatically used to create maps of relative target catch potential and bycatch risk (described in a submitted manuscript by *Welch et al.*). Second, the tool has been transitioned from remote sensing output to ROMS output, which enables better prediction of habitat (*Brodie et al.*, 2018) and ensures consistency of SDMs developed on historical data with our future projections. For modeling individual target and bycatch species of interest to the swordfish fishery, switching from remote sensing to model output has enabled us to explore environmental variables that capture vertical structure in the water column, several of which have proven to be powerful predictors of species habitats – specifically isothermal layer depth (ILD, a measure of vertical mixing) and upper ocean buoyancy frequency (a measure of stratification). ILD and buoyancy frequency came out as the 1st and 4th best predictors of swordfish distribution out of 16 variables tested (*Brodie et al.*, 2018; Figure 3, left).

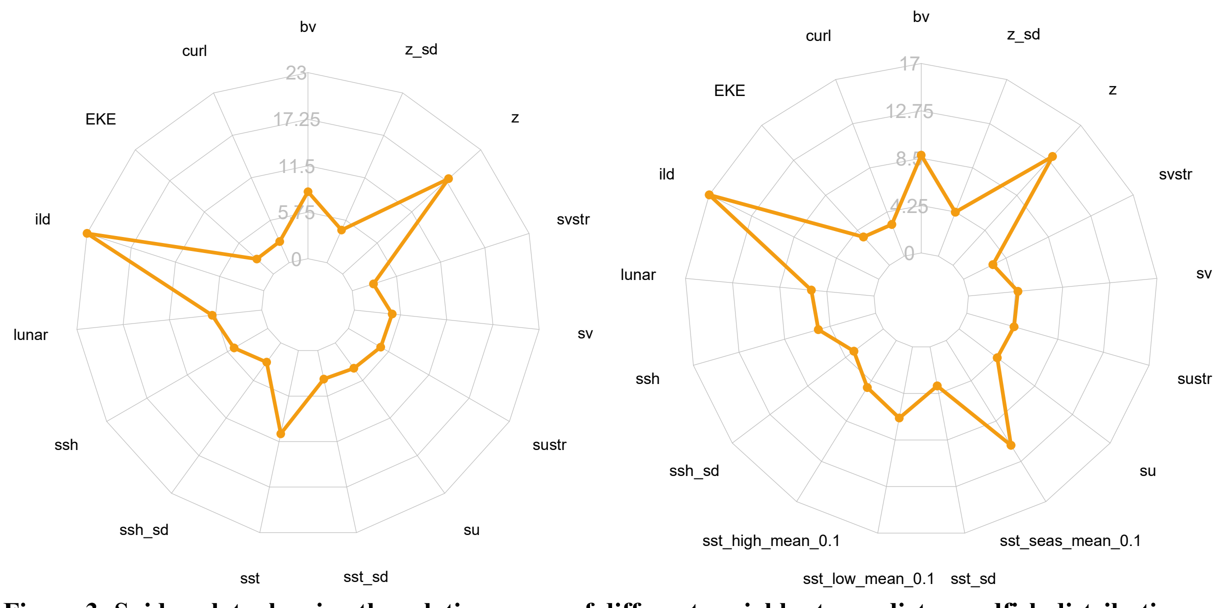

Figure 3: Spider plots showing the relative power of different variables to predict swordfish distribution. Variables include Brunt-Vaisala frequency (bv), bottom depth (z), surface wind stress (sustr, svstr), surface currents (u,v), sea surface temperature (sst), sea surface height (ssh), lunar illumination (lunar), isothermal layer depth (ild), eddy kinetic energy (EKE), and wind stress curl (curl). The suffix _sd indicates spatial standard deviation of a variable. The right panel is as in the left but with SST decomposed into seasonal, low frequency, and high frequency components.

We have also started to explore the spatiotemporal scales of variability that drive skill in habitat models. We decomposed SST into its seasonal cycle (i.e., climatology), a low frequency component (i.e., interannual variability), and a high frequency component (sub-annual variability), and used each in the model of swordfish distribution. The greatest variance was explained by the seasonal cycle, followed by the low frequency and then high frequency variability (Figure 3, right). These results inform which variables we need to test for forecast skill in our physical forecasts in order to generate skillful species distribution forecasts, and suggest that skillful predictions of changing distributions will be tied more to phenological shifts and low frequency variability than to high frequency variability (e.g., eddies).

Outreach

The Pacific Fisheries Management Council (PFMC) solicited a series of webinars in early 2018, including one on 'the state of the art in ecosystem modeling at short, medium, and long timescales', where PIs Jacox and Siedlecki presented on our seasonal forecasting efforts. We also presented to NOAA's California Current Integrated Ecosystem Assessment (CCIEA) team, who have included the seasonal forecasts in their new 3-year plan. PI Jacox is part of a joint NMFS-DFO (Canada) working group to strengthen collaborations between the two, including exploring climate impacts on west coast fish stocks. We are coordinating with relevant US and international efforts through the North Pacific Marine Science Organization (PICES) working group on Climate and Ecosystem Predictability, a Climate Impacts on Oceanic Top Predators (CLIOTOP) task team on Seasonal forecasting and dynamic ocean management for pelagic ecosystems, and a Clivar research focus group on Eastern Boundary Upwelling Systems. Team members have given ~20 presentations related to the project at scientific conferences, seminars, webinars, etc.

Marine Prediction Task Force

PI Jacox is co-chairing the NOAA/MAPP Marine Prediction Task Force (MPTF) and all other team members are participating. We have presented our project to the MPTF with a focus on its overall structure and objectives as well as mechanisms of predictability we are aiming to exploit for seasonal forecasts. Jacox is leading a paper, "Mechanisms of Marine Ecosystem Predictability Along U.S. Coastlines", which will draw on the expertise and findings of all MPTF members. To date, the paper has been outlined and was discussed on the latest MPTF call, and a number of people have expressed interest as co-authors and have offered preliminary input. We are also contributing to a paper being led by Antonietta Capotondi and discussing observational needs for marine ecosystem modeling and forecasting. An abstract for that paper was submitted and accepted for Ocean Obs '19; it has been outlined and discussed with the MPTF and will be written in the coming months for submission at the end of September.

4. Highlights of Accomplishments

- *Forcing files for ROMS reforecasts have been created using output from CanCM4, including a bias-corrected version, and we have begun work on more involved statistical downscaling based on EOFs to recover fine-scale structure from coarse global forecasts. We have also analyzed the individual members of the CanCM4 ensemble to inform our choice of how many downscaled ensemble members to run.*

- *A paper describing the EcoCast tool has been published, we have operationalized the tool using remote sensing data, and we have run it on historical ocean model output to ensure consistency with forecasts that will be based on ocean model output.*
- *We have evaluated species distribution models to determine (i) the physical variables most important for skillful species distribution predictions, and (ii) the spatiotemporal scales most important for skillful species distribution predictions.*
- *We have conducted outreach to collaborate with a number of research groups pursuing related efforts and to inform and support managers who we hope will ultimately use the forecasts.*

5. Transitions to Operations

None

6. Estimate of current technical readiness level of work

For the oceanographic seasonal forecasts, we are at about RL 3, working on proof-of-concept for the downscaled forecast system. For the species distribution modeling (the EcoCast product), we are at RL 6 – the product is live but is not yet in operational use by fishers or managers.

7. Publications from the Project

Brodie, S., M. G. Jacox, S. J. Bograd, H. Welch, H. Dewar, K. L. Scales, S. M. Maxwell, D. K. Briscoe, C. A. Edwards, L. B. Crowder, R. L. Lewison, E. L. Hazen (2018), Integrating dynamic subsurface habitat metrics into species distribution models, Frontiers in Marine Science, doi: 10.3389/fmars.2018.00219.
Link: https://www.frontiersin.org/articles/10.3389/fmars.2018.00219/abstract

E.L. Hazen, K.L. Scales, S.M. Maxwell, D. Briscoe, H. Welch, S.J. Bograd, H. Bailey, S.R. Benson, T. Eguchi, H. Dewar, S. Kohin, D.P. Costa, L.B. Crowder, R.L. Lewison, 2018. A dynamic ocean management tool to reduce bycatch and support sustainable fisheries. *Science Advances*, 4: eaar3001. DOI: 10.1126/sciadv.aar3001.
Link: http://advances.sciencemag.org/content/4/5/eaar3001.full
**This paper did not result directly from this project, but the research is being highly leveraged and expanded upon.*

Welch, H., E. L. Hazen, S. J. Bograd, M. G. Jacox, S. Brodie, D. Robinson, K. Scales, L. Dewitt, R. Lewison, Practical considerations for operationalizing dynamic management tools, submitted.

8. PI Contact Information

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9. Budget for Coming Year

No changes are expected to the UCSC budget. UW has spent 0% of the funds to date with the UConn subaward pending for Y1 and Y2-Y3 will be transferred to UConn.

10. Future Work

In the coming year we will be focused on (i) statistical downscaling of the atmospheric forcing from CanCM4, (ii) running downscaled reforecasts in ROMS forced by CanCM4, and (iii) evaluating downscaled reforecast skill with attention to the influence of adjustments to the forcing. We plan regular PI meetings to discuss model evaluation strategies and comparisons between the J-SCOPE and CCS-wide seasonal forecasts.