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RTP SHIP Inclusion of Environmental Uncertainty for Automated Ship-Routing Guidance

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LONG-TERM GOALS

The long-term goal of the project is to improve ship routing guidance. This will be achieved by the inclusion of more accurate and comprehensive environmental information in the STARS++ optimizer calculation. Also, it will be achieved by the addition of a multi-objective optimization capability to the STARS++ optimizer. Improvements in ship routing guidance will result in fuel efficiencies, improved sea-keeping and mission effectiveness, and a reduction in scheduled ship maintenance by avoiding hazardous environmental conditions during transits.

OBJECTIVES

This project's objective is to formulate, test, and demonstrate an ensemble system that provides superior low-level wind and wave forecasts for use in ship-routing, and construct a web-services solution that allows objective ship routing guidance to be generated by the Ship Tracking and Routing System (STARS++) and returned to end users.

APPROACH

The technical approach is to leverage prior investments in the NRL-developed NAVGEM (Navy Global Environmental Model) atmospheric ensemble prediction system (EPS), along with new post-processing techniques developed under the NUOPC project, and the STARS++ ship routing optimization system to deliver an improved ensemble forecast product capable of producing superior ship-routing products. This will be accomplished by incorporating methods to account for model uncertainty and SST variability into the design of the NAVGEM ensemble prediction system (EPS) together with improved model dynamics and physics. In addition, new methods for post-processing will be facilitated by generation of an atmosphere-wave ensemble climatology for several seasons. Collaborations with Fleet Numerical Meteorology and Oceanography Center (FNMOC) and the NITES-Next project will ensure step-by-step coordination.

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WORK COMPLETED FOR FY14

Executive Summary: Significant progress was made in FY14 on all major milestones, despite having only six months of the fiscal year to work with. First steps toward operational transition were taken for several items, including a stochastic-forcing scheme upgrade to the NAVGEM EPS, a post-processing scheme (for bias-correction of WW3 wave output), and a beta-test version of the ship-routing system. The most notable accomplishments for each major milestone are summarized below.

- Milestone: Demonstration of ship-routing capability

  Two formal demos of the ship-routing capability were undertaken at the FWCs. The first of these demos was impromptu and unexpected, and consequently we were forced to exhibit an immature version of the ship-routing user interface (UI). As a result, the feedback from the FWCs about the UI functionality was in some cases severe. Nevertheless, the feedback was useful and led to substantial improvement in the UI in time for the second demo. Feedback from the second demo at FWC-San Diego was very favorable and more intensive collaboration with FWC-San Diego is scheduled going forward.

- Milestone: Upgrades to NAVGEM EPS

  Validation was completed for a method of stochastic forcing of the NAVGEM NWP model, called stochastic kinetic energy backscatter (SKEB). The configuration of SKEB tested for the project (called SKEB-mc) is novel in that it uses a moisture convergence mask to determine where in space to apply the random perturbations. Scorecard results were tabulated for a multi-season comparison between a forecast ensemble with SKEB-mc and a forecast ensemble without SKEB-mc (known as the control ensemble). The scorecard mimicked the official FNMOC operational ensemble scorecard and measured performance using four metrics: Root-mean-square error of the ensemble mean (RMSE), Continuous Ranked Probability Skill score (CRPS), the bias of the ensemble mean, and a measure of the spread-skill relationship. Five variables were analyzed including 10m wind speed, 250 hPa wind speed, 500 hPa geopotential height, 2m air temperature, and 850 hPa air temperature. For this scorecard, a positive (negative) score would mean that the ensemble with SKEB-mc was statistically significantly better (worse) than the control ensemble. The scorecard results indicated that SKEB-mc was beneficial to the ensemble distribution in many respects. It yielded net positive grand scores (i.e. scores summed across all regions, metrics, and variables). Also, it yielded net positive grand scores for 10m wind speed, which is a critical variable in the ship routing problem as it is the most important atmospheric input to the WW3 wave model. Further, it yielded net positive grand scores for 10m wind speed in the North Pacific Ocean and North Atlantic Ocean regions, two regions which are of central importance to the ship-routing problem. These results hold in general whether one considers all statistically significant forecast differences, no matter how small, or whether one considers only statistically significant forecast differences that are associated with major relative improvement/degradation (e.g. $\geq 5\%$ in magnitude).

  Given the favorable validation results, a formal transition process was initiated for SKEB-mc. This included creating a summary presentation of SKEB-mc for AMOP and presenting SKEB-mc results to FNMOC colleagues.

In addition to SKEB-mc, initial code development/porting/testing was completed for incorporating a persisted SST anomaly capability and an SST analysis perturbation capability in the NAVGEM ET ensemble. This effort laid groundwork for further NAVGEM EPS upgrades in FY15-16.

- Milestone: Post-processing of NAVGEM EPS

  A large, multi-month archive of operationally configured NAVGEM ensembles was generated to serve as a basis for the statistics that are necessary for post-processing. Tests using these statistics to bias-correct ensemble 10m wind speed fields were undertaken and yielded very promising results. In particular, a clear relationship was found between 10m wind speed and bias, and the bias correction based on this relationship significantly improved the ensemble 10m wind speed forecast. These results give the project two candidates for post-processing operational transition in FY15: bias-correction for waves, and bias-correction for ensemble 10m wind speed. Further, the promising results make possible a series of experiments to define the benefit of post-processing the ship-routing input. Specifically, experiments are planned to look at the relative benefit of post-processing just ensemble 10m wind speeds prior to input into WW3, of just post-processing the WW3 wave output, and of post-processing both ensemble 10m wind speeds prior to input into WW3 and the WW3 wave output. The promising results also make possible a series of experiments to examine the synergies between SKEB-mc and post-processing.

- Milestone: Development of STARS++ web services

  A basic, functional UI was developed using a mix of the OpenLayers mapping API and Google Earth. The use of OpenLayers for the ship-routing UI ensures that the UI's mapping functionality will be consistent with the requirements of NITES-Next, as OpenLayers is the API of choice for NITES-Next. The routing capabilities included in the UI were guided by the requirements outlined in the FWC Statement of Work for an Optimum Track Ship Routing (OTSR) service. A parallel effort was able to identify algorithmic options that would allow the ship-route optimizer to take account of environmental uncertainty (as embodied in the weather and wave forecast ensembles) in a formal and theoretically sound manner. One such algorithm treats weather uncertainty with a discount factor, giving situations with high uncertainty a low weight in the optimization calculation, and vice versa. A proper choice of algorithm is essential to getting the most benefit from the available environmental uncertainty information. Work with the contractor DRS Inc. has laid the groundwork to expand the ship-class database in FY15. Additionally, the first steps have been taken to integrate the "routing ladder" used by the FWCs into the UI. This integration will allow the UI to fit much more seamlessly into the ship-routing schema of the FWCs.

- Milestone: Validation and verification of ship-routing guidance

  An official ship-routing scorecard was defined based on a set of ten canonical routes. Also, a series of sensitivity analyses of the ship-route solutions were undertaken. These compared ship-route fuel usage as a function of ocean current specification (specifically, the use of surface versus sub-surface currents); as a function of route choice (e.g. naïve great-circle track versus optimum track); and as a function of weather specification (e.g. climatological weather versus NWP forecast weather). Additionally, the capability was implemented to compare the predicted optimum ship-route fuel usage against the actual ship-route fuel usage given the verifying weather along the route.

- Milestone: Transition of ship-routing system to FNMOC

  A best-test version of the ship-routing system was installed on the FNMOC NIPR system at the end of FY14 (September). This beta-test version will allow FWC-SD to commence exercising and fault-testing the system and will allow NRL to begin training FNMOC personnel on system operation and support.

RESULTS

Selected results are shown below for several milestones.

1) Milestone: Upgrades to NAVGEM EPS

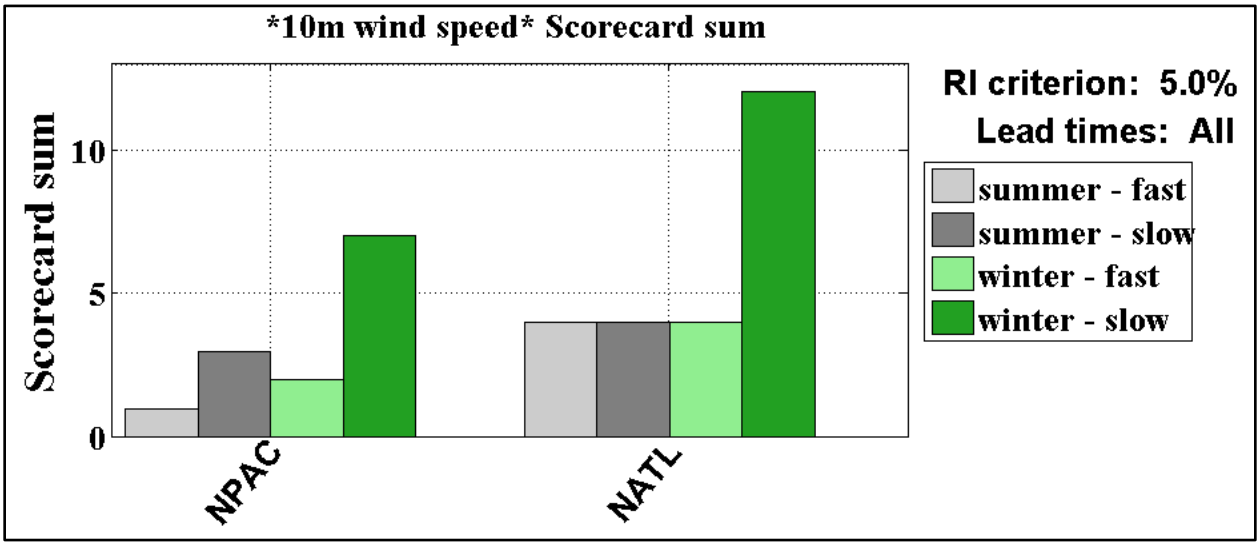

Figure 1 (above) from the ensemble testing of SKEB-mc stochastic forcing: The ensemble scorecard sum for 10m wind speed for the North Pacific Ocean (NPAC) and North Atlantic Ocean (NATL) regions as a function of season (i.e. winter or summer) and forcing decorrelation time (i.e. fast or slow decorrelation). A positive scorecard sum indicates the test ensemble with SKEB-mc outperformed the control ensemble without SKEB-mc. Scores are significant at the 95% threshold and yield at least 5% relative improvement. The results indicate that SKEB-mc yields major benefits to the ensemble 10m wind speed in both the NPAC and NATL.

2) Milestone: Post-processing of NAVGEM EPS

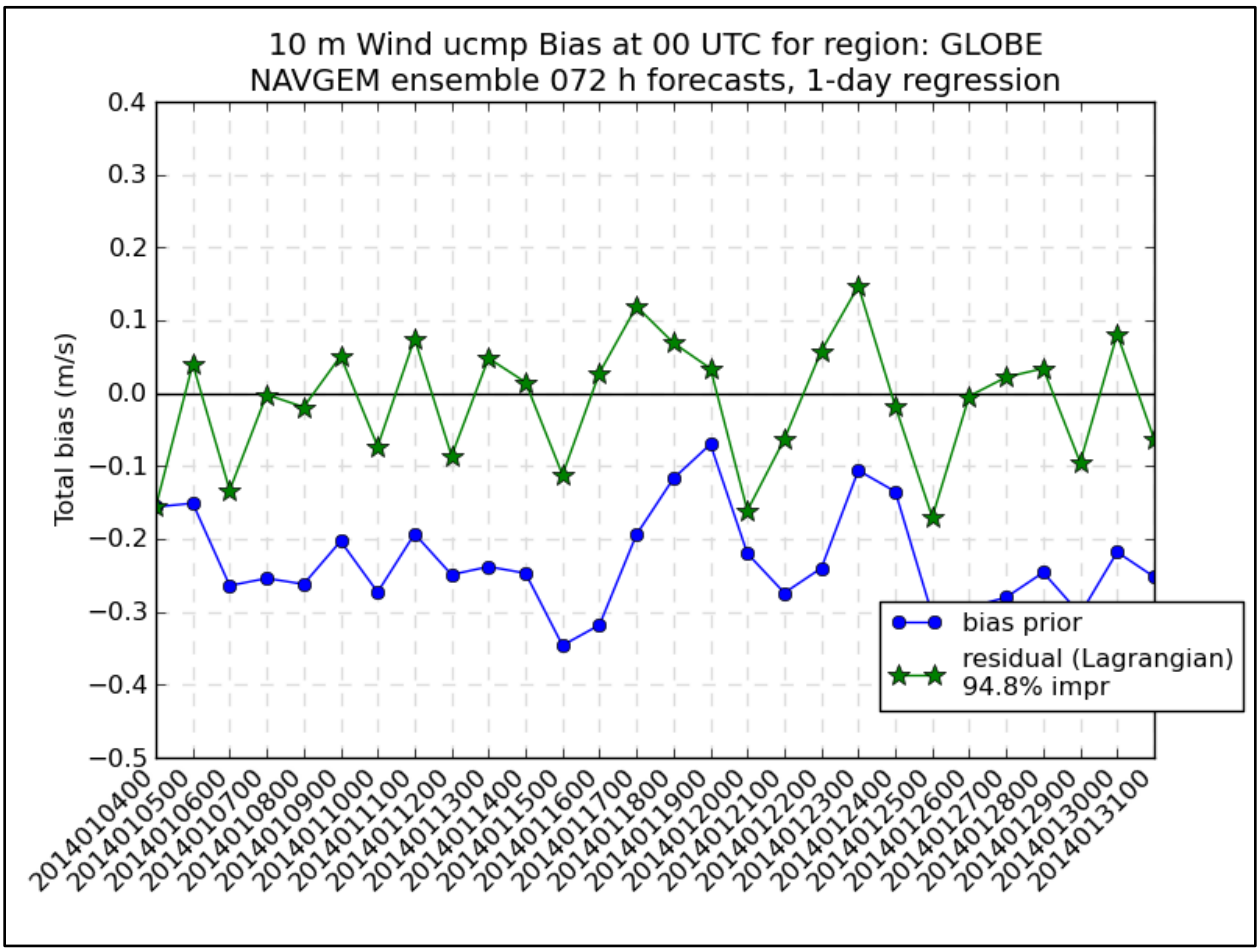

Figure 2 (above) from the testing of post-processing bias correction of NAVGEM ensemble 10m wind speed: Global bias of ensemble-mean 10m wind speed at the 72h lead time before bias correction (blue line) and after bias correction (green line) for the month of January 2014. Results demonstrate that a substantial reduction in the 10m wind speed bias is gained from the post-processing.

3) Milestone: Development of STARS++ web services

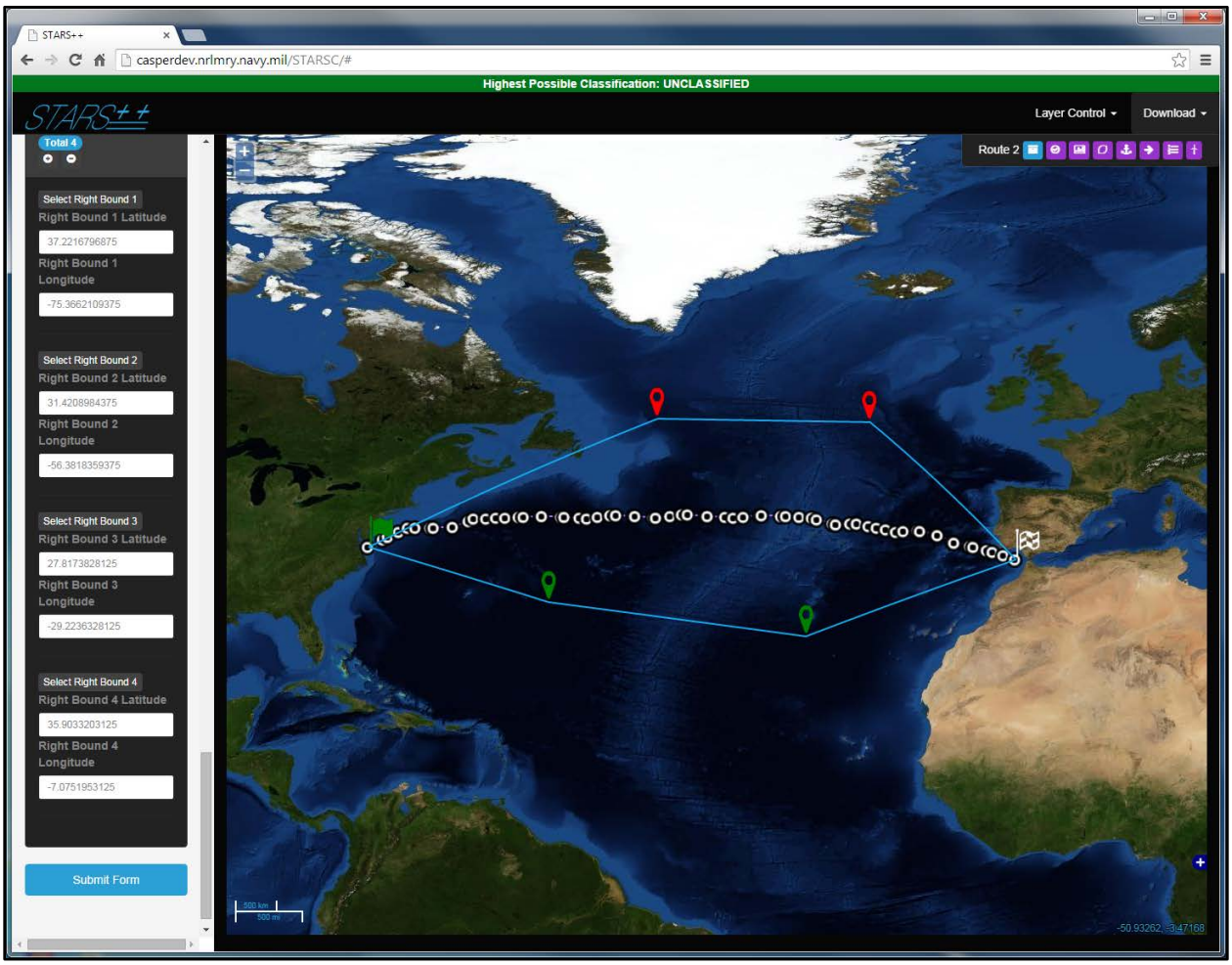

Figure 3 (above) Screenshot of the latest STARS+ user interface (UI) showing an example route for an oiler ship on a voyage between Norfolk and Gibraltar beginning 02 October 2014. The optimum route is indicated by the open white circles and the envelope of possible routes for the voyage is indicated by the blue lines. The UI is based on the OpenLayers mapping application, in accordance with the NITES-Next project. Ship, route, and METOC choices are submitted using the form on the left of the screen. The UI is being beta-tested in collaboration with FWC-San Diego and FNMOC.

IMPACT/APPLICATIONS

Improvements in ship routing guidance will result in fuel efficiencies, improved sea-keeping and mission effectiveness, and a reduction in scheduled ship maintenance by avoiding hazardous environmental conditions during transits. Also, the SKEB-mc stochastic forcing method will not only improve the 10m wind forecasts that are critical to the ship-routing problem, but will also enhance the overall performance of the NAVGEM EPS as well as the performance of downstream systems that take the NAVGEM EPS forecasts as input, such as the NAAPS aerosol prediction system. Likewise, the post-processing of waves and 10m winds will enhance the performance of downstream applications that take 10m winds and waves as input, such as the Wave Watch 3 model and the HICOM ocean model.

TRANSITIONS

- The SKEB-mc stochastic forcing method is scheduled for FY15 transition.
- The wave bias correction post-processing method is scheduled for FY15 transition.
- A basic, deterministic version of the ship-routing system was transitioned to the FNMOC NIPR system at the end of FY14.

RELATED PROJECTS

The project leverages previous investments by CNMOC, PMW-120, ONR, and NAVSEA in the STARS infrastructure that produced STARS++. The STARS++ system was successfully demonstrated during RIMPAC 2012. Inclusion of physics upgrades to the NAVGEM EPS are dependent upon progress in implementing these physics upgrades in the deterministic NAVGEM under the PMW-120 6.4 NAVGEM project.