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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. 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 ensemble and post-processing systems that provide 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 of waves and 10m winds will be developed. Collaborations with Fleet Numerical Meteorology and Oceanography Center (FNMOC) and the NITES-Next project will ensure step-by-step coordination.

WORK COMPLETED FOR FY15

Executive Summary: Significant progress was made in FY15 on all major milestones, building on the success of FY14. Operational transition was made of SKEB-mc (Stochastic Kinetic Energy Backscatter with moisture-convergence mask), a stochastic forcing scheme for the NAVGEM EPS. A new wind post-processing scheme was formulated and completed initial testing, with very strong results. A new version of the ship-routing optimizer was developed with the capability to utilize ensemble uncertainty information in the routing calculation. The most notable accomplishments for each major milestone are summarized below.

- Milestone 1: Demonstration of ship-routing capability

There were no formal demos scheduled for FY15. Previously, a demo had been scheduled, but this demo was moved up to FY14 and carried out far ahead of schedule. However, as a result of the ship-routing system being installed on the FNMOC SIPR network, the FWCs had the opportunity to test the ship-routing system at their convenience all throughout FY15. The testing traffic was not as heavy as we would have liked, because the FWCs had indicated they are mainly interested in ship classes that are not yet part of the ship-routing optimizer’s database.

Given the need for more ship classes, 17 new ship class response files were obtained through coordination with DRS Inc. late in Q4 FY15. These new files encompass 10 combat ship classes and 7 MSC ship classes, and should facilitate more testing by the FWCs in FY16.

Very productive coordination continued with DRS Inc. and the UConn optimization group. Both DRS and UConn developed important new capabilities for the user interface (UI) and the STARS++ optimizer (See Milestone 4 for highlights of these new capabilities).

Other advocacy efforts included a discussion with representatives of NITES-Next about inclusion of the ship-routing system in NITES-Next FCR3. An update was also provided to CNMOC.

- Milestone 2: Upgrades to NAVGEM EPS

SKEB-mc stochastic forcing for the NAVGEM EPS passed OPTEST and was successfully transitioned to FNMOC operations on 23 April 2015. This is the first-ever stochastic forcing capability for NAVGEM.

Meanwhile, an unexpected property of NAVGEM v1.3 required emergency R&D on the NAVGEM EPS in Q3-Q4 FY15. To provide some background on the problem, tests found that the spatial distribution of variability of the NAVGEM v1.3 model is very different from that of v1.2. In particular, v1.3 supports much greater variability in the tropical upper atmosphere. The general consensus is that this added upper-atmosphere variability is desirable from a physical and dynamical standpoint. However, due to the nuances of the operational local ensemble transform (ET) ensemble generation scheme, this added upper-atmosphere variability was very disruptive to the quality of the EPS in the troposphere. To compensate, a significant reconfiguration of the ET for NAVGEM v1.3 was required.

The end products of the emergency R&D are several new versions of the ET that lead to much improved NAVGEM v1.3 EPS winter-season performance compared to the operational NAVGEM v1.2 EPS. Of particular relevance to the ship routing problem, major improvements in 10m wind speed scores are gained for the North Atlantic and North Pacific (Figure 1). Testing of the new ET versions for the summer season was ongoing at the close of FY15.
In addition to the R&D on the new ET, the first tests were completed for a higher resolution (T359) NAVGEM EPS (versus the current T239). The T359 NAVGEM EPS needs to be retested in Q1 FY16 using the new ET, but remains a candidate for FY16 transition.

The first round of testing also was completed for the incorporation of two types of SST variation into the NAVGEM EPS: diurnal SST variation and SST analysis perturbations. Both the diurnal SST and the SST analysis perturbations yielded a net positive (favorable) scorecard relative to the operational ensemble. There was overall improvement in 10m wind speed and 2m air temperature, suggesting that inclusion of the SST variation has some potential to benefit the ship routing process and is a candidate for FY16 transition. However, like the T359 NAVGEM EPS, these SST capabilities need to be retested in Q1-Q2 FY16 using the new ET.

- **Milestone 3: Post-processing of NAVGEM EPS**

  The wave bias correction code was standardized and officially released to FNMOC in early FY15. Beta testing was ongoing at the close of Q4 FY15 and it remains a candidate for FY16 transition.

  For the wind bias correction, a new, two-step methodology was formulated and performed very strongly in first tests.

  - In the first step, multivariate regression is used to jointly correct the biases in the u,v wind components.
  - In the second step, regression is used again to scale the variance of the wind components while preserving the bias-corrected means of the wind components. It can be shown mathematically that this scaling yields an approximate bias correction of the wind speed.

  The initial validation results for the wind bias correction, using regressions based on global data, exceeded our wildest expectations. A one-year, multi-season test indicates that reductions in the speed bias of 50-100% can be gained consistently, even for lead times as long as 144h (Figure 2). Furthermore, the results suggest that the gains can be achieved using an archive dataset of minimal size (the most recent one-day’s worth of verifying forecasts), which should greatly alleviate any concerns about data storage requirements. Also, the bias correction has negligible effect on wind direction, even though direction is not explicitly constrained in the methodology. Final testing of the wind bias correction method is expected to meet or beat schedule (Q2 FY16), and the wind bias correction is a very promising candidate for FY16 transition.

  Plans were also defined to quantify the value of the wave and wind post-processing methods to the ship routing problem. In brief, permutations of the ship-routing environmental input will be made using the post-processing methods and then the ship route performance will be evaluated for each of the permutations. For instance, one can make a four-way comparison between the value to ship routing of 1) raw WW3 waves, 2) bias-corrected WW3 waves, 3) WW3 waves forced by bias-corrected winds, and 4) bias-corrected WW3 waves forced by bias-corrected winds.

- **Milestone 4: Development of STARS++ web services**

  Numerous refinements were made to the basic ship routing system that was inherited from FY14, listed below. The web services remain on track to have the promised capabilities and to meet the requirements of NITES-Next.

  Major system improvements:

  - Multiple new optimizer capabilities were developed in coordination with the UConn optimization group. Among the capabilities is uncertainty-based discounting, which factors
into the route optimization measures of ensemble uncertainty such as ensemble variance. In the discount approach, situations with high uncertainty are given a low weight in the optimization calculation, and vice versa. Another capability is time-windowing, which allows the ship to wait at a location to carry out training or to allow for the passage of unfavorable weather.

- The optimizer was updated to account for all five available swell wave trains. This is advantageous because lower energy trains can still have meaningful impact on the route calculation if the higher energy trains happen to be on the ship's beam.
- Enhanced gridding was incorporated into the optimizer, in coordination with DRS Inc. This has many advantages; For example, it allows for automatic grid generation based upon a shortest-path algorithm, and it allows for variable grid spacing, such that one could use a coarse grid in the open ocean and a fine grid near islands for running gaps (Figure 3).
- The optimizer was recoded to use openMP distributed operations, leading to a considerable reduction in computational expense.
- The initial porting of the user interface (UI) to the Ozone Widget Framework (OWF) was completed. This was necessary to meet NITES Next requirements.
- The UI and STARS++ optimizer were ported to the Continuous Integration Environment (CIE), also to meet NITES Next requirements.
- Knowledge of FWC CONOPS for wintertime operations and safety margins was incorporated into the UI and optimizer.
- The METOC climatology was updated to use climatological percentiles (e.g. the 60th or 90th percentile) in response to FWC-N feedback that the existing climatology was too smooth.

- **Milestone 5: Validation and verification of ship-routing guidance**

  Extensive sensitivity analyses of the ship-route solutions were undertaken using a handful of canonical routes (e.g. Pearl Harbor – San Diego) from the official ship-routing scorecard. Results from these analyses show that the STARS++ optimal routes are advantageous compared to both naive great circle (i.e. METOC-independent) routes and routes based on climatological METOC, no matter the metric used (fuel used, distance traveled, or time enroute). The expected fuel burn reduction if one uses the ship-route optimizer in conjunction with METOC information is 1-3%. These results are consistent with those from past ship-routing studies.

  The process was begun to move the V&V toward a “replanning” methodology (where routes can be updated over the course of a voyage). This will enable the V&V to better emulate the planning process that the SROs use. Basic but functional replanning scripts were developed as part of this process.

  Additional new metrics were formulated to complement the standard ship-route metrics (fuel usage, distance traveled, time enroute) and to more fully capture the properties of the ship-route guidance. The new metrics include the “smoothness” or degree of “windshield-wiper behavior” of the route, the frequency of replanning, the aggregate displacement between the forecast and perfect route, the number of diversions enroute, and the number of limit exceedances.

- **Milestone 6: Transition of ship-routing system to FNMOC**

  SKEB-mc passed OPTEST and was transitioned to FNMOC operations on 23 April 2015.
The wave bias correction package was moved to beta testing at FNMOC in Q3 FY15, opening the way for eventual transition to operations.

The STARS++ back-end and the UI front-end were both installed on the FNMOC SIPR network, well ahead of schedule. This enabled FWC and FNMOC personnel to begin familiarization with the system in Q1 FY15.

Development began on a UI user guide to be provided to operational partners (FWC, FNMOC) upon transition of the ship routing system.

RESULTS

Selected results are shown below for several milestones.

1) Milestone: Upgrades to NAVGEM EPS

*10m wind speed* Scorecard sum (NPAC & NATL only)

![Scorecard Sum Chart]

RI criterion: 5.0%
Lead times: All

NAVGEM v1.3 EPS
with new ET

Figure 1 (above) Ensemble scorecard sum for a winter-season test of the NAVGEM v1.3 EPS with a new version of the ET. The sum is for 10m wind speed for the North Pacific Ocean (NPAC) and North Atlantic Ocean (NATL) regions as a function of verification metric. RMSE = Root mean square error of the ensemble mean, CRPS = continuous ranked probability score, BIAS = average error of the ensemble mean, and VARR = variance to squared error relationship. A positive scorecard sum indicates the NAVGEM v1.3 ensemble with the new version of the ET outperformed the operational NAVGEM v1.2 ensemble with the original ET. Scores are significant at the 95% threshold and yield at least 5% relative improvement (RI). The results indicate that the NAVGEM v1.3 ensemble with new ET yields major net benefits to the ensemble 10m wind speed over the midlatitude oceans.
2) Milestone: Post-processing of NAVGEM EPS

Figure 2 (above) Wind bias correction of NAVGEM ensemble 10m wind speed: Blue line (green) line is global bias of ensemble-mean 10m wind speed at the 144h lead time before (after) bias correction for the time period 0000UTC 03 Aug. 2014 to 0000UTC 31 May 2015. Results demonstrate a remarkable reduction of close to 100% in the 10m wind speed bias owing to the post-processing.
3) Milestone: Development of STARS++ web services

Figure 3 (above) Screenshots of the adaptive gridding capability developed for the latest STARS++ ship-routing system by DRI Inc. The route is Houston-Diego Garcia via Gibraltar and the Suez Canal. Note the higher density grid in the more confined areas of the Mediterranean and Red Sea.

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 upgrades to the NAVGEM EPS (including SKEB-mc, the new ET, the resolution increase, and the SST variation) 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 was transitioned to operations on 23 April 2015.
- The wave bias correction post-processing method began beta testing at FNMOC in Q3 FY15.
• A basic, deterministic version of the ship-routing system was transitioned to the FNMOC SIPR system in Q1 FY15.

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.